Safety and electric passenger cars

Update to fact sheet, 2020

CE Delft

Committed to the Environment

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CE Delft
Committed to the Environment

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Summary

Reason for the study

Electric cars are becoming more and more common, both in the Netherlands and elsewhere. Rising popularity has lately led to a number of publications in the media regarding the potential risks or hazards these cars entail. Members of Parliament also asked questions about a number of incidents involving electric cars in September 2019. This increased attention for the safety risks of electric cars has prompted the Netherlands Enterprise Agency to take action. To that end, it asked CE Delft to update the 2014 overview of the potential safety risks of electric passenger vehicles.

Approach to the study

CE Delft identified and reviewed 280 scientific and semi-scientific sources and media reports concerning safety risks in connection with electric cars. They also interviewed 25 experts. As a result, this study offers an extremely comprehensive overview of the available knowledge in this area.

Main conclusion

On the whole, electric cars do not seem to pose a greater safety risk than 'conventional' vehicles that run on fossil fuels (petrol, diesel or LPG). The same safety risks that apply to electric cars often apply to conventional cars as well. In addition, both conventional and electric cars must comply with numerous existing national and international safety regulations.

One safety risk the study found is thermal runaway, a process whereby a high temperature or internal resistance in the cells of battery packs can cause a fire and the release of toxic gases. Another safety risk is car fires inside parking garages, which poses a risk for both electric and conventional vehicles. The actual risk is a combination of the chance that a given incident will occur and the effect if it does occur. The literature and practical tests do not suggest that these safety risks are very likely. There is also no evidence at this time to suggest that the effects would be significantly greater. In the future, statistics and practical data will be needed to determine the accuracy of these conclusions.

If thermal runaway leads to a fire, there is not necessarily a higher safety risk than for a conventional car with an internal combustion engine (ICE). However, cases involving an electric vehicle do call for a different approach to incident management. More specifically, this applies to fires in a parking garage: battery fires can last a long time, and batteries can reignite. Also, it is not always immediately clear where the battery pack is located in the car. As a result, a large volume of water is needed to put out a fire, it is difficult to tow the car away and responders must locate the battery pack before they can take action. There are other questions for which there is no answer yet, such as: what happens when the battery pack gets older? And also: how reliable is the system that checks for voltage and temperature in the battery pack as it gets older?

The persons who were interviewed by CE Delft asked some of the same questions about possible safety risks in electric cars as the media and politicians. CE Delft found that the actual added risk of electric cars was low. It based this conclusion on current knowledge and applicable regulations. Additional experimental or practical research may answer some of the remaining questions.

Partial conclusions

CE Delft set out nine themes in its research. Its main conclusions on the safety aspects of electric cars for these themes were as follows:

1. **Vehicle safety:** crash tests show that electric cars are at least as safe as cars that run on fossil fuels. The safety of a car does not depend on any single factor, such as the mass or the centre of gravity of the car. Rather, vehicle safety depends on the relationship between different factors. Modern safety systems have a positive effect.
2. **Battery damage:** the greatest risk is thermal runaway. Based on practical tests, this does not seem likely to happen following an incident. Additional research could provide evidence to support this conclusion.
3. **No sound:** the compulsory Acoustic Vehicle Alerting System (AVAS) lowers the risk associated with the car not making any sound at low speeds.
4. **Fire safety:** based on the literature and interviews, CE Delft cannot conclude that electric cars are more likely to catch fire. There is also no reason to believe that the effects are worse if such a fire should occur. Statistics and practical data can help confirm this view in the future.
5. **Safety in enclosed spaces:** in recent decades, parking garages have become a larger safety risk for all types of vehicles. Recent studies show that electric cars do not seem to be at greater risk than cars that run on fossil fuels. The duration of the fire and the chance of a new fire starting inside a parking garage make it more difficult to manage incidents. This makes it harder to put out fires and recover electric cars.
6. **Incident management:** this is different for an electric car compared with a car that runs on fossil fuel. See the main conclusion.
7. **Maintenance and safety:** there are protocols and training courses for garage staff who work on electric cars. The risk is that these protocols are not known to consumers who try to fix cars themselves or to non-certified garages.
8. **Immersion in water:** there are various standards for batteries under water. Batteries of electric cars are designed to continue working even if completely immersed. CE Delft found no literature on the risks of a battery that is partially immersed. It expects these risks to be limited in nature.
9. **Charging infrastructure:** charging modes with built-in control systems are safe.
   The regulations and technical standards for charging points are sufficient to ensure safe charging. While all charging modes are at risk of damage from collisions, charging modes with built-in control systems will switch off automatically in such an event.
   Monitoring the installation of public, semi-public and private charging points is not regulated centrally. It is not clear whether this entails an additional risk to safety.

1 Introduction

1.1 Reason for the study

Electric cars are becoming more and more common, both in the Netherlands and elsewhere. Yet compared to petrol and diesel-fuelled vehicles, also known as ICE (internal combustion engine) vehicles, electric cars remain a relatively new and unknown quantity. Aspects which are relevant to parties such as the Dutch government (and others) include the overall safety risks that accompany the introduction of a new technology such as electric vehicles.

In order to obtain a picture of the safety risks associated with electric vehicles, the Netherlands Enterprise Agency and TNO compiled the 'Fact sheet on electric vehicles and safety' in 2014. This document offered a brief summary of the safety risks in connection with electric cars and their use (TNO, 2014). Since then, the use of electric vehicles has increased exponentially. Between 2014 and 2020, the number of fully electric passenger cars jumped from 4,620 to over 130,000. To that, one can add over 100,000 plug-in hybrids and around 80,000 other vehicles with a plug-in connector such as delivery vans, two-wheelers and heavy trucks.

Increasing practical experience and the research community's interest in electric vehicles are yielding a growing body of available information regarding the safety aspects that play a role in connection with electric vehicles. Recently, the popularity of electric vehicles has also resulted in more stories in Dutch media about possible safety risks. And due to a number of incidents involving electric cars, members of Parliament asked questions about safety risks in 2019 as well (Ministerie van Justitie en Veiligheid, 2019). Topics these questions involved included:
- charging electric cars in parking garages;
- preventing and extinguishing battery fires, including those caused by charging points or damage to a vehicle/battery;
- the severity and consequences of damage to battery packs;
- the severity and consequences of vehicle fires involving electric cars.

In light of the developments since 2014 and the interest from Parliament, the Netherlands Enterprise Agency has asked CE Delft to compile an overview of current information with regard to the safety of electric vehicles, focusing on electric passenger cars in particular.

1.2 Objective of the study

The objective of the study was to gain the most complete and up-to-date overview possible of the current knowledge in connection with the safety of electric vehicles and their use. To that end, an extremely thorough literature study was conducted. This literature study was supplemented with interviews conducted with a total of 25 experts from various professional fields whose work deals with electric vehicles and potential risks to safety.

The study attempted to answer the following research questions:
1. What relevant research results have been published in the Netherlands and abroad with regard to safety and the use of electric vehicles?
2. Which laws and regulations, standards, safety requirements and quality marks exist in connection with electrically powered transportation and safety? Are these regulations being met with compliance? Are they being enforced?

3. Are existing laws and regulations sufficient?
4. What is the course of the procedures within the EV safety domain? How does information reach the security regions, for example?
5. Which topics still need to be addressed and what knowledge is still lacking in connection with electrically powered transportation and safety?
6. What recommendations can be made in light of the study results and the knowledge gaps identified?

A secondary objective of the study was to conduct an inventory of knowledge gaps. This pertains to both those knowledge gaps that have been recognised as such in the literature and those put forth by the (expert) parties interviewed. The most important knowledge gaps are listed in Chapter 5. This chapter also includes recommendations on how to remedy those gaps in knowledge.

1.3 Structure of the document

Chapter 2 addresses the investigative approach used. It also defines the scope established for the study and sets out the various safety-related themes which are the primary focus of the study. Chapter 3 discusses the results of the literature study and the interviews. This chapter also includes a meta-analysis of the sources found and/or consulted and the distribution of these sources across the various safety-related themes. In Chapter 4, the current legislation and regulations with regard to the safety of electric vehicles are addressed. Chapter 5 deals with the identified gaps in knowledge and sets out recommendations on how to eliminate these gaps. In Chapter 6, we present our conclusions and thereby provide answers to the research questions.

2 Investigative approach

2.1 Scope

In this study, we will concern ourselves primarily with electric passenger cars that use a plug-in charging system. This includes both fully (battery-powered) electric passenger cars (BEVs) and plug-in hybrid passenger cars. Although fuel-cell electric cars (also known as hydrogen cars) are categorised as electric cars as well, they fall outside the scope of this study.

As this study focuses on electric passenger cars, no research aimed specifically at other types of vehicles — such as two-wheelers, delivery vans, lorries or other means of transportation — has been carried out.

In this study, the safety of electric cars is explored based on the following themes:

1. **Vehicle safety:** this refers to those safety aspects relevant to electric cars with regard to the safety of the driver, other road users, mechanics and safety services, as well as the standards that all plug-in hybrid and electric passenger cars must meet.
2. **Battery damage:** this topic deals with the risks associated with damage to batteries.
3. **No sound:** this pertains to potential risks to traffic safety as a result of the lower sound production of electric cars.
4. **Fire safety:** this theme explores the similarities and differences between conventional cars[1] and electric cars at the moment the vehicle catches fire. This includes both the risks of combustion (spontaneous or otherwise) and the risks during the fire, as well as the tools required to extinguish the fire.
5. **Safety in enclosed spaces:** this theme is in line with the concept of fire safety in general and deals with the additional risks in the event a fire begins in or around an electric car while inside a tunnel or parking garage.
6. **Incident management**: this theme concerns the potentially differing instructions needed to guide the actions of emergency services in case of accidents involving electric cars.
7. **Maintenance and safety:** the focus here is the knowledge that garage staff, auto mechanics and technicians (and consumers who try to fix cars themselves) must have in order to properly manage the specific safety risks associated with electric cars.
8. **Immersion in water:** this pertains to the potential risks of electrocution when an electric car is partially immersed or fully submerged in water.
9. **Charging points:** this section deals with the safety and risks of the charging infrastructure when charging vehicles or in the event of a collision with a charging point.

This version differs from the 2014 fact sheet in that the topics ‘battery damage’ and ‘safety in enclosed spaces’ have been added.

In connection with the specific topic of charging points, we have taken the safety aspects of public and semi-public charging points, located inside structures and outdoors, into account in our study. Safety aspects of private charging stations located on private sites fall outside the scope of this study.

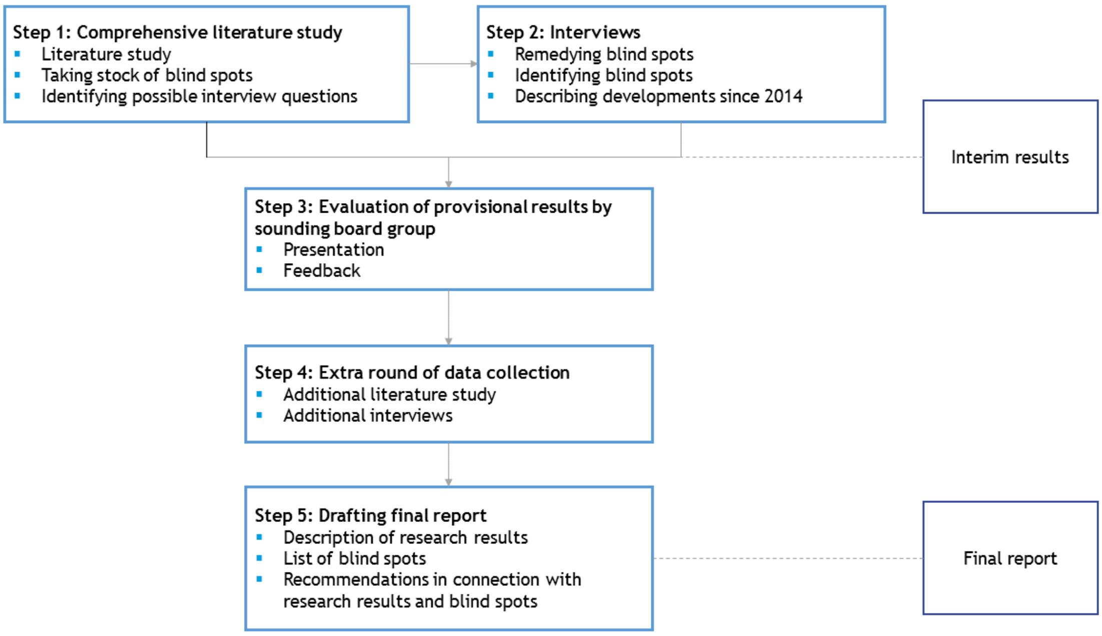
[1] When we use the term ‘conventional car’, this is intended to mean ‘a car powered by fossil fuel’.

The emphasis of the study lies on the physical safety aspects described in the literature and interviews in connection with the nine themes. In addition, attention in a broader sense has been paid to:
- laws and regulations: this refers to international (global and European) and national laws and regulations that either directly or indirectly impact the safety of electric vehicles;
- organisational aspects: this section deals with the manner in which the agencies responsible have been tasked with ensuring safety and how these parties should cooperate with one another.

2.2 Research method

The results of the study have been obtained by means of an extensive literature study and conducting interviews. The various steps carried out in the course of the study are shown in Figure 1. Below the figure, we provide further explanation of the most important steps.

Figure 1 - Steps of the study



Literature study

In conducting this literature study, we have relied on both national (Dutch) and international sources to the greatest extent possible. That includes making as much use of scientific (peer-reviewed) articles and grey literature as we could. We have supplemented these sources with news items and other documentation when necessary. The articles were found in trade journals such as the *World Electric Vehicle Journal*; we have also made use of contributions to industry-related conferences, such as the ‘International Conference on Fire in Vehicles’. We attempted to utilise as many sources as possible published after 2014, when the previous version of the fact sheet was published.

In addition, a meta-analysis of the quality and nature (scientific or otherwise) of all identified sources was conducted, as well as an analysis of their distribution across the nine safety themes. This meta-analysis (Section 3.1) provides an initial impression of the possible lack of knowledge corresponding to each safety theme and serves as a prelude to the inventory of knowledge gaps (see below as well).

Interviews

In part alongside carrying out the literature study, interviews were conducted with 25 different parties who are active in a variety of professional fields in which they deal with electric cars and potential safety risks. A list of the organisations and businesses interviewed is included in Appendix A and a list of the interview questions can be found in Appendix B.

The same two key points were addressed during each interview. The first key point involved comparing and contrasting the findings of the literature study with the reality of day-to-day practice. This yielded insight into the degree to which the prevailing knowledge (obtained through research) deviates from or corroborates the real-world practice encountered by the interview subjects.

The second key point of the interviews pertained to creating an inventory of questions which occupy the minds of experts and for which there are (currently) no answers available. These questions have been used to determine the gaps in existing knowledge.

Inventory of knowledge gaps

Compiling a list of knowledge gaps was no easy matter, as a great many, often dissimilar and extremely specific or situational questions emerged in the course of the study.
In general, the existing literature fails to supply answers to highly specific or situational questions. These as yet unanswered specific questions, however, might potentially prove vital with regard to identifying possible safety risks.

The researchers/authors of this report have attempted to assign priority to the questions that occupy experts and to include the most pressing ones in the list of knowledge gaps. Initially, priority was assigned by checking whether the same (or same type of) question had been asked by more than one interview subject. The more parties asking the same or similar question, the greater the likelihood that the query would be classified as a gap in knowledge. Next, the researchers evaluated whether it would be feasible to research these questions. In other words, we formed an expert opinion as to the possibility of finding an answer to a given question by conducting research (or by other means), while being mindful that the effort expended should be proportional to the potential risk. The resulting list of knowledge gaps was discussed in the sounding board group and additions were made as deemed necessary and/or desirable.

3 Results of the study

In this chapter, we provide an account of the knowledge described in the literature for each of the nine safety aspects. This chapter also sets out the findings from the interviews. Before discussing the results of the literature study and interviews for each of the safety aspects, we will share a meta-analysis that offers an overview of the total number of sources consulted and how these are distributed across the safety topics that have been defined.

3.1 Meta-analysis of the literature study

For this study, a total of 280 sources pertaining to the safety of electric cars were identified and consulted (263 of these were published in 2014 or later).

Table 1 shows the distribution of the sources found in terms of topic and year of publication. Note that the number of sources we found differs strongly from one safety-related topic to another. Few sources were found for ‘immersion in water’ and ‘maintenance and safety’. However, this does not mean that the information available for both topics is insufficient. Based on the sources located in connection with ‘maintenance and safety’, we were able to form a clear picture of the development and available information in this area. For ‘immersion in water’, we looked specifically for information on partial immersion in water because the 2014 fact sheet stated that little was known about that subject and that research in that area was called for. In conducting our study, we found no literature to suggest that additional information on this has since been published.

One update is the combination of ‘fire safety’, ‘charging points’ and ‘parking garages’. While many sources were found for both ‘fire safety’ and ‘charging points’, few scientific sources address all three of these topics at the same time. In addition, the sources relating to charging points do not cover all the specific questions we were given by the client. We found a particularly small number of scientific sources that address safety aspects of the charging infrastructure.

Table 1 - Number of publications found for each theme, by publication year

Year of publication	Vehicle safety	Sound	Incident management	Maintenance & safety	Fire safety	Immersion in water	Enclosed spaces	Invisible damage to battery	Charging infrastructure
2012	3	1	0	0	1	0	0	0	0
2013	2	3	1	1	1	1	1	1	1
2014	4	7	2	4	5	2	2	6	5
2015	0	4	1	0	1	0	0	0	1
2016	1	5	0	0	5	0	1	2	2
2017	1	3	0	0	4	1	1	0	4
2018	7	0	2	1	7	1	1	7	9
2019	14	5	11	2	25	0	9	20	22
2020	27	3	16	3	41	2	26	21	35
Unknown	1	0	0	2	1	0	0	2	0
Total	**60**	**31**	**33**	**13**	**91**	**7**	**41**	**59**	**79**

Table 2 shows how the literature sources found are distributed across the research domains 'physical safety', 'organisational aspects' and 'laws and regulations'. It is abundantly clear that the majority of relevant literature deals with the physical safety aspects of electric cars. In contrast, little has been written about the laws and regulations, and particularly little about the manner in which the agencies responsible have been tasked with ensuring safety.

The interviews served as the most important source for understanding the responsibilities of the parties and exploring how they cooperate with one another.

Table 2 - Distribution of literature sources across the three domains of the study

Domain	Vehicle safety	Sound	Incident management	Maintenance & safety	Fire safety	Immersion in water	Enclosed spaces	Invisible damage to battery	Charging infrastructure
Physical safety	46	28	26	7	89	6	36	47	54
Organisational aspects	1	0	3	0	0	0	0	0	5
Laws and regulations	15	3	4	6	2	1	3	15	20
Total	**62**	**31**	**33**	**13**	**91**	**7**	**39**	**62**	**79**

3.2 Vehicle safety

3.2.1 Revisiting the 2014 fact sheet

In 2014, new requirements for electrically powered vehicles were added to the Road Traffic Act 1994; these pertain specifically to the electric powertrain. The requirements are European type-approval regulations, supplemented with Dutch standards and requirements. All new car models must undergo safety testing before they can be brought to market.
In 2014, most models were already being subjected to Euro NCAP collision tests as well, which revealed electric cars to be relatively safer as compared to petrol and diesel cars (TNO, 2014). The 2014 fact sheet also includes the results of research into the safety of two-wheelers (TNO, 2014). This falls outside the scope of the current study.

3.2.2 Current status as of 2020

The vehicle safety of electric cars is a topical issue that often features in stories in the media and is the subject of political focus. Voices in various media have expressed concerns regarding the safety of electric cars as compared to that of conventional cars. Recent news items, for instance, have asserted that the greater mass of electric cars could result in more serious accidents (FD, 2020; Vos, 2020). These reports are based on a recently released study that concluded that electric cars will lead to greater damage in the future (Automotive Insiders ; Trend-Rx, 2020). Both the automotive industry and the scientific community have been critical in their response to this study and the resulting media reports (AMWeb, 2020; nu.nl, 2020; Hoekstra, 2020).

In other words, opinions vary as to the vehicle safety of electric cars. There are also more aspects that can influence the vehicle safety of an electric car than just its mass. We will sum these up below. In doing so, we will first address the aspects we found in the literature and then move on to what we learned from the interviews.

Studies and publications

Electric cars work differently than conventional cars. These differences are as follows.

- Different powertrain: an electric car is propelled (in part) by an electric motor rather than a combustion engine.
- Centre of gravity: electric cars have a lower centre of gravity than conventional cars (Office of Energy Efficiency & Renewable Energy, 2020).
- Mass: as it stands now, electric cars still have a greater mass than comparable conventional cars.
- Acceleration: electric motors are able to immediately generate maximum torque, allowing the car to accelerate from standstill faster than a comparable conventional car (ev-database, 2020).
- Braking: when a car decelerates by braking, kinetic energy from movement is converted into a different form of energy. In the case of conventional brakes, the kinetic energy is converted into friction energy and therefore heat. With electric cars, it is possible to recover a portion of the energy expended in braking through regeneration and to store that energy in the battery pack. As a result, electric cars can brake a fraction of an instant sooner as well as harder (electrek, 2018).
- Systems: electric cars are usually equipped with systems to ensure safety, such as an Advanced Emergency Braking System (AEBS) and a Battery Management System (BMS) (Manners, 2020; Battery University, 2019b).

In this section, we will describe how the aforementioned characteristics affect the safety of the people in the car and those in its vicinity. The BMS is discussed in Section 3.3.

Different powertrain

An electric car is equipped with an electric motor that is fuelled by a battery pack. When an incident occurs, this entails different risks than those associated with incidents involving conventional cars. In Section 3.3, we address the safety risks of battery packs. In Sections 3.5 through 3.7, we present our findings with regard to fire safety and incident management in connection with electric powertrains. A number of components linked to an electric motor operate under high voltage. For this reason, the requirements for working on and/or with an electric car are different than in the case of conventional vehicles. We will provide further explanation of this matter in Section 3.8.

To a certain extent, electric cars offer greater design freedom than conventional cars: the electric motor does not necessarily have to be installed at the front of the vehicle because electric motors are quite compact (Clean Technica, 2018). In recently developed designs, the battery pack can be positioned in a safe and space-saving way. This, together with the powertrain's more compact construction, offers the carmaker greater flexibility and potential for providing the persons in the car and their fellow road users with optimum safety in case of an accident. The crumple zone, for instance, must be taken into account when determining the position of the motor, because the zone absorbs energy in the event of a collision (Clean Technica, 2018).

Centre of gravity

The centre of gravity exerts an influence on the stability of a car (along its length, from the side and from above). In electric cars, the centre of gravity tends to be lower than in conventional cars. While the mass of an electric car is greater, its lower centre of gravity offers increased stability, which in turn reduces the chances of vehicle rollover. A lower centre of gravity also serves to improve the driving quality (Office of Energy Efficiency & Renewable Energy, 2020).

The crashworthiness in case of head-on collisions depends mainly on the centre of gravity and the crumple zone at the front end of the car. Any change to the centre of gravity will therefore alter the crashworthiness of the vehicle (Mazumder, et al., 2012). This is particularly relevant when a vehicle is retrofitted, with a conventional car being converted into an electric car. The process of converting a car changes both its centre of gravity and its crumple zone. Although conversion of a conventional vehicle into an electric car will have a detrimental effect on its centre of gravity, this will indeed enhance the effectiveness of its crumple zone (Sakurai & Suzuki, 2011). This detrimental effect results from the need to install a battery pack in an existing chassis which was not designed to accommodate one; space must be found somewhere, such as in the boot or engine compartment.

Mass

At this point in time, electric cars have a greater mass than comparable conventional models. The literature (concerning cars in general, not electric cars specifically) is unanimous in stating that, in the event of a head-on collision between two cars, the mass of the cars involved will affect the resulting damage and injuries (Titheridge, et al., 2013). Generally speaking, the occupants of the lighter car will have more severe injuries than the occupants of the heavier car. The reason for this is that most of the energy released during a collision will be absorbed by the lighter car (EC, 2020b). This was confirmed by a data study conducted by the Japanese Ministry of Transport, which showed that in nearly all cases, the occupants of the light car suffered greater injuries.[2] The lighter car's impact zone was deeper than the heavier car's as well (SAE International, 1996). Yet the literature reviewed shows that the shape of the car exerts a greater influence than its mass in the event of a head-on or side (i.e. front-to-side) collision (Fildes, et al., 1993).

High vehicle mass does not always benefit the driver and passengers. For instance, high mass has negative consequences for the impact experienced by occupants of a vehicle in the event of a collision with a rigid object. Higher mass also negatively affects the stability of a vehicle when making sharp turns. Modifications can be made to the construction of a car in order to reduce these risks.

When a car collides with a pedestrian or two-wheeler, the difference in mass between the car and the other party is extremely large, which can lead to greater harmful consequences for the latter. The pedestrian or two-wheeler will absorb the energy released from the collision; they also typically lack protection such as seatbelts or airbags that would absorb a portion of that energy. Certain cars on the market today, however, do feature airbags on the front end in order to protect fellow road users. Since Euro NCAP also evaluates the protection of vulnerable road users, car manufacturers are increasingly taking this into account in their designs. The difference in mass between a car and a pedestrian or cyclist is tremendous. Relatively speaking, the difference in mass between an electric car and a conventional car (the former having a greater mass) is not so great that it will do much to

[2] The studies cited in this paragraph are based on cars in general and not on electric cars specifically.

change the effect of such a collision. Besides mass, speed plays a particularly important role in determining the injuries incurred by pedestrians and two-wheelers. Data from the European Commission shows that when a car travelling at 64 km/h strikes a pedestrian, the incident will prove fatal in 85% of cases (EC, 2020b).

Acceleration

Electric cars can accelerate faster due to the strong torque generated by their motor and the fact that the clutch does not need to engage. Whether this actually occurs, depends on the driving style of the driver. We have found no literature on safety risks associated with more rapid acceleration.

Regenerative braking

In most cars, it is possible to manually adjust the degree of regenerative braking.
In principle, regenerative braking must be switched off whenever possible in order to conserve energy. The system must be engaged only when it is time to apply the brakes.
The advantages of regenerative braking are:

- It is possible to begin braking to avoid an accident a fraction of an instant sooner, as compared to a conventional brake system (LV, 2019; Office of Energy Efficiency & Renewable Energy, 2020; TNO, 2013). This is a technical possibility. The reality additionally depends on the reaction speed of the driver and whether or not they do, in fact, apply the brakes sooner.
- Regenerative braking involves the recovery of energy. Not all energy is recovered; some form of energy loss invariably occurs (electrek, 2018).
- In some modern cars, the car's system automatically modulates the degree of regenerative braking by means of a radar that measures the speed of the vehicle in front of the car and adjusts the regeneration accordingly. If the road in front of the car is clear, the system will allow the vehicle to roll to a standstill and will not need to make use of the regenerative braking system.

Potential disadvantages of a regenerative braking system are:

- Regenerative braking becomes more effective as the size of the vehicle increases. It is therefore less worthwhile to install regenerative braking systems in small cars (electrek, 2018).
- In some systems, it is possible to manually control the degree of energy recovery (regeneration). This requires knowledge and experience on the user’s part.
- During a test involving 90 participants who were asked to drive a route in an electric car and then in a conventional car, measurements indicated that the car braked extremely rapidly during this regeneration phase. This could be a potential risk to the drivers of any cars driving behind an electric vehicle (Nitsche, et al., 2014).
- When the regenerative braking system is used often, the other brakes in the car may rust (electrek, 2018).

No other studies were found to describe how regenerative braking affects overall safety.

Advanced systems

Like other modern vehicles, electric cars are equipped with advanced systems to ensure the safety of the driver, passengers and the surroundings. These are auxiliary systems such as an emergency braking system, lane keeping assistance and a rear-view camera.
Such systems will be mandatory in all new passenger cars from 2022 (EU, 2019; ANWB, 2019). Electric cars are also equipped with a Battery Management System (BMS).
This system is discussed in Section 3.3. The emergency braking system, also known as the Advanced Emergency Braking System (AEBS), calculates whether a collision is likely (Manners, 2020).

The best way to illustrate the effect of applying these systems is to give an example. Although, as previously mentioned, the mass of a vehicle certainly influences the extent of injury or damage to a pedestrian or two-wheeler in an accident, systems in the car play a role as well. Accident statistics from BRON[3] show that pedestrians are less likely to be injured in a collision with an SUV than in a collision with a regular passenger car. Collisions between cyclists and SUVs, however, do result in greater injuries than those between a cyclist and a regular passenger car. Testing by Euro NCAP has shown that SUVs have a positive effect on the safety of other road users. This might be explained by the fact that SUVs have automatic braking systems (or better versions of such systems) while not all regular passenger cars do (Ministerie I&W, 2020).

Electric cars comply with modern legislation, and in many cases feature a wealth of special features to increase their appeal. As a result, electric cars tend to be well-equipped in terms of such safety and driver assistance systems. When an electric vehicle has such systems in place, the effect of its (greater) mass on the injury/damage to pedestrians or two-wheelers is compensated or possibly even decreased.

Practical testing

Just as they do for modern conventional passenger cars, car manufacturers make every effort to ensure that modern electric cars meet all applicable safety standards. When it comes to safety, modern electric cars perform just as well in crash tests as modern conventional cars, both in head-on and side collisions and when rear-ended by another vehicle. Numerous test results have demonstrated this:

- In the United States, tests were conducted on 42 plug-in hybrids and electric cars. This testing was carried out at a variety of speeds and from different directions. These tests revealed the crashworthiness of the hybrid and electric cars to be greater than that of comparable conventional cars (O'Malley, et al., 2015).
- As previously in 2014, multiple electric cars have completed the Euro New Car Assessment Programme (NCAP). This includes testing of head-on collisions at 64 km/h, side collisions at 50 km/h, and 'side pole' tests at 29 km/h. The latter is meant to replicate a collision with an object like a tree or lamppost. No problems with the electrical systems or the battery were encountered during these tests (European Road Safety Observatory, 2018).
- The safety level of different Tesla models has been tested in a number of trials. The Model 3, along with the BMW 3 series, was chosen as the safest in its class of 'large family cars' in Euro NCAP tests (including collision testing) in 2019 (Euro NCAP, 2020b). For the Tesla Model S, other side-collision tests yielded results similar to those of comparable cars with a combustion engine, while front and rear-end collision testing yielded better outcomes for the driver of the car (Allen, Allen, Allen & Allen, 2020). The NHTSA[4] also awarded the Tesla Model S the highest possible safety rating in connection with crashworthiness. Compared to other electric cars, the Teslas scored particularly well in the areas of driver safety and safety assistance from the vehicle.
- Euro NCAP testing paints a mixed picture of the safety of electric and hybrid vehicles for pedestrians and cyclists (Euro NCAP, 2020c).
- Volvo conducted a collision test with a Polestar 2, a battery-powered electric car. The test consisted of an offset head-on collision in which the test car drove into an

[3] BRON stands for '*Bestand geRegistreerde Ongevallen in Nederland*'; it is the Dutch road accident registration database.

[4] NHTSA stands for 'National Highway Traffic Safety Administration'.

obstacle while travelling at a speed of 64 km/h. During the test, the front wheel detached at an early stage, which limited the chances of the construction bunching-up and the interior becoming distorted. Additionally, the battery sustained no damage and the SPOC block[5] remained intact. The SPOC block is a small metal bracket attached to the left and right front corners of the chassis. In case of a collision, it prevents any metal from ending up in the interior (Polestar, 2020). The crash zone was also widened to compensate for the lack of a large engine block that could absorb the impact of a collision. This was done by placing a large aluminium block behind the front wheels. This distributes the energy more effectively in the event of a crash (RTL Nieuws, 2020).

- In cooperation with the University of Göttingen, DEKRA conducted crash tests with a Renault ZOE and three Nissan LEAFs. Both types of car earned the maximum score according to the Euro NCAP system. Three of the four vehicles were subjected to side collision tests that involved striking a pole at speeds of 60 km/h and 75 km/h. The fourth car was subjected to a head-on collision at 84 km/h. The damage pattern from the crash tests was comparable with that of conventional cars and the voltage system of the car shut down automatically. While the chance that someone could survive a side collision at the speeds tested is slight, the same is true for conventional cars as well (DEKRA, 2019).

Besides the crash tests, the Insurance Institute for Highway Safety (USA) named the Tesla Model 3 and the Audi E-Tron SUV as its 'top safety pick +'. This is the highest possible distinction. In this category, however, the Tesla Model S fell just short of the highest distinction (The Verge, 2019).

Interviews

With regard to the differences between electric and conventional cars, no additional safety aspects having to do with vehicle safety were mentioned in the interviews. We did, however, hear that a growing number of members of the Dutch automobile association ANWB cite perceived safety as an argument against electric vehicles. Through the interviews, we also gained information on type approvals.

Manufacturers consider safety as a vital theme in every phase of their production, specifically in relation to manufacturing parts, the choice of materials, the construction of the components and the entire cars. Before an electric car is introduced to the market, it is subjected to extensive practical and other testing. These tests assess whether the legal requirements have been met and evaluate any additional manufacturer safety requirements. Such testing is important because the risks for the manufacturer are severe if something goes wrong.

In Europe, the type approval for electric cars sufficiently addresses the safety risks for this kind of vehicle. Individual approvals often involve a limited series that must meet local standards. In these cases, the manufacturer does not intend to sell the vehicle all over the world. Such smaller series often entail compromises in order to reduce costs as much as possible — without making any concessions in terms of safety — and typically involve modification of an existing vehicle. When serial production is not yet possible, individual approvals offer the possibility of opening up the market in order to admit new technologies in a safe way.

[5] SPOC-block stands for 'Severe Partial Offset Crash-block'.

The parties interviewed also indicated that the level of knowledge among electric-vehicle users could be improved. The CBR (Dutch registration office for driving licenses), for instance, could consider devoting attention to driving electric cars. An argument put forth in the interviews was that in future most people currently taking their driver's exam will find themselves driving an electric vehicle, yet only are learning how a conventional car works. In addition, most driving lessons and exams take place in vehicles with a standard (manual) transmission to prevent having to endorse a driver's licence, stating someone is solely authorised to drive automatic transmission vehicles. Electric cars are operated like a vehicle with an automatic transmission and are therefore not typically used for the purpose of driving lessons and examinations. There are already initiatives calling for a number of driving lessons to take place in an electric car.

Conclusions

The technical differences between conventional and electric cars have been clearly identified:

- Different powertrain: the different powertrain must be taken into account when designing an electric vehicle, for instance as it relates to the crumple zone and the safe position of the battery pack within the car. The carmaker has greater design freedom (in terms of enhancing safety for the occupants and fellow road users) than with a conventional car thanks to the larger space under the bonnet.
- Centre of gravity: electric cars tend to have a lower centre of gravity. This has a positive effect on the stability of the car.
- Mass: electric cars have a greater mass than comparable conventional cars. This has a positive effect in some areas and a detrimental effect in others.
- Acceleration: based on the literature and interviews, we are unable to state an opinion regarding the safety risks in connection with more rapid acceleration from standstill.
- Braking: based on the literature and interviews, we are unable to state an opinion regarding the safety risks in connection with regenerative braking.
- Systems: in electric cars, the advanced safety and driver assistance systems built into most modern cars partly compensate for the detrimental effect of the greater mass, thus contributing to the safety of both the car's occupants and other road users.

The systems built into electric cars ensure that, in the event of an unsafe situation, injuries can be kept to a minimum. The AEBS, for example, brings the car to a standstill, which will limit the injuries and damage to pedestrians and two-wheelers. It will do the same in the event of a head-on collision with a lighter car because the braking reduces the amount of energy released in the collision which needs to be absorbed.

The results of crash testing we reviewed show that electric cars perform similarly or better with regard to safety. By law, electric cars must meet the same safety standards as conventional cars. It is worth noting that the various electric cars rated by Euro NCAP in 2019 differed greatly in the degree of safety they afforded pedestrians and cyclists. This is the result of the different car (body) designs, with some potentially having a detrimental effect on any injuries to pedestrians or cyclists in the event of a collision. Another cause is AEBS performance.

In the case of the lowest-scoring car, the AEBS did function, but not well. The AEBS in the other cars did work well. The conclusion to be drawn here is that it is not so much the electric powertrain, but rather differences in car design and AEBS performance that impact the safety performance of electric vehicles.

Without exception, the literature states that electric cars must meet the same safety standards as conventional cars, as established by law. We can conclude that it is not possible to critically assess the safety of a car (electric or conventional) based on a single factor. Rather, it is vital to consider multiple factors simultaneously, and — when designing an electric vehicle — to take all factors into account in determining the design process, in order to ensure user safety. The effect of the greater mass of electric cars therefore cannot be viewed separately from the safety systems present in the car, such as the AEBS.

3.3 Battery damage

3.3.1 Revisiting the 2014 fact sheet

In 2014, no specific information on damage to batteries was included in the report.

3.3.2 Current status as of 2020

Battery-powered electric cars have undergone extensive development in the past decade. The most commonly used batteries in electric cars are lithium ion (Li-ion) batteries (hereafter referred to as 'batteries'), which may have varying compositions. In the past decade, the batteries in vehicles have become lighter, cheaper, and can store more energy, while the service life per unit of power has increased. The development of batteries for electric cars is still in its infancy; many studies are currently being conducted into ways to improve the batteries and design new types (Kesseler, 2020). While it is difficult to predict exactly how battery development will proceed, the overall level of knowledge will continue to increase as a result, which in turn can yield greater insight with regard to battery safety. Numerous studies are currently being conducted into increasing the capacity of the battery pack and reducing the weight per unit of power. Recently, the results of several studies related to the safety of battery packs were published. We will discuss those results in the following section.

Studies and publications

With regard to the safety of batteries, we will address the following topics:
- The battery pack: the battery pack works as a system that includes various components. We will explain the different components within the battery pack, define the concept of service life with regard to a battery pack and describe how the BMS works.
- Thermal runaway: in the event of high temperature or increased internal resistance in the cells of a battery pack, fire may occur and toxic substances may be released. We will describe this process and present mitigating measures.
- Practical testing: we will describe the results of a number of practical tests conducted on battery packs.

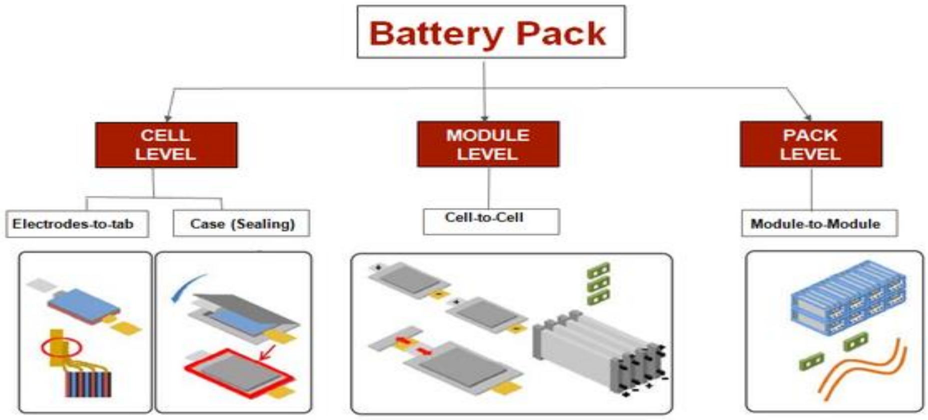
The battery pack

A battery pack is comprised of various modules containing cells in which energy is stored, see Figure 2. The specifications of a given cell[6] depend on the structure of the cell and the materials used in its construction (Samsung SDI, 2016). By combining multiple cells to form a module, it is possible to store a larger quantity of energy. Such modules — along with a busbar, connectors, print plate, housing and other materials — combine to form the battery pack (UFO Battery, 2020). We found a great deal of literature on the composition of battery

[6] A cell consists of a cathode, anode, separator and electrolyte.

packs and how they work. This varied from descriptions at the level of the battery pack to scientific sources reporting on research into the materials and components of a cell, such as the cathode, anode and separator[7] (Zhua, et al., 2018) (Wang, et al., 2020). For the purposes of this study, it would go too far to address aspects at the level of cell components and materials. We will therefore limit ourselves to a general description of the safety risks at the cell and battery levels.

Figure 2 – Structure of a battery pack



Source: (UFO Battery, 2020).

Depending on its capacity, a battery pack is able to store a certain amount of energy. The State of Charge (SoC) is the percentage to which the battery is currently charged as compared to its capacity. The quantity of energy stored in a given battery pack determines the magnitude of a potential fire or explosion. When a battery is fully charged, more energy will be released than in a case involving the same type of battery, but only partially charged (Larsson, et al., 2016; Zhua, et al., 2018). A high SoC yields a high heat release rate (HRR), which is the quantity of energy released per unit of time during a fire (NIST, 2018; Larsson, et al., 2016).

The battery pack in a vehicle has reached the end of its service life when only 80% of the battery capacity remains. After that, the battery pack can still be used for other purposes. In discussing the service life of a battery, we distinguish between 'calendar ageing' and 'capacity fade'. Calendar ageing refers to a battery reaching the end of its service life due to age; this form of ageing is unrelated to battery use. Capacity fade refers to a battery reaching the end of its service life as a result of the number of times it has been fully charged, that is the number of times it has been through the entire cycle of charging and discharging (Battery University, 2020a).

- Capacity fade: the battery packs of new electric cars being sold today are expected to last 1,500-3,000 cycles before 20% of their capacity has been lost. The expectation is that by 2030 the service life will increase to 5,000-10,000 cycles (Hoekstra, 2019). The service life in kilometres depends on the range of the battery pack. if the range is 200 km and the service life is 1,500 cycles, the service life is 1,500 x 200 = 300,000 km.
- Calendar ageing: under the right circumstances, it is possible to keep the capacity fade under 10% for fifteen years.

[7] Testing from a variety of approaches has been used to identify failure mechanisms that must be taken into account when designing a battery. Different Li-ion batteries appear to behave differently when used.

The capacity of the cells in a battery pack may vary as time passes (EV Reporter, 2020). While at first the ageing process is rapid, it becomes slower over the course of time (Battery University, 2020a).

The Battery Management System (BMS) is an electronic system that ensures a rechargeable battery functions safely and efficiently (EV Reporter, 2020). It is an integrated system with electronic components that is connected to the battery pack and collects data for the purpose of transmitting signals to the user of the car; see Figure 3. Among others, the objectives of the BMS include the following:

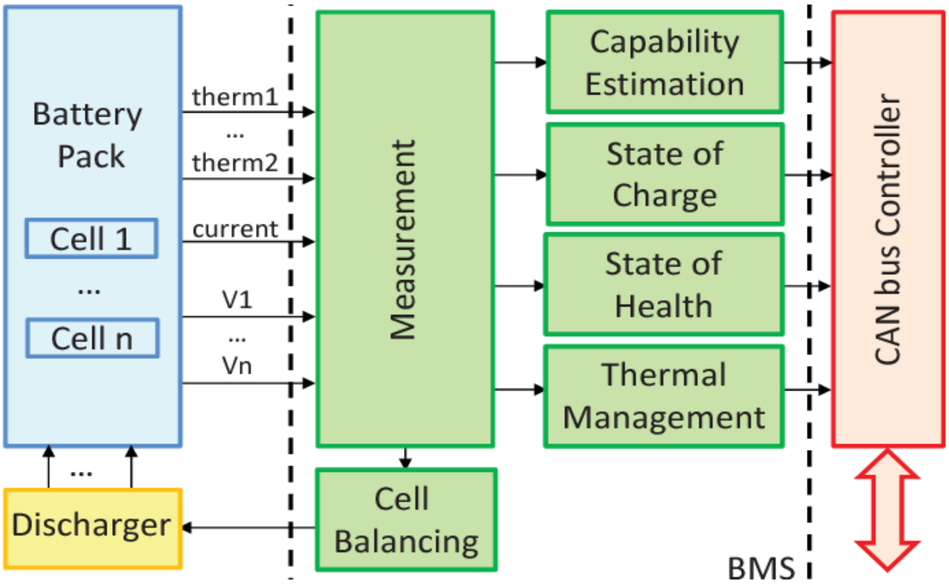
- Safety: monitoring temperature, voltage and current within the battery pack at the cell level (EV Reporter, 2020; Battery University, 2019b).
- Performance: the BMS communicates with the charging station to determine how much power can safely be charged and is able to regulate the power supply. While the vehicle is being operated, the BMS also monitors the voltage in the cells to ensure it does not become too low. The difference in capacity between the different cells is also monitored and harmonised by using current from the cells with a greater charge load than others (cell balancing) (EV Reporter, 2020; Battery University, 2019b).
- Monitoring health and diagnostics: the BMS system estimates the SoC and the State of Health[8] (SoH) based on the data collected and relays this information to the user of the vehicle (EV Reporter, 2020).The BMS checks for deviations in the behaviour of cells and has the ability to trigger failsafe mechanisms to ensure the health of the battery pack (EV Reporter, 2020; Battery University, 2019b).
- Communication: the BMS communicates with other electronic components of the car and with the charging station (EV Reporter, 2020; Battery University, 2019b).

Not every feature described above is available in every BMS. In all cases, the BMS monitors the total current flow through the battery pack, the voltage of the battery pack and the cells, and the temperature within a module (Battery University, 2019b). A BMS typically contains a single temperature sensor per module in order to conserve costs and reduce weight and volume (RISE, 2019). When any of the parameters deviate, the BMS switches off the voltage and the car cannot be restarted.

Although information on the SoC and SoH is not yet available in all BMS systems, this is currently in development. Capacity fade is difficult to measure because, under normal circumstances, capacity fade does not affect the voltage and the internal resistance. The latter are parameters which could indeed be measured by the BMS (Battery University, 2019b).

[8] State of Health is the current state of the battery as compared to its original capacity.

Figure 3 – Battery Management System (BMS)



Source: (EV Reporter, 2020).

Thermal runaway

The greatest point of concern in relation to battery safety has to do with the cells that make up the battery pack. If these cells are damaged, gas may be released, causing a release of energy that can result in an explosion. If the voltage or temperature within the battery becomes too high, this may trigger a chemical reaction that will lead to internal short circuit or an increase in internal temperature (RISE, 2019). The critical temperature differs from one battery to another (fire services apply a standard of 60 degrees Celsius) and a high external temperature can exacerbate this process (Economic Times of India, 2019) (Brandweeracademie, 2020a; Brandweer.nl, 2018a). The cell may then fail, releasing flammable gases and possibly leading to a fire or explosion. This process is known as thermal runaway and can last a few seconds or for hours. The battery itself may produce oxygen, which can allow the vehicle to reignite (Brandweeracademie, 2020b; SP Technical Research Institute of Sweden, 2017).

When thermal runaway occurs, the heat from a cell in the battery pack can spread to an adjoining cell, so that the second cell will become thermally unstable as well. This may result in a chain reaction in which all cells disintegrate and the battery pack becomes damaged and unusable. This may take anywhere between a few seconds and a few hours. It is important to install barriers between the cells in order to prevent the heat transfer described (Battery University, 2019a). On the basis of the literature, we are unable to determine the extent to which barriers are installed in the current battery packs. Among other causes, thermal runaway can result from a collision if the crash causes mechanical deformation which inflicts damage to the battery cells. The effect of a collision is not always immediately visible, as it depends on the chemical reactions in the cells of the battery pack. Minor damages can alter the internal structure of the battery, which can lead to issues like accelerated ageing and an increase in the internal resistance.

These structural changes may cause the battery to overheat, resulting in a loss of energy and a decrease in power and capacity. These occurrences will be detected by the BMS. This is why a collision that does not initially seem serious may have long-term consequences for the battery pack and potentially affect both the service life of the battery (Simeone, et al., 2018) and the safety of the user. Another risk associated with accidents is the release of gases (HF, POF_3, $LiPF_6$ and HCl) or liquids in combination with a source of ignition (Battery University, 2019a; RIVM, 2019). The seriousness of a potential internal short circuit will depend on multiple factors, such as heat generation and electrical discharge (RISE, 2019; Economic Times of India, 2019).

We found a number of recent studies that describe measures and avenues of exploration in connection with the prevention, inhibition and/or limitation of thermal runaway. At the vehicle level, these might include limiting the incidence of risk-enhancing situations such as collisions, high temperatures and vandalism. In the event that, despite measures, these situations present themselves, additional protection of the battery pack may prevent thermal runaway from occurring immediately or at a later point in time.

Mitigating measures within the battery pack and/or the battery cells may be chemical, mechanical, electrical or thermal in nature (Feng, et al., 2020). In reviewing the literature, we found the following measures to prevent thermal runaway:
- Ensuring the thermal stability of the battery cell in risk-enhancing situations (Feng, et al., 2020).
- Limiting the flammability of the materials in the battery cells (Feng, et al., 2020; RISE, 2019).
- A (smart) Thermal Management System with barriers between cells and cooling mechanisms in each cell (Feng, et al., 2020).
- Increasing the temperature at which thermal runaway occurs[9] (Kolp & Jossen, 2018; RISE, 2019).[10]
- Increasing the level of heat dissipation within the battery (Kolp & Jossen, 2018).
- Adding thermal resistance between cells (Kolp & Jossen, 2018).
- Protecting adjacent cells (Kolp & Jossen, 2018).
- Installing cells in a branched configuration within the module is safer than installing them as a series of linked cells (RISE, 2019).

In reviewing the literature, we found the following measures to inhibit thermal runaway and limit its effects:
- Reducing the amount of energy released in case of thermal runaway (Feng, et al., 2020).
- Integrating electrical fuses to reduce the electrical energy in the event of an internal short circuit (Kolp & Jossen, 2018).
- Preventing thermal runaway from spreading between cells by installing other materials between battery cells[11] or by modifying the module in which the cells can be installed (Lee, et al., 2020). Modifications to the module might include the addition of open spaces between the cells, the installation of heat shields, insulation or heat sinks, heat conductors, fire retardants or a coating (RISE, 2019).
- Separating the modules in the battery pack can reduce the chances that thermal runaway will spread from one module to another (RISE, 2019).

We found no literature regarding the effectiveness of the measures described above.

[9] This can be achieved by switching the separator to PE, PP/PE/PP, PE with a ceramic coating.

[10] In the event of thermal runaway, most of the oxygen released comes from the cathode. By applying 'transition metals' to the cathode, it is possible to increase the temperature at which thermal runaway occurs.

[11] For this study, tests were conducted in which small perforations were introduced between battery cells and then filled with different materials. While none of the materials was able to prevent the development of thermal runaway entirely, it was possible to retard the process by a factor of more than 17.

Identifying a possible thermal runaway and issuing a warning in the early stages of occurrence were put forth in the literature as measures to mitigate risk (Feng, et al., 2020). This can be achieved by using the BMS to monitor conditions inside the cells or modules. In concrete terms, this means that sensors are installed in the battery cells or modules which are connected to the BMS. If a thermal or chemical change occurs, the BMS sends a signal to alert the driver (Feng, et al., 2020). While such sensors are already in use, typically only a single temperature sensor is installed in each module. The risk here is that a cell which is not in the immediate vicinity of the sensor can become overheated and no warning signal will be issued. In the event the BMS does detect changes, the BMS can shut down the module or the battery pack in order to prevent further problems. There are no BMS systems capable of detecting an internal short circuit within cells (RISE, 2019).
The reason more sensors are not being placed in the modules or in the battery cells is that this conserves costs and reduces the weight and volume. Besides the installation of sensors in cells, we have found no other concrete solutions for identifying and reporting thermal runaway at an early stage and/or for receiving warnings.

While the measures described above are suggestions for mitigating thermal runaway, not all of these measures have been subjected to study to determine their effectiveness.
The literature states that the impact of measures can be studied by investing in simulation tools and by developing methods for testing the battery cells and the battery pack.
Using simulation tools can also serve to reduce the costs of practical testing (Feng, et al., 2020).

There is some uncertainty regarding the relationship between ageing of the battery pack and the likelihood of thermal runaway. Detection by the BMS measuring deviations can help manage that risk. IFV (2020b) states that an increased likelihood of thermal runaway is a possible consequence of battery ageing. The finding in the IFV report is based on a study conducted in 2013. A more recent study from 2019 asserts that ageing is a factor which influences the likelihood of thermal runaway (Ren, et al., 2019). This study was conducted at the component level. The research showed that the ageing of lithium plates in particular affects performance in connection with thermal runaway (Ren, et al., 2019), yet this is the only source we encountered that asserts such a relationship.

We did, however, locate numerous sources which describe the relationship between charging and battery ageing. From these sources, the following points emerged:
- Charging the battery to maximum capacity every time accelerates the capacity fade process. Charging to lower levels more frequently and charging only to the kWh needed for a specific trip will extend battery service life (Battery University, 2020a).
- Fast charging decreases the service life and safety by causing greater heat generation and accelerating the capacity fading and lithium plating processes,[12] which increases the chances of thermal runaway (Du, et al., 2019; UPS Battery Center, 2014). Any deviations are detected by the BMS.
- Ageing occurs faster when charging takes place at lower temperatures, particularly under 0°C. Charging and using a cold battery lowers the capacity and therefore shortens its service life (Battery University, 2020a; 2020b). Charging at low temperatures can also result in an internal short circuit. The BMS can prevent charging from taking place when it is too cold (RISE, 2019).
- The ideal temperature for a battery during charging is room temperature (Battery University, 2020a).
- Li-ion batteries perform best when the SoC (State of Charge) remains between the lower and upper limit. These limits differ from one battery to another. If the battery's

[12] Lithium plating is the formation of metallic lithium around the anode of Li-ion batteries during charging.

state of charge is allowed to dip below the lower limit or exceed the upper limit, the battery will age more quickly (EV Reporter, 2020).

Practical testing

Battery packs can be vulnerable to penetration in the event of side collisions or head-on collisions and as a result of debris on the road (gravel, debris from previous crashes, etc.). Because conducting tests on battery packs is quite costly in practice, much of the available data is based on numerical analyses (RISE, 2019). In the literature, however, we did find the results of a number of practical tests involving a battery pack:

- In crash tests conducted by the DEKRA and the University of Göttingen (a description of the test can be found in Section 3.3), the batteries of the car were deformed but did not ignite (DEKRA, 2019; VROOM, 2020). It is unclear from the literature whether this is based on the instant of the collisions or if the researchers observed the behaviour of the battery during the period following each collision.
- In the crash test of the Polestar 2 (the test is described in Section 3.2), the battery remained undamaged. According to Polestar, this type of collision does not usually result in risks to the battery. The testing was conducted in a crash lab where an immersion bath was present so that, if necessary, the electric car could be placed in the bath should battery damage or fire occur (Polestar, 2020). Based on the account of this test, it is also unclear whether the behaviour of the battery was monitored during the period following the collision.
- In the EVERSAFE project, a Euro NCAP side impact test was carried out on a Mitsubishi iMiEV travelling at 35 km/h. The battery pack of the Mitsubishi iMiEV showed only minor damage to the battery housing. In the weeks following the test, no unusual temperature fluctuations were observed and no toxic chemicals were detected outside the battery. The HV system outside the battery pack was switched off automatically 0.2 seconds after the impact of the crash (RISE, 2019; Robert Thomson, 2014).
- In the OSTLER project, a Euro NCAP side impact test was carried out on a hybrid Toyota Yaris travelling at 50 km/h. The battery pack in the Toyota Yaris showed penetration to a depth of 154 mm in the battery pack. Passive and active methods of protecting the housing surrounding the battery pack were tested as well. The passive method involved reinforcing the housing, while the active method was a construction designed to inflate the instant a crash occurred. The passive protection resulted in a 50% reduction in penetration, while the active method led to a 26% reduction (RISE, 2019; EC, 2014).
- In a side impact test conducted by the Mercedes Car Group, damage to the battery pack was clearly visible yet no thermal or electric reaction occurred within the battery pack (RISE, 2019).

Interviews

In virtually every interview, the phrase 'thermal runaway resulting from collisions' was mentioned as the single greatest risk of battery packs and as the cause of fires. Thermal runaway was also named as a consequence of a fire starting in another vehicle. If the fire spreads to an electric car, it will result in an increase in temperature that may lead to thermal runaway. We were unable to find statistics on the actual occurrence of thermal runaway.

Thermal runaway can also be caused by an error in the manufacturing process. The DEKRA has informed us that car manufacturers set practical requirements for the manufacturing processes of their suppliers in order to minimise these risks. To that end, they also review the materials used in the battery pack and the composition of the cells.

We do not, however, know whether every car manufacturer has established similar requirements.

Two possibilities for combating thermal runaway are methods implemented after it has occurred (suppression) or involving making the battery pack safer in order to prevent thermal runaway. The latter can be achieved by establishing additional requirements for battery packs. Solutions mentioned in connection with inhibiting thermal runaway once the process of thermal runaway has begun include:

- installing break points in cooling ducts in the battery in order to halt thermal runaway at an early stage;
- installing a mechanism in the battery pack that halts thermal runaway at an early stage by injecting water into the battery pack;
- the application of magnesium to the cathode to inhibit thermal runaway;[13]
- installing a fluid-filled housing around the battery pack.

Adding extra ridges to the battery pack housing can also serve to make the battery pack more robust. This reduces the likelihood of damage to the cells in the battery pack, decreasing the chances of thermal runaway. It was also asserted that Tesla is working on installing heat barriers between the cells.

Battery ageing is another safety aspect that was mentioned. The extent to which battery ageing affects thermal runaway is unclear, based on the interviews, nor is it readily explained in the literature. In one interview, we were told that batteries hardly age at all and recent research conducted by Eindhoven University of Technology (TU/e) in the Netherlands confirms this (Hoekstra & Steinbuch, 2020). We were also told that battery pack charging is automatically switched off when the battery pack is sufficiently charged or when the BMS detects a deviation. Taken together, these factors should ensure a low level of risks associated with ageing. We found no evidence to substantiate this in the literature.

At its own initiative, the Dutch automobile association ANWB conducted crash tests involving battery packs. These tests focused on heat generation in the battery pack. While battery packs are currently not disassembled to examine the damage inflicted, it is likely that this will be done at some point in the future. These tests showed that no problems occurred with the battery pack. In addition, the DEKRA has told us that these safety risks are being managed so effectively that the only way for dangerous voltage to occur is if the battery pack breaks in half. We found no information on this in the literature.

Conclusions

With regard to battery damage, we can conclude the following:

- The service life of batteries is defined in terms of capacity fade (based on the number of times the battery pack is charged to full capacity) and calendar ageing (caused by the actual passage of time). The BMS ensures the safe and efficient use of the battery pack.
- Based on the literature and interviews, thermal runaway emerges as the major risk in connection with the use of battery packs in cars. A great deal of information on the process of thermal runaway is available in the literature. Information on mitigating measures is available to a lesser degree.
- The number of practical tests involving battery packs is quite minimal.

[13] The ANWB (Dutch automobile association) is discussing this topic with battery suppliers.

It is unclear, based on the literature and interviews, how often thermal runaway actually occurs in practice. The majority of mitigating measures for the battery pack are potential avenues for seeking solutions that, as far as can be concluded from the literature and interviews, have not yet been applied. The most important areas for attention in combating thermal runaway were stated to be the prevention of spread to other cells and the reduction of heat.

In addition, neither the literature nor the interviews provide an unambiguous picture of the relationship between the ageing of the battery pack and thermal runaway. It has been established that certain factors can accelerate that ageing, such as charging or incorrect charging, charging in cold temperatures and an extremely hot environment. These factors result in (among other things) an increase in the internal resistance of the cells. An increase in the internal resistance is also mentioned in connection with thermal runaway.
It is therefore possible that a relationship exists between those factors that cause ageing and the thermal runaway process. However, this relationship has not been described as such in the literature and further investigation is required.

In none of the practical tests described in the literature we reviewed did thermal runaway occur after a crash test had been conducted. In at least one of the tests, measurements were taken during the period following the collision in order to exclude the possibility of thermal runaway occurring at a later point in time. No thermal runaway was detected later on in that test, either. Based on the tests, the chance that thermal runaway will actually occur appears to be small. If we apply the formula r = l * e, with ‘r’ the risk, ‘l’ the likelihood of occurrence and ‘e’ the effect in the event it does occur, then — based on these tests — the risk appears to be slight (a small ‘l’ yields a small ‘r’). On the other hand, there are few tests actually being conducted these days and the impact when thermal runaway does occur has not yet been quantitatively defined. In the interviews, multiple parties expressed concerns with regard to the risks should thermal runaway occur.
A quantitative risk analysis is needed, as are additional requirements for battery packs in order to prevent thermal runaway.

3.4 No sound

3.4.1 Revisiting the 2014 fact sheet

Electric cars generate virtually no sound when driving at speeds of approximately 20 km/h or less. At higher speeds, the noise made by the tyres becomes audible. Hybrid and electric cars must be equipped with an acoustic vehicle alerting system that is active up to the speed of 25 km/h. The lack of sound does not appear to increase the chances of an accident involving a pedestrian (TNO, 2014).

3.4.2 Current status as of 2020

Studies and publications

In this section, we will address the following points:
- No sound.
- The Acoustic Vehicle Alerting System (AVAS) is a system that deploys an acoustic signal (sound) to alert other road users to the presence of an electric vehicle (electrive.com, 2019) (The Verge, 2019).

No sound

Replacing conventional cars with electric cars can yield a reduction in noise because (as was the case in 2014) most studies show that an electric vehicle produces virtually no sound at speeds under 20 km/h (RVO, 2014; Pallas, et al., 2015; Stelling-Konczak, et al., 2015; Moller Iversen, et al., 2013; Czuka, et al., 2016; Campillo-Davo, et al., 2016; The New York Times, 2019; SWOV, 2011). While the majority of studies conclude that the absence of sound does not pose an additional threat to the safety of other road users (SWOV, 2011; Dudenhöffer, et al., 2011), some studies have found an increased safety risk for pedestrians and cyclists:

- British research has shown that electric cars are 40% more likely to be involved in a collision with a pedestrian than a conventional vehicle (Guide Dogs, 2014).
- A 2013 study arranged for electric and conventional cars to drive toward participants at low speed, starting from a distance of 50 metres. The participants heard the electric car coming when it was 14 metres away; the conventional car was audible at 36 metres (Altinsoy, 2013). Other sources confirm that pedestrians do not hear an electric car approaching until it is closer than a conventional car would need to be (EC, 2019a; Dudenhöffer, et al., 2011).

At speeds greater than 20 km/h, the difference in sound between electric and conventional cars decreases as speed increases and from 50 km/h and faster, the difference disappears entirely. In addition, the tyres of an electric car and those of a conventional car generate more or less the same amount of noise (Berge, et al., 2015; Ejsmont, et al., 2014).
The largest reduction comes from the deployment of noise-reducing asphalt and not from the use of special tyres for electric cars (Vejdirektoratet, 2015).

The AVAS system

The AVAS has been compulsory for new electric type vehicles since 1 July 2019 and since 1 July 2021 for all new electric cars in the EU (electrive.com, 2019; EC, 2019a). The AVAS issues signals to alert other road users and is meant to mitigate potential risks to safety.

Research into different types of warning signals that an AVAS could produce shows that not all sounds have the same effect. Major differences were found between various warning signals. Some signals led to an improvement in timely detection of the vehicle, in some cases even earlier than in the case of a conventional car. This was not true of other warning sounds. The drivers of the electric car perceived some sounds as annoying (Poveda-Martínez, et al., 2017). In addition, another study found that warning signals are easier to hear under dry conditions than when it is raining (Parizet, et al., 2014). A third study observed no difference in the detection time of warning signals between blind participants and participants with no visual impairment (Swart, et al., 2016).

Interviews

The Dutch traffic safety organisation Veilig Verkeer Nederland provides teaching packages to primary schools. Electric cars are now covered as part of these teaching packages due to the negligible sound they produce at low speeds. With the introduction of the AVAS system, however, this problem is temporary in nature. At this time, checking the AVAS system is not part of the compulsory annual vehicle inspection (APK).

Conclusion

With regard to sound, the following aspects are of importance:

- No sound: much information is available regarding the lack of sound (and consequences thereof) in connection with electric cars. While most studies conclude that the absence of sound does not pose any additional threat to the safety of other road users, there are also studies which indicate that the absence of sound does present risks to safety;
- The AVAS system: from 1 July 2019, this system has been compulsory for new electric type vehicles and from 1 July 2021 it will be required in all new electric cars. The system alerts other road users to the presence of an electric car.

Based on the literature and interviews, the expectation is that the AVAS system will ensure sufficient safety at speeds lower than 20 km/h. At speeds greater than 20 km/h, the AVAS system is unnecessary because the difference in sound produced by an electric vehicle and a conventional car decreases as speed increases. From 50 km/h, the difference disappears entirely and tyre noise becomes the primary sound heard. Checking the AVAS system is not part of the compulsory annual vehicle inspection (APK).

3.5 Fire safety

3.5.1 Revisiting the 2014 fact sheet

Car manufacturers have strict fire-safety requirements for their electric cars. In 2014, a detailed protocol describing what to do in case of fire was available from each manufacturer. Training sessions were developed for emergency services in the Netherlands as well. There were also questions regarding the potential consequences of an emergency involving damage to the electrical installation or the battery pack. The fact sheet contains data on the fire testing conducted by DEKRA. Electric cars performed well in these tests, with the caveat that the smoke can be particularly toxic and that a large quantity of water was needed to extinguish the fires (TNO, 2014).

3.5.2 Current status as of 2020

A fire in an electric car is fundamentally different than a fire in a conventional car because the two are powered by different energy sources. For instance: it may take hours for a battery pack to be fully consumed by a fire, while a fire in a conventional car will progress much more quickly, start to finish. As with conventional vehicles, a fire in an electric car may have an external cause such as arson or fire spreading from somewhere else.
A difference between the two types of vehicles is that only electric cars are subject to possible thermal runaway (see Section 3.3 for an explanation of thermal runaway).

Studies and publications

In this section, we will address the following topics:

- Similarities and differences between fires in conventional cars and in electric cars: in reviewing the literature, we found both similarities and differences between fires involving electric cars and those in conventional vehicles.
- Fighting fires: due to the differences in a fire involving an electric car, fire services must use different methods.
- Practical testing: we found a variety of practical testing described in the literature. We will discuss the results of those tests in this section.

Similarities and differences between fires in conventional cars and those involving electric cars

A fire in an electric car is comparable to a conventional vehicle fire in a number of ways:

- Temperature: the Dutch Institute for Safety (IVF: *Instituut Fysieke Veiligheid*) conducted a literature study aimed at differences in temperature between fires in conventional and electric cars. Their research revealed that fires involving both types of cars have a similar temperature level (IFV, 2020b).
- Intensity of the fire: the intensity of a fire is expressed in terms of its heat release rate (HRR). This is the speed at which a fire generates heat. A number of factors affect the Heat Release Rate, including the SoC and the energy stored in the battery pack or the fuel tank. Several trials conducted in studies comparing electric and conventional vehicles have shown that the HRR is similar in both types of vehicle (Sun, et al., 2020; Lam, et al., 2016; IFV, 2020b).
- Fire load: the fire load of an electric car depends on the size of the battery pack and the SoC at the time of ignition. The same generally applies to conventional cars as well: a large fuel tank can hold more fuel and can therefore store a greater quantity of energy. The fuller the fuel tank, the greater the fire load. On average, electric and conventional cars have a similar fire load (Sun, et al., 2020).
- Fire behaviour: this refers to the progression of a fire in terms of temperature and intensity over time (IFV, 2020b). A fire in a battery pack may last for hours, while a fire in a conventional car will burn itself out more quickly. In an electric car, the battery pack heats up slowly and the fire develops more slowly and evenly in the first few minutes than is the case with a conventional car. In the event of thermal runaway, however, the temperature will increase rapidly (Sun, et al., 2020; IFV, 2020b). Another difference is that with a conventional car, there is no chance of reignition once the fire has been extinguished, something that can happen with an electric car. Such reignition is caused by the energy still present in cells that have not yet ignited but are damaged or too hot (SP Technical Research Institute of Sweden, 2017).
- Toxic gases: a vehicle fire – whether it involves a conventional or electric car – releases toxic gases (Sun, et al., 2020). Many of these substances are the same in either case. The difference is that a battery fire releases more hydrofluorides (1.8 times more) (Lecocq, et al., 2012). An elevated concentration of hydrogen fluoride may lead to skin irritation (IFV, 2020b). Fire services can work safely provided they maintain good occupational health practices and avoid lengthy exposure with more than 20 to 30 minutes in the smoke (IFV, 2020a).
- Heat radiation: when flammable materials are present, the heat radiation is the quantity of heat released per unit of surface area (IFV, 2020a). The literature shows that when the SoC is 100%, the heat radiation of an electric car is comparable to that of a conventional car (Sun, et al., 2020; IFV, 2020b).
- Fighting fires: because of the difference in fire behaviour and the presence of hydrogen fluoride, extinguishing a fire in an electric car requires different methods (Brandweeracademie, 2020a; 2020b).

Based on the literature, it can be concluded that the chances that an electric car will catch fire while parked are probably no greater than those of a conventional car (Sun, et al., 2020). A data analysis on fires in conventional and electric cars between 2010 and 2015, conducted by WWU Munster, supports this conclusion (WWU Münster, 2018).

The practical testing described in Section 3.3 showed good results in terms of fire safety and the occurrence of thermal runaway following a collision (DEKRA, 2019; Polestar, 2020; Robert Thomson, 2014; RISE, 2019).

Fighting fires

Several factors make fighting fires involving electric cars a unique undertaking: the chance of reignition due to thermal runaway, the extended duration of the fire and the fact that the battery pack is thoroughly encapsulated (IFV, 2020b; ANWB, sd). When putting out a fire in a single electric car, more than 10,000 litres of water are needed to extinguish a fire in the battery pack[14] (US Fire Administration, 2020). A fire service water tender has a capacity of 2,000 litres, meaning you will need either a hydrant or more than one of these fire service vehicles to gain control of a fire in an electric vehicle (Brandweer.nl, 2018a). For this reason, emergency services often allow electric car fires to simply burn themselves out and then remove the vehicle by placing it in a salvage or immersion container. An explanation on these containers is included further on in this section.

In 2020, to support efforts to fight fires in electric vehicles, the Dutch fire service published an 'info sheet' and presented a perspective for action on how to put out fires in electric cars (IFV, 2020b). These describe how to approach an electric car and what to do when there is a risk of fire or a fire occurs. A distinction is made between the following two scenarios:

1. Fighting fires: in this scenario, water must be applied to the car to extinguish the fire and a number of safety measures must be taken in order to minimise risks. The recommended method for extinguishing the fire is to use two low-pressure water jets, with one jet aimed to extinguish the battery pack and one for the car itself. Next, the battery pack must be cooled for quite some time, either with a low-pressure water jet or by immersion in water (Brandweeracademie, 2020b; Brandweeracademie, 2020a).
2. Damaged battery pack: this scenario deals with preventing thermal runaway. The recommended course of action is to use a gas meter to measure toxic gases and to cool the battery back with a low-pressure water jet (Brandweeracademie, 2020b; Brandweeracademie, 2020a).

In the literature, we found numerous methods for extinguishing fires in electric vehicles. Among these, we can distinguish between methods that are already in use and those that are under development (or could be developed in future). The methods currently being used include the following:

- Regular extinguishing with water: this is done using a water tender (Brandweer.nl, 2018a).
- Immersion container: this is a container that can be filled with water, into which an electric vehicle can be placed. In actual practice, these containers are used not only when a car is or has been on fire, but also after a collision when there is a risk of ignition during the period following the impact (Vreugdenhil BV, 2020). A disadvantage of immersing electric cars is the high cost due to the complicated salvage and removal process, and due to the fact that it results in the car being a total loss.
- Salvage container: a salvage container is a container that has been equipped with a loading floor, a winch, a sprinkler system and the Condensed Aerosol fire extinguishing system.[15] This type of container can be deployed when the electrical system or battery pack has been damaged but the car has not yet caught fire (Transport Online, 2019).

[14] The exact quantity of water needed to extinguish a fire depends on the amount of energy present in the battery at the time of ignition.

[15] Once activated, the Condensed Aerosol fire extinguishing system initiates a reaction in which the substances being released form chemical bonds with the radicals from the combustion (FirePro, 2020). While this is an efficient method for putting out a fire, it only works in small enclosed spaces such as inside a salvage container.

The fire-extinguishing methods currently under development (or which could be developed in future) are the following:

- Installing a sprinkler inside the battery pack, to provide cooling and fire extinguishing at the cell level (IFV, 2020b).
- Attaching a fire hose connector to the housing around the battery pack. This would make it possible to directly attach a fire hose so that water can be introduced into the battery pack. Renault has experimented with this system (IFV, 2020b).
- The DEKRA has carried out tests involving a thermal lance. A mark is made on the battery pack to show where the steel housing surrounding the battery pack can be pierced. Water can then be introduced directly at this spot (DEKRA, 2019; IFV, 2020b).
- A company in Wijchen, the Netherlands, has filed for a patent on a plant-based fire-extinguishing foam. The fire-extinguishing foam bonds to water molecules to provide long-lasting cooling (De Gelderlander, 2019).

Parties who respond to incidents, such as the fire brigade, must be taken into account when developing these methods.

Once ignition occurs, lithium oxide will be present in the battery pack. This reacts with water to form lithium hydroxide, which can increase the pH of the water. This process will continue for as long as there is water in contact with the burning battery pack (RIVM, 2019). There is a difference between the environmental impact of standard fire-fighting methods and that of immersion in an immersion container:

- Standard fire-fighting methods: the literature shows that the water used to extinguish a fire in an electric car has more or less the same environmental impact as in cases involving conventional cars. It is therefore safe to allow the water (the run-off after putting out the fire) to enter the sewer system (IFV, 2020b).
- Immersion container: when an immersion container is used, the same volume of water remains in contact with the battery pack for a lengthy period. During this interval, the pH of the cooling water may rise. As a result, the use of an immersion container may have a greater impact on the environment than a standard fire-fighting method (IFV, 2020a).

Practical testing

We found the following practical tests relating to fire safety in electric cars:

- During crash-testing by DEKRA, tests involving a thermal lance were conducted in which the battery pack was pierced in order to introduce water. This means that the fire-extinguishing action takes place within the battery, which is intended to prevent the fire from spreading to other cells in the battery pack. While, based on the DEKRA tests, this method would appear to have potential, more research is needed in order to clarify how effective and safe this method actually is. None of the vehicles tested caught fire following the collisions and, because the high-voltage system was automatically switched off following the impact, there was no risk of electrocution for the fire service employees. Because no fire occurred after the crash tests were carried out, the researchers intentionally generated a short circuit to enable them to carry out tests. It was possible to effectively extinguish this fire using CO_2. The researchers advised monitoring the temperature of the battery packs using thermal imaging cameras (VROOM, 2020; DEKRA, 2019).
- At the behest of two French car manufacturers, fire tests involving battery packs and fuel engines were conducted. One test was carried out on a fully charged electric car and the other on a conventional car with a full tank of diesel. The test was based on the scenario of a fire breaking out in the vehicle interior, where the passengers are. The HRR, the heat released in general and the heat of combustion were virtually identical in the battery-powered and fuel-powered engines. The cumulative mass of

the gases released — CO_2, CO, hydrocarbons, NO, NO_2, HCl and HCN — was also more or less the same in both the electric car and the diesel-powered car. However, the quantity of HF released was greater in the electric car.
The researchers indicate that the results will be different in the event of internal short circuit in the battery pack or battery overload. There is no explanation as to what will be differences will be in those cases (Lecocq, et al., 2012).

- In a study by the Canadian National Research Centre, fire tests were carried out on a total of seven electric cars, hybrid cars and conventional cars. Each vehicle was exposed to fire emanating from a puddle of benzine for a period of 30 minutes. The temperature, heat flow, HRR and the voltage in the battery pack were measured. Every vehicle tested had a full fuel tank and the influence of the SoC was investigated. The conclusion was that, overall, electric cars pose no greater fire risk than conventional cars. The conventional vehicles showed higher peaks in the HRR and heat flow. These peaks occurred earlier or at the same time as the peaks in the electric cars. A second peak in the HRR could be observed in the electric cars as well. The first peak likely had to do with the combustion of vehicle components while the second (lower) peak was caused by the combustion of the battery pack. A higher SoC caused this peak to occur earlier than in the case of a lower SoC (Lam, et al., 2016).
- In a Swedish study of fires in battery packs, tests were carried out on the two most commonly-used Li-ion battery cells[16] and battery packs which included these cells. The HRR and the toxic gases released were measured. The study concluded that it is difficult to form an opinion regarding a larger system (an electric car) on the basis of tests involving single cells or a group of cells. This conclusion applies to the behaviour of hydrogen fluoride emissions and the HRR. During the tests, it was observed that the mass and the separation of the cells exerted an influence on the behaviour of the fire (Struk, et al., 2015).

Interviews

Generally speaking, our findings from the literature study were supported by the interviews. Because the likelihood of fire cannot be quantified, no assertions can be made as to the actual risks. The perception of the interview subjects is that, while the chance of a fire in an electric car is no greater than in a conventional car, the process of fighting such fires is different. The causes and effects of a fire cannot be effectively quantified due to a lack of both national and international statistics. There are, however, developments in this area. Fire services, for instance are working to set up a database for storing information on incidents involving electric cars.

During the interviews, additional alternatives for fire-fighting methods were put forth:
- Fire blankets that can be draped over the car to prevent a fire from spreading.
- Techniques that make it possible to cool the chassis directly.
- The possibility is being explored of manufacturing cars in such a way that thermal runaway can be halted at an early stage at the level of the battery pack itself, for instance by injecting liquid coolant into the battery pack.

Besides these fire-fighting methods, another idea mentioned was to link the BMS to eCall,[17] so that when the BMS detects fire or a risk thereof, it will alert eCall to the problem. In that case, eCall would then report the problem to the 112 central, so that emergency services can be quickly sent to the scene.

[16] These are Lithium Iron Phosphate (LFP) and Lithium Nickel Manganese Cobalt Oxide (NMC) batteries.

[17] eCall (Emergency Call) automatically contacts emergency services in the event of an accident (Rijksoverheid, 2018).

Conclusions

The following topics have been addressed:

- Similarities and differences between fires in conventional cars and in electric cars: based on the literature, it can be concluded that a fire in an electric car will behave differently (slower to develop, but longer duration) than a fire in a conventional car. For the most part, the toxic gases released will be the same, although an electric car released more hydrogen fluoride. Aspects such as the temperature and intensity of a fire, the fire load and heat radiation are comparable for both types of cars.
- Fighting fires: extinguishing a fire in an electric car requires much more water than you would need for a conventional car. Various fire-fighting methods are currently in development, with most involving methods for introducing water directly into the battery pack.
- Practical testing: a variety of practical tests involving fire in electric vehicles were carried out in order to compare them with conventional cars. These tests confirm the perception that, generally speaking, electric cars pose no greater fire risk than conventional cars in terms of temperature, heat radiation and fire intensity. The tests showed that while the gases released are more or less the same, a fire in an electric car will release more hydrogen fluoride. The fire behaviour is different: conventional cars show higher peaks in intensity and heat flow. The peaks in conventional cars occurred earlier or at the same time as the peaks in the electric cars; a second peak could be observed in the electric cars as well. In crash testing, none of the vehicles tested caught fire (immediately) following the collisions and the high-voltage system was automatically switched off.

Based on the literature and practical testing, there is no reason to assume that the chance of a fire is greater in electric cars than in conventional cars. The real-world data we found supports this assertion. The actual risk is a combination of the chance that a given incident will occur multiplied by the effect if it does occur. On the basis of the literature, it can reasonably be assumed that the chance of occurring is slight. This automatically results in a smaller risk. The data also creates the impression that the effect of a fire in an electric car is no greater than a fire in a conventional car. By compiling statistics on the subject, it may be possible in future to substantiate this impression with more real-world data.

3.6 Safety in enclosed spaces

3.6.1 Revisiting the 2014 fact sheet

The 2014 fact sheet did not contain a chapter on the topic of ‘safety in enclosed spaces’. At the time, it was merely mentioned that ‘fire brigades no longer need to be cautious about issuing permits for charging stations in parking garages’.

3.6.2 Current status as of 2020

When discussing the safety of electric vehicles in enclosed spaces, fire safety is particularly relevant. A fire in an enclosed space such as a tunnel or parking garage entails relatively serious risks, whether it involves an electric car or a conventional one. This is because there is a good chance that the fire will spread due to the proximity of other vehicles, because the toxic smoke remains in the space, because the structure of the building itself may be damaged by the heat and because such fires are very difficult for fire services to extinguish. The building damage mentioned may pose an extra serious risk in case of fire in a parking garage if there are homes, offices or shops located above it. For a detailed discussion of the risks of fire (as compared to conventional cars), we refer the reader to Section 3.5.

When electric vehicles are involved in a fire in a garage, practical experience also shows that fighting the fire will be even more complicated.

Due to these specific risks, we have devoted a separate chapter of this study to discussing the safety of electrically propelled vehicles in enclosed spaces. The safety of electric cars in parking garages has received a great deal of attention in the past year. Members of Parliament also asked questions about this subject, which was one of the reasons for compiling this report (Ministerie Binnenlandse Zaken en Koninkrijksrelaties, 2020).
Various media outlets have focused on the subject as well (Trends in auto leasing, 2020; NH Nieuws, 2020a; Economic Times of India, 2019; AD, 2020). In the last year, relevant studies and recommendations on this subject have been published both in the Netherlands and internationally. The Institute for Safety has published an extensive report on the fire safety of parking garages in connection with electrically propelled vehicles (IFV, 2020b). This study mentions that the general risk of fire in parking garages has increased drastically in recent decades, as both electric and conventional cars continue to increase in size and include greater quantities of flammable plastics in their construction. This means that existing parking garages will not always be equipped to deal with the occurrence of vehicle fires. Independent of that development, parking and charging electric cars has become a new reality in parking garages – one which entails different safety risks as well.

Studies and publications

In this section, we will discuss the following topics:

- Risks of fire in an enclosed space: car fires inside parking garages (i.e. multi-storey and underground car parks) yield certain specific risks. Because fires in electric vehicles are different than those in conventional cars, a fire in an electric car entails other risks as well.
- Recommendations on measures to mitigate risk and incident management: a summary of the recommendations formulated with regard to the mitigation of risks and the management of incidents involving electric cars in enclosed spaces, including charging stations in parking garages.
- Practical testing: this heading covers any conclusions that can be drawn based on the tests conducted and actual incidents of fires in parking garages.

Risks of fire in an enclosed space

A fire in an enclosed space such as a tunnel or parking garage entails different risks than a fire in an open space, such as outside on the street. These risks can be divided into risks that apply to all vehicles and risks that apply specifically to electric cars. The risks which apply to vehicle fires in enclosed spaces in general are:

- danger to humans due to heat and flue gases;
- accumulation of flue gases die to limited exhaust possibilities;
- major risk of the fire spreading due to close proximity of other vehicles;
- risks of damage to the structure of the building, with the worst-scenario being collapse of the garage;
- difficulties for fire brigade in fighting the fire.

As is explained in Section 3.5, certain differences exist between a fire in an electric car and a fire in a conventional car. The major difference in incidents involving an enclosed space is that battery fires are difficult to put out. In practice, this means that a large quantity of water is needed or an immersion container must be used to manage the incident.
In practical terms, this method of incident management is quite difficult in parking garages because it is impossible to bring the immersion container to the car in question.

The Swedish research agency RISE conducted a study into the specific risks of fires involving electric cars in parking garages in Norway. The study concluded that there is no reason to believe that charging electric vehicles increases the likelihood of a fire (RISE, 2019). The Institute for Safety, however, asserts that there is a need for more research into the chance of a fire resulting from charging an electric car in a parking garage, as the charging itself is an additional potential cause of a fire (IFV, 2020b). This indicates a current lack of consensus in the literature with regard to whether, and if so to what extent, the charging of electric cars yields greater risks to safety in parking garages.

Recommendations on measures to mitigate risk and incident management

Based on the available knowledge, the Institute for Safety has issued a report containing recommendations on how to mitigate risks and manage any incidents that occur (IFV, 2020b). This report from the Institute for Safety first sets out a number of general categories, each of which contains specific measures, which provide fire-safety solutions for both electric and conventional care in garages. For a comprehensive explanation of these recommendations, please refer to the Institute for Safety's report. The following is a brief summary of the recommendations which apply specifically to parking and charging electric cars. These recommendations should be viewed as possibilities that could be considered for a given, specific location and not as cumulative requirements.

- Architectural adjustments: this might include modifying the parking garage structure to better protect it from fire, possibly with specific adjustments to the areas where charging stations are located. Charging points can also be equipped with collision protection to reduce the chance of a fire, while in underground car parks there is the option of requiring electric vehicles to park in a 'basin' section below floor level.[18]
- Technical adjustments to installations: with regard to the charging infrastructure, the possibility of being able to switch off all charging facilities at once is an avenue to explore. Another step that can be considered is to avoid placing charging stations and parking spaces for electric cars near ventilation openings and escape routes. In addition, displacement ventilation and/or a smoke and heat exhaust can ensure toxic gases are vented quickly.
- Organisational measures: this category pertains primarily to instructions and information. Examples are instructions on using the car park and charging facilities correctly and steps to inform drivers on what to do in case of fire and how to respond to malfunction alerts.
- Repressive measures: repressive measures can prove useful in fighting complex fires. This might, for instance, entail modifications to the fire-fighting and/or water extraction facilities in order to supply the very large quantity of water needed to put out a fire in an electric car. It is possible to give the fire service better chances of fighting a fire by ensuring: the fire is reported quickly; there is effective smoke ventilation; the site is easily accessible (from the street); and that sprinkler systems have been installed. Visual markers that identify the locations of charging points can help fire services form an accurate initial impression of an incident. Another potential area for attention is the method used to remove the electrically propelled vehicle from the garage once the fire has been extinguished.

[18] If the cars are parked in a 'basin' construction (i.e. under the adjacent floor level) that can be filled with water, any fires can be extinguished by doing so. In terms of building design, this option applies primarily to parking spaces on the lowest level of the car park.

In the literature, we found descriptions of the following measures to limit safety risks in connection with charging stations in parking garages:

- Disconnecting the power supply: a facility by which all charging points can be switched off through a single action (IFV, 2020b).
- Structural safety: additional measures may be installed in the car park at or around charging points to protect the building structure (IFV, 2020b).
- Location of charging facilities: these should not be placed at sites to which air ventilation is directed, to prevent any products of combustion from spreading further into the structure (IFV, 2020b).
- Agreements with users: in private car parks, agreements regarding safe use of the charging facilities can be made with users by means of a user agreement. In public car parks, charging instructions for users can be posted near the charging facilities.

Practical testing

Relatively little practical testing has been conducted in connection with the effects of fires involving electric vehicles in enclosed spaces. Such research is quite costly when carried out at actual scale; this explains why such studies are infrequently conducted. A recent Swiss study involved simulating a tunnel fire involving an electric car at a reduced scale, using a 4 kWh battery. The study yielded the following conclusions (Mellert, et al., 2020):

- toxic gases remained under the threshold values and the substances released are no more hazardous than those from a fire in a conventional car;
- no corrosion of the construction was observed;
- in case of vehicle fires, modern ventilations systems in tunnels and garages can adequately manage the venting of toxic smoke, even if the vehicle on fire is an electric car;
- with regard to heat development, a burning electric car is not more dangerous than a conventional vehicle on fire.

In reviewing the literature, we also found a study by the French tunnel institute in which experiments were conducted with regard to the tunnel safety of electric cars.
The experiments were carried out in an actual tunnel. No collision tests were conducted and the study included no research aimed at the possibility that collisions involving electric cars might take place in tunnels. The study concluded that (Mellert, et al., 2018):

- the chance of fire in a tunnel involving an electric car is comparable to the risk for a conventional car;
- the toxic gases released when an electric car catches fire do pose a hazard in the event the ventilation system of the tunnel is insufficient;
- based on the results, the researchers do not predict a need to make adjustments to existing tunnels, although incidents will require different management than those involving conventional cars.

In addition to planned practical tests, it is also possible to learn useful lessons from situations where actual fires occurred in parking garages and where electric cars were involved. Two examples of this recently took place in the Netherlands: the car park fire in the Singelgarage in Alkmaar and the fire in the car park under Marktplein square in Epe (NH Nieuws, 2020a; 2020b; De Stentor, 2020). The fire in the Singelgarage in Alkmaar destroyed two cars, one of which was an electric car. The incident in the car park in Epe concerned an electric car that caught fire due to an unknown cause.

According to the incident investigation of the fire in the Singelgarage, the fire was most likely the result of arson (IFV ; Brandweeracademie, 2020d). The two cars which were destroyed were parked more than fifty metres apart. The electric car was not plugged in to a charging station. When, after around two hours, the fire brigade reached the burning vehicles, only a few small flames remained visible. The cars were nearly completely burnt out. Both cars were extinguished with water. Some time after the fire was put out, flames again emerged from the battery of the electric car; these were once again extinguished. Because the battery of the car was still hot and there was concern regarding instability of the battery pack, the electric car was moved out of the structure using a transport robot belonging to The Hague police force, at which point the car was placed in an immersion container and taken away. Such use of transport robots is relatively new in the context of fighting fires in parking garages. The fire largely went out by itself, probably as a result of the parking garage having fire doors. The fire was limited to the two cars in which it began. The incident investigation also revealed that the concrete ceiling above both burnt out cars had been damaged. The damage above the conventionally powered vehicle was deeper (more of the steel rebar within the concrete was exposed), while the damage above the electric car extended over a very long area. Based on the incident investigation, it is unclear which area of damage was more severe. The fire did not result in any danger of collapse. Another relevant detail is that the conventional car in question was parked three metres away from a Tesla. Despite the high temperatures, the fire did not spread to the Tesla.

The fire in a car park at the airport in Stavanger, Norway, did indeed lead to the collapse of a large portion of the structure. While this fire was not caused by an electric car, electric vehicles were involved. The Swedish research institute RISE investigated this fire (RISE, 2020). Their investigation concluded that the presence of electric cars did not increase the intensity of the fire's development as compared to what would be expected with conventional cars. It was also concluded that the toxic substances in the batteries did not result in the pollution of nearby water sources.

Interviews

The fire safety of electric cars in parking garages (i.e. multi-storey and underground car parks) came up in many interviews. The picture that emerges from the interviews seems to indicate some ambiguity as to whether parking electric cars poses a greater risk than parking conventional cars. Many parties indicated that while a lack of statistics makes well-substantiated assertions impossible, they estimate the risks to be similar to those of conventional cars. Also unclear are the recommendations and guidelines concerning the realisation of charging facilities and parking spaces for electric cars in parking garages. On one hand, there is a need for a rapid transition to electric vehicles, which in turn creates a strong demand for charging facilities in car parks. Yet on the other hand, we have learned from the interviews that the perceived potential safety risks can cause the rollout of charging stations in parking garages to stagnate. As a result, this is the subject of some confusion with regard to potential safety risks among stakeholders such as car park owners.

Additionally, the division of responsibilities among incident managers (i.e. emergency responders) is not always clear (see also Section 3.7) and there is some discussion regarding the relatively high costs of salvaging electric cars in parking garages. These matters are currently the topic of consultation with incident managers, salvage companies and insurers.

The interviews revealed that the majority of the measures suggested by the Institute for Safety have not yet been put into practice, or only to a very limited extent, as this report was only recently published.[19] Another factor is that there are questions as to the practical applicability and cost effectiveness of the various options for safety measures in parking garages. An example of this is the creation of special compartments for electric cars there. The objections put forth in connection with such a measure are that it is difficult to enforce, as electric cars can also park in spaces where there is no charging point, and that that such measures will no longer be possible once a large percentage of all vehicles on the road has become electric.

There is also a difference between charging in public car parks and charging in private ones. In public parking garages, for instance, the ability to shut down all charging facilities from a single central point has already become standard, while this is typically not the case for those belonging to a homeowners' association. It is also the case that such measures are often difficult to implement in cases involving homeowners' associations because each of the power cables that supply the charging stations comes from a different private home. Moreover, most charging points in parking garages are installed by certified companies and are Mode 3 Type 2, while there is much less oversight regarding the quality of charging points in private car parks. The impression also emerged that the likelihood of an incident occurring in a private garage is greater.

Interviewees also expressed a strong demand for more efficient salvage and removal techniques that can be implemented in enclosed spaces. While multiple potential solutions were put forth, these are not yet (to our knowledge) being used in real-world practice. Firstly, fire blankets are being developed which can be draped over a burning electric car at an early stage in the fire to prevent the blaze from spreading. Research is also being conducted into techniques for removing a burning electric car from a garage with the help of unmanned electric vehicles. An alternative recommended by parties including the Institute for Safety is to create a 'basin' in the floor of garages with a high risk profile, which could then be filled with water when necessary. The car could be driven into the basin to extinguish the fire, as it is not possible to bring an immersion container into the garage. Another avenue that should be explored is the possibility of designing electric cars in such a way that thermal runaway can be halted at an early stage.

The interviewees gave varying responses when asked about the role of the government in regard to safety in parking garages. On the one hand, some parties asserted that the government bears responsibility because the issue affects the safety of citizens. Because the government also promotes the use of electric vehicles, it seems only reasonable that they would have a hand in identifying the associated risks. On the other hand, we were told that market parties are being encouraged to develop their own innovative solutions when no or limited government funding is made available.

[19] The extent to which specific directives on electric vehicles will be included in the new Buildings Decree is unclear at this time. At the time this report was submitted, the standards committee (with whom we were unable to speak directly in an interview) was still deliberating on this issue.

Conclusions

Based on the literature and interviews, we can draw the following conclusions:

- Risks of fire in an enclosed space: Based on the literature and interviews, it can be concluded that (in general) the fire safety risks in parking garages have increased in recent decades. This development is taking place independently of the introduction of electric cars.
- Recommendations on incident management: incident management proves difficult in actual cases of parking garage fires involving electrically propelled vehicles. This is primarily due to the fact that battery fires are difficult to put out. A potential partial reason for this is the relatively unknown nature of the technology, as a result of which the most efficient means of fire fighting is thus far unknown as well.
- Practical testing: due to the limited number of tests that have been conducted in enclosed spaces in practice, it is difficult to assess exactly how great the risks are of a garage fire and whether electric cars pose greater risks. The practical tests we are aware of showed encouraging results: no significantly higher risks were observed as compared to a fire involving a regular car. However, since it is not always clear how accurately such studies represent real-life situations in actual garages and tunnels, it can be concluded that there is a need for additional research.
- Recent fires in parking garages: recent fires in which electric cars were affected (but not the source of the fire) provide insights into the risk of fires involving electric cars in parking garages. An investigation into a large fire in a garage in Norway showed that the presence of electric cars did not increase the intensity of the fire's development as compared to what would be expected with conventional cars, and that the toxic substances in the batteries did not result in the pollution of nearby water sources. Two recent fires in Dutch parking garages did not result in danger of collapse.

In one fire, the fire in the electric car was put out by the sprinkler system, while the other fire largely burnt out on its own (due in part to the presence of fire doors). The latter fire was investigated after the fact, revealing that the damage to the ceiling above the electric car was not deeper than that above the conventional car. While no general conclusions can be drawn from these two cases, they do provide insight into the fire behaviour, impact on the building and deployment of emergency services in these cases specifically.

In general, fire safety risks in parking garages have increased in recent decades. This development is taking place independently of the introduction of electric cars. Neither actual events nor the studies and publications available give reason to believe that electric cars result in an increased risk of fire in parking garages. The limited number of practical tests and research aimed at recent fires in such car parks present the same picture. Here, too, the actual risk is the chance that a given incident will occur multiplied by the effect if it does occur.

Due to the limited number of tests conducted in practice and the lack of statistical data, assertions in this area cannot be made with any certainty, so it is important to compile statistics and investigate the causes of the fires in order to provide a broader factual basis for this discussion. Regulations must also be brought up to date in order to mitigate the risks in connection with fire safety in parking garages.

3.7 Incident management

3.7.1 Review of 2014

There was a safety guideline on 'safety measures in the event of incidents', which included an appendix on electric cars. In addition, electric passenger cars were included in the Crash Recovery System (CRS), which is linked to the registration number database of the Netherlands Vehicle Authority (RDW). The CRS contains details such as the type of fuel a car uses. The CRS is a commercial tool. Training courses exist to teach emergency services personnel how to deal with alternative propulsion vehicles. Because of the extremely high torque that an electric car generates at a low rpm, the vehicle must be completely disconnected in order to work safely on or near it. Furthermore, an electric car may not be towed with the wheels on the ground (rolling) because when the wheels are rolling, additional energy will be stored in the battery. This may result in damage to the electronics and/or battery (TNO, 2014).

3.7.2 Current status as of 2020

Studies and publications

In this section, we will address the following topics:
- Perspective for action in incident management: we will provide a description of the available tools and risks in connection with the management of incidents involving electric cars.
- Removal and salvage of electric cars: we will discuss the process of salvaging electric cars.

In this section, we will not discuss practical testing because the practical tests described in the previous sections are relevant to the topic of incident management. Section 3.3, for instance, addresses how to combat thermal runaway and methods for extinguishing fires are covered in Section 3.5.

Perspective for action: incident management

In the info sheet on 'incident management in an e-vehicle', fire services lay out scenarios for fire and for damage to the battery; see also Section 3.5. In addition to these scenarios, the following potential risks were mentioned as well (Brandweeracademie, 2020b):
- a continuous supply of power from the charging station during a fire;
- voltage in the battery pack and the vehicle, resulting in an arc;
- spontaneous rolling because an electric car makes no sound when the motor is on.

The risk of spontaneous rolling applies to all cars, with the difference being that electric and hybrid vehicles produce little to no sound when they begin to roll, which may result in additional danger. The risk of rolling can be eliminated by blocking the wheels. Electric cars are also equipped with a high-voltage system. When attempting to put out a fire in the vehicle, this voltage must be switched off (Brandweeracademie, 2020b; Brandweeracademie, 2020a).

The emergency services at the scene first identify the situation and the type of vehicle. A layperson will not immediately be able to see that the car in question is electric because only the propulsion system is different. When the electric car in question is one for which no conventional models exist (such as a Tesla Model S), the risk is smaller than for a car that has both electric and conventional versions (such as a Volkswagen Golf).

Various tools and rescue sheets are used to determine whether the car in question is an electric vehicle, which include the following:

- A thermal imaging camera: a thermal imaging camera can be used to see whether there is heat development within the car.
- Crash Recovery System (CRS): a company called Moditech has developed a tool which, using the registration number, displays an interactive model-specific illustration on the screen; see Figure 4. The CRS is a commercial tool for which users must pay a fee. The same information is shown for every make and model of vehicle (Moditech, 2020).
- FIA Rescue Sheets: the FIA provides rescue sheets containing model-specific information free of charge. As these rescue sheets come directly from the car manufacturers, the sheets vary in appearance from one model of vehicle to the next (ADAC, 2020).
- Euro Rescue: this app is being developed by Euro NCAP and the CTIF.[20] The app will allow users to request information on the vehicle, such as to help them determine the location of the battery in a particular model (EuroNCAP, 2020a; CTIF, 2020). The interface is pictured in Figure 4.

Figure 4 – Interfaces of the CRS tool (left)

Source (Moditech, 2020) and Euro Rescue (right), source (CTIF, 2020).

Removal and salvage of electric cars

When an incident occurs involving an electric car, the car is turned over to a specialised salvage company. Specialised salvage companies have immersion and/or salvage containers into which an electric car can be placed when necessary. At this time, only a few salvage companies in the Netherlands have such systems, meaning electric cars must sometimes cross the entire country before being immersed.[21] A rollout in multiple regions could eliminate this problem. For example, the Dutch IJsselland security region set a goal of ensuring all salvage companies in the region would have immersion containers by summer 2020 (Veiligheidsregio IJsselland, 2019), and at the start of 2020, fire services asked a number of salvage companies in the northern Netherlands to develop immersion containers (DvhN, 2020). It is unknown whether the immersion containers are indeed now in use in both regions.

[20] CTIF is the international association of fire and rescue services.

[21] As far as we know at this time, there are multiple salvage companies with immersion and salvage containers in their possession, but only Vreugdenhil Berging B.V.is currently using these.

Immersing electric cars is expensive and is not necessary for every (kind of) incident (AMWeb, 2020). Together with fire services and salvage companies, the insurers association is developing a protocol that will include objective criteria for determining when a car must be immersed in a container (Aftersales Magazine, 2019). These criteria will be incorporated into a decision tree. This protocol is intended to provide salvage companies with tools for ensuring the safety of their employees when salvaging and/or removing an electric car and to facilitate effective agreements regarding the financial settlement. One reason for developing such a protocol is the concerns regarding safety from those active in the salvage sector (Transport Online, 2019; VBM, 2019).

Salvaging electric cars in parking garages entails new challenges; see Section 3.6. Once a fire has been extinguished, the electric car must be removed to prevent reignition inside the car park. An electric car cannot be placed in an immersion or salvage container inside a parking garage; this must be done outside the garage. Cooperation between fire services and the salvage company is needed in order to remove a car from such parking garages. According to the Institute for Safety, the division of responsibilities between the fire services and the salvage company is an area for attention (IFV, 2020b).

Practical testing

Most of the practical tests described in the previous sections have to do with incident management.

Interviews

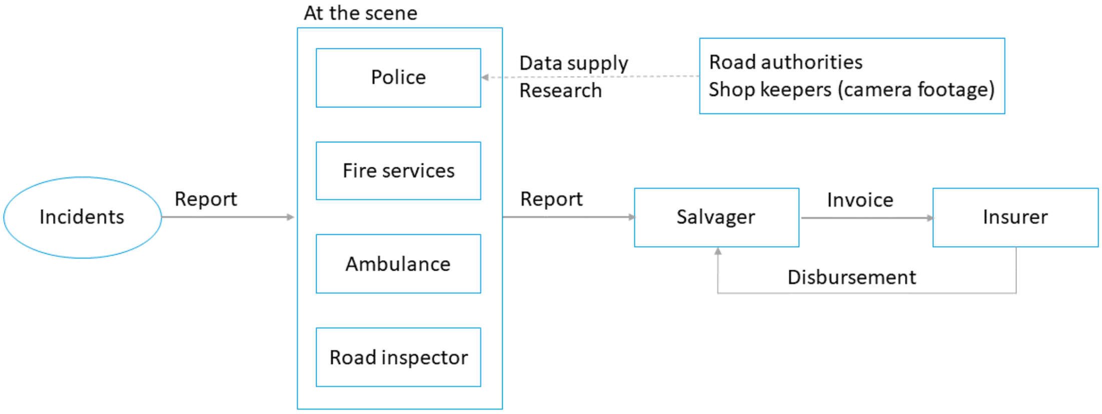
When a fire occurs in a vehicle, emergency services hope that passers-by will quickly report the fire. A report is received by a traffic control centre or via a call to 112, at which point the fire services head out in response. The 112 centre has no special code to indicate that an incident involves an electric car. While the interviews did not reveal a need for this, they did mention the need to be able to identify the car in question based on the registration number. The eCall system is one of the systems helping to make this possible. Emergency services are expected to be familiar with the REVI guideline and to act in accordance with it.

In situations on the motorway, the road traffic controller can close off a lane of traffic with a red X (Rijkswaterstaat, 2020). Depending on the location and the seriousness of the incident, the road inspector and/or emergency services will come to the scene; see Figure 5. The division of roles here is as follows:

- The road inspector takes measures – such as placing roadblocks – to ensure that emergency service personnel can work safely. The road inspector will visit the scene of an incident only if it takes place on a national motorway. In the case of incidents on provincial/municipal roads or in a parking garage, a regional authority will come to the scene.
- The police will visit the scene only if the incident involves a criminal act or the accident is a serious one and a vehicle must be towed. The police will investigate the cause of the incident, taking both the vehicle and the surroundings into account. Data will be requested from road authorities and other sources.
- The fire service offers help with putting out fires but also with rescuing people from such emergency situations.
- An ambulance will be dispatched to the scene only if injury has occurred.

The emergency services personnel on the scene will decide if the vehicle must be salvaged and will contact a salvage company if necessary. Once the vehicle has been salvaged, the salvage company will submit the invoice to the insurer, at which point the insurer will disburse payment to the salvage company.

Figure 5 – Typical incident management chain



The emergency services at the scene first identify the situation and the type of vehicle. A layperson will not immediately be able to see that the car in question is electric because only the propulsion system is different. When the electric car in question is one for which no conventional models exist (such as a Tesla Model S), the risk is smaller than for a car that has both electric and conventional versions (such as a Volkswagen Golf). The tools we found in the literature were discussed during the interviews. The emergency service workers interviewed indicated that, in an ideal scenario, it would be possible to scan the car (e.g. via a QR code on the vehicle) and then have the vehicle details be immediately displayed. The challenges here are that the code must remain intact and legible in the event of an incident, and that every manufacturer must have such a system in place.

We were able to interview one of the few specialised salvage companies in the Netherlands for the purpose of this study. Vreugdenhil Berging B.V. has a single immersion container on its premises and another mobile immersion container that can be taken to the scene of an incident. As a result, the salvage company must travel back and forth across the entire country to salvage electric cars. This is not feasible in the longer term since the number of incidents involving electric cars will increase along with their rising numbers.[22] The salvage company trains its own employees based on standards and first-hand experience and advises other salvage companies to train their employees first before attempting to use the immersion containers. Partly for this reason, not all salvage companies in the Netherlands that have immersion containers are currently using them.

Because of the equipment needed to salvage and remove an electric car, along with the fact that an electric car is a total loss once it has been immersed, the costs of salvaging an electric car are five to six times higher than those associated with a conventional car. While insurers have been disbursing payment to salvage companies thus far, there are a

[22] In this context, an ‘increase in the number of incidents involving electric vehicles’ means that as electric vehicles become more common (more numerous), it is inevitably so that a larger number of the incidents that occur will involve electric vehicles. This does not mean that electric vehicles will cause more incidents than vehicles which run on conventional fuel. Making that kind of comparison would require quantitative research based on growth scenarios, data, assumptions concerning developments in battery science and starting points such as the average annual mileage of the vehicles.

great many questions surrounding this issue. For instance: as it currently stands, in the event of an incident the decision is often made to immerse an electric vehicle. Yet the perception of the persons interviewed is that this is not always necessary. In addition, the salvage industry has expressed a need for guidelines on how to safely salvage electric cars.

Technological developments are moving too quickly for emergency services to keep up, and as a result, emergency personnel are sometimes unaware that a new technology exists until the moment they are dispatched to manage an incident involving that technology or development. The risk here is that knowledge among emergency service workers will fail to keep pace with developments. To prevent this, the fire service is working to provide input regarding solutions for safety in case of incidents at an earlier stage in the process. Another problem that was mentioned is the wide-ranging knowledge required of first responders such as police officers. A police officer may be called to respond to a variety of incidents, ranging from disputes between neighbours to collisions involving an electric car. The decision has therefore been taken increase basic knowledge, such as learning to check whether a vehicle has an exhaust pipe. If no exhaust is visible, it is very likely that the vehicle in question is electric.

A lack of data was a frequently discussed point in the interviews. Manufacturers are mentioned as data owners, but do not share their data. In the Netherlands, the police force keeps a database on traffic accidents. If the police also register the registration number of vehicles involved in traffic accidents, this can be linked to the RDW's registration number database, which contains several pieces of vehicle information. This will not, however, make it possible to determine whether the electric vehicle caused the accident, whether the electric powertrain played a role in it or what the severity of the accident is. This can be ascertained only through a more specific investigation of the accident in question. The fire service is also working to set up a database for recording all incidents involving fire service personnel. The goal of this database is to identify the actual risks (estimation) and whether, in hindsight, the actions taken were correct (evaluation). Yet these two collections of data will not provide a complete picture, as the fire service and police are not present at the scene of every incident. The fire service will also share this data with the CTIF, a global organisation for data bundling. This data will be shared with the manufacturers as well.

The ANWB offers vehicle assistance to its members. Calls for assistance involving electric cars usually have one of two causes:

1. The car has come to a standstill because the battery pack is empty.
2. The charging cable is stuck in a charging point and cannot be dislodged.

In the interview with the ANWB, we were told that providing vehicle assistance in accordance with established standards can prove difficult in certain circumstances. When the car in need of help is connected to a charging station, the car is subject to the NEN 9140 standard while NEN 3140 applies to the charging station. Effectively, this means that two technicians are needed — which is not a workable solution. The ANWB is working with road assistance providers to gain a more in-depth picture of this topic. Together with the DEKRA, the ANWB offers training programmes for roadside assistance and fire service personnel.

Conclusion

In this section, we addressed the following topics:

- Perspective for action in incident management: the incident management chain for motorways (and other places) functions according to the REVI guideline. Electric cars present different areas for attention for incident managers, such as the high voltage in the vehicle.
  Various tools are available on the market for identifying electric cars.
- Removal and salvage of electric cars: the salvage of unstable/burning electric cars is carried out by specialised salvage companies who have immersion and/or salvage containers. The number of salvage companies in the Netherlands with this specialisation is currently small. Within that industry, the companies are working with insurers and fire services to draft a protocol for safely salvaging unstable/burning electric cars. This protocol will include (among other things) objective criteria for determining when immersion in a container is necessary and when other methods can be deployed.

Incident management presents a number of challenges:

- It is not always easy for emergency services personnel to identify an electric car due to the knowledge level among personnel (wide-ranging knowledge, not only regarding electric cars) and the availability of tools. The rescue organisations are considering taking steps to increase the knowledge of all emergency services personnel. Now that the EURO Rescue app is being developed, the expectation is that it will become easier to identify electric vehicles.
- Because no databases on incidents involving electric cars exist, it is difficult to quantify the risk of an incident and to evaluate whether the method applied did indeed prove effective. The fire service is developing its own database and the police have (limited) data available. Linking these two sources, and potentially supplementing them with data from additional sources, could provide a clear overview and good information.
- Safety-related concerns exist in the salvage industry with regard to the salvage and removal of electric cars. At this time, there are few salvage companies in the Netherlands that are equipped to salvage electric cars, while the number of electric cars continues to grow. It is therefore important that sufficient equipment be made available and that salvage workers obtain sufficient knowledge. A protocol is being developed which can serve as a tool for guaranteeing the safety of salvage workers. When sufficient equipment is present, knowledge of safety risks is needed to work safely; such knowledge can be provided through employee training.

3.8 Maintenance and safety

3.8.1 Revisiting the 2014 fact sheet

Electric cars place different demands on garage staff, mechanics and technicians. Electric motors have fewer moving parts and therefore require less maintenance than conventional passenger cars. The NEN 3140 standard applies to electrical work involving more than 24 volts. NEN 9140, derived from NEN 3140, was developed specifically for the automotive sector. Training courses on ‘working safely on electric and hybrid cars’ are available from various institutes. Similar training programmes have also been developed for emergency services personnel, random-sampling inspectors and other technical employees of the RDW. Together with the DEKRA, the ANWB has introduced a training programme on how to provide vehicle assistance.

3.8.2 Current status as of 2020

Studies and publications

In this section, we will address the following topics:
- Working on electric cars: people who work with and on electric vehicles are required to have special certification.
- The training of roadside assistance and other emergency services personnel to work on electric cars.

Working on electric cars

Work carried out on electric cars can be divided into three categories: maintenance and repairs, diagnostics, and damage. Each category requires the use of different tools.
For maintenance and repairs, for instance, the tools that will be used to carry out the work are already present in the workshop/garage. The specific equipment used to block off the area, such as red-and-white striped tape, indicates that the vehicle in question is electric (AMT, 2019) (Würth, sd). The tools are supplemented by Personal Protection Equipment (PPE) in order to work safely on electric cars.
The necessary tools and PPE are (AMT, 2019):
- material to block off the area, such as poles and chains, and to mark the vehicle as a high-voltage hazard;
- a set of insulated tools;
- a bipolar voltage detector with safety insulation;
- protective footwear for electricians;
- a safety helmet;
- a hydraulic workbench on which to place the battery pack.

Compared to conventional cars, the voltage used in electric cars is much higher. Many tasks require the voltage in the vehicle to be disconnected completely, according to an established protocol, before any other work can be done. The electrical wiring that carries high AC or DC current is orange coloured (OOMT, 2018). According to the Occupational Health and Safety Catalogue, there are six steps which must be taken to ensure all electrical current in a vehicle has been switched off (Arbocatalogus, 2015):
1. Switch the ignition of the vehicle on and back off again.
2. Carefully store the ignition key.
3. Disconnect the 12V battery.
4. Turn off/remove the HV Service switch (every manufacturer puts this in a different place).
5. Wait ten minutes until the capacitors are fully discharged.
6. Carry out a 0-Volt check using a suitable instrument.

Training is required in order to properly disable the current in a vehicle. Various institutes offer the training course ‘Basics of working safely on e-vehicles (ev-VOP NEN 9140)’. Attendees of this course learn how to safely work on, with or near electric cars according to the NEN 9140 protocol. During the training course, the following aspects are addressed (Innovam, 2020; VOC, 2020):
- learning what high voltage is, along with the corresponding hazards;
- the high-voltage system, other components specific to electric cars (battery, converters, charger, wiring) and types of powertrain;
- how to disable the current in an electric car;

- PPE and other safety measures for working with/on electric cars, including inspecting the condition of the PPE;
- standards that tools and measuring instruments must meet;
- estimating the threat of electrical hazard;
- possibilities for carrying out repairs as directed by the manufacturer, or not;
- vehicle diagnostics based on error codes.

Training roadside assistance and other emergency services personnel to work on electric cars

Today, the training course is available to roadside assistance and other emergency services personnel so that they can work safely on electric cars. The training course was developed by the ANWB in cooperation with the DEKRA, with some 900 roadside assistance and fire service employees having completed it to date.

Interviews

During the interviews, a number of points were made in addition to those from the literature study:

- At this time, the annual vehicle inspection (APK) does not include checks of battery maintenance and status. While the replacement of a battery is registered, the quality is not. The inspector does not, for instance, check to see how many times the battery has been charged and therefore which stage of its service life the battery is in. According to the ANWB, it is difficult to include this aspect in the APK because the condition of a battery pack is hard to quantify. Temperature measurements can be used to evaluate the current state of the battery; in actual practice, roadside assistance personnel do this with cars that have been involved in an accident. However, we were also informed that this method is more suitable for evaluating cars that are showing signs of a problem than for the purposes of an APK annual vehicle inspection. In addition, the BMS can itself indicate the status of the battery pack.
- It is unclear whether ageing of the battery affects the safety of the battery pack and the electric car.
- Lack of expertise is a risk factor with regard to vehicle maintenance. This applies, for example, to hobbyists who attempt to repair or modify the cars themselves.

Conclusion

The following topics were discussed in this section:

- Working on electric cars: Specific training programmes are available for garage staff in order to teach them to work safely with, on and near electric cars.
  The most important safety aspects are the high voltage and fire safety of the electric car.
- Training roadside assistance and other emergency services personnel to work on electric cars: this training course was developed by the ANWB in cooperation with the DEKRA, with some 900 roadside assistance and fire service employees having completed it to date.

It seems that to date, no regulations exist with regard to consumers and safely working on or repairing/modifying electric cars. Besides regulations, it might be worthwhile to consider efforts to inform and increase awareness among consumers and owners of small garages with regard to the safety risks involved in working on electric cars due to the high-voltage installation in such vehicles. This could be achieved by devoting attention to electric cars during driver's exams at the CBR or by means of a public information campaign.

3.9 Immersion in water

3.9.1 Revisiting the 2014 fact sheet

At the time when the previous fact sheet was being compiled, the risks of total immersion of electric vehicles were well known. While the risk of electrocution is non-existent, there is a small chance of hydrogen and oxygen gases accumulating due to electrolysis.
When removing the vehicle from the water, it is therefore important to either open the doors or break out the windows. Little was known about the risks of partial immersion in 2014.

3.9.2 Current status as of 2020

Studies and publications

We found few new studies related to the risks of immersion in water of electric cars.
This can be explained by the fact that the risks of total immersion of electric vehicles were already well known in 2014 (TNO, 2014). On the specific topic of partial immersion of vehicles, however, little information is available. All existing Dutch sources on immersion in water refer to the 2014 fact sheet, which seems to indicate that it is the most recent national source of information (TNO, 2014).

In the United States, the NFPA provides an overview of steps to take and dangers in case of flooding. It is unclear whether partial immersion of vehicles was considered specifically in this context. The overview is part of 'NFPA's Alternative Fuel Vehicles Safety Training' for incident managers. The overview states that the problems in the event of immersion in water will depend on the kind of water. Salt water or polluted water, for instance, conducts electricity better and may increase the likelihood of a short circuit. In addition, when describing a course of action, a distinction is made between 'cars that are immersed in water' and 'cars which have previously been immersed in water'. In connection with the former, the recommendation is to avoid contact with cables and HV components and, if possible, to switch off the motor. When a car has previously been immersed, the recommended course of action is to avoid contact with the damaged car and/or battery and to disconnect the battery. Small bubbles coming out of the battery pack are not an indication that there is an increased risk of electric shock. Fire service personnel are advised to wear protective clothing and use an air pack (SCBA: self-contained breathing apparatus) (NFPA, 2017).

Interviews

The interviews indicate that few special safety precautions are required in the event an electric car is immersed in water. While in principle the battery is well insulated, salvage workers do wear high-voltage protection gloves because the risk of live voltage is difficult to ascertain. As far as we know, no one has ever been electrocuted as a result of an EV immersion. As with other incidents, responders are always cognisant that the vehicle may begin spontaneously rolling during and after the process of removing it from the water.
An electric car can be submerged in water without posing a hazard and, in case of flooding, charging will be switched off first.

Less is known about the partial immersion in water of electric vehicles. A potential difference is that no oxygen can reach the battery when the car is completely submerged, while in the case of partial immersion this might still be possible. However, there is no record of any actual situations in which this was a problem.

Conclusion

Batteries of electric cars are designed to continue working even if completely immersed; there are various standards for this (see Section 4.8). Compared to 2014, no new knowledge has been gained with regard to partial immersion of cars, although the standards do distinguish between the battery being submerged in deep water and it being submerged in shallow water. A potential difference is that no oxygen can reach the battery when the car is completely submerged, while in the case of partial immersion, this might still be possible. Salinity and pollution in the water also entail greater risks in connection with fire safety because such water is a better electricity conductor. The expectation, however, is that this will pose no great risk because guidelines were (in part) developed with a situation where flooding occurs in mind. In the event of a flood, the car — and therefore the battery pack — will not always be completely submerged.

3.10 Charging infrastructure

3.10.1 Review of 2014

The 2014 fact sheet contains no specific information regarding the charging infrastructure.

3.10.2 Current status as of 2020

The National Charging Infrastructure Agenda (NAL: *Nationale Agenda Laadinfrastructuur*) includes the projection that by 2030, a total of 1.7 million public, semi-public and private charging stations will be needed to charge electric passenger cars (RVO, sd). As the number of charging points increases, so will the importance of charging infrastructure safety.

Studies and publications

In this section, we will address the following points:
- System architecture of the charging infrastructure: here, we will set out the differences between charging modes and provide a description of the digital architecture of charging stations and charging points.
- Safety risks of charging infrastructure: we will address the safety risks associated with the charging infrastructure, divided into the categories of usage, physical safety and digital security.
- Practical testing.

System architecture of the charging infrastructure

It is possible to charge an electric car in several different ways, as several different methods of charging exist. Charging stations also vary in terms of location and their type and/or appearance. It is possible to charge a vehicle at home, but also while out and about (public) and on-location such as in a parking garage or at your work (semi-public).
In addition, 'charging squares' have been built at a number of locations in the Netherlands;

these can accommodate multiple electric cars, charging these either simultaneously or consecutively (De Nieuwe Stad, 2020).

Currently, multiple charging techniques are either in development or in use, such as induction charging and charging via a pantograph (Lanova laadpalen, 2020; The Verge, 2019). In this study, we will restrict our attention to charging with a plug and will exclude these developments from our discussion as they are not being used (or only to an extremely limited degree) with electric passenger cars in real-world practice. Charging infrastructure is complex and includes many different components, both physical and digital. For the terminology in this section, we refer the reader to the Netherlands Enterprise Agency report 'Charging Electric Vehicles', which contains definitions and explanations of terms related to charging electric cars (RVO, 2019).

In addition to the Netherlands Enterprise Agency's report, we will provide an explanation of the built-in safety systems in an electric car and the charging stations based on Table 3. Table 3 shows that charging modes 2, 3 and 4 are each equipped with their own distinct built-in safety system, while Mode 1 has no built-in safety systems at all. However, Mode 1 charging is not used for electric passenger cars. The built-in safety systems make it possible for the car and the charging station to communicate with one another. This communication ensures that the current stops when the battery is fully charged and that the amount of current can be limited to a level appropriate to the car. In Mode 2, the communication takes place through the In-Cable Control Box (ICCB), a portable safety device that is built into the charging cable. In Mode 3 and Mode 4, the communication takes place via the BMS (EV Reporter, 2020).
- Mode 3 charging: the BMS communicates with the charger in the car to monitor and control the charging of the battery pack.
- Mode 4 charging: a connection is made between the charging station and the vehicle. The BMS communicates regarding the required voltage and current that needs to be received from the charging station. The BMS issues instruction to the charging station about when to start and stop the charging process.

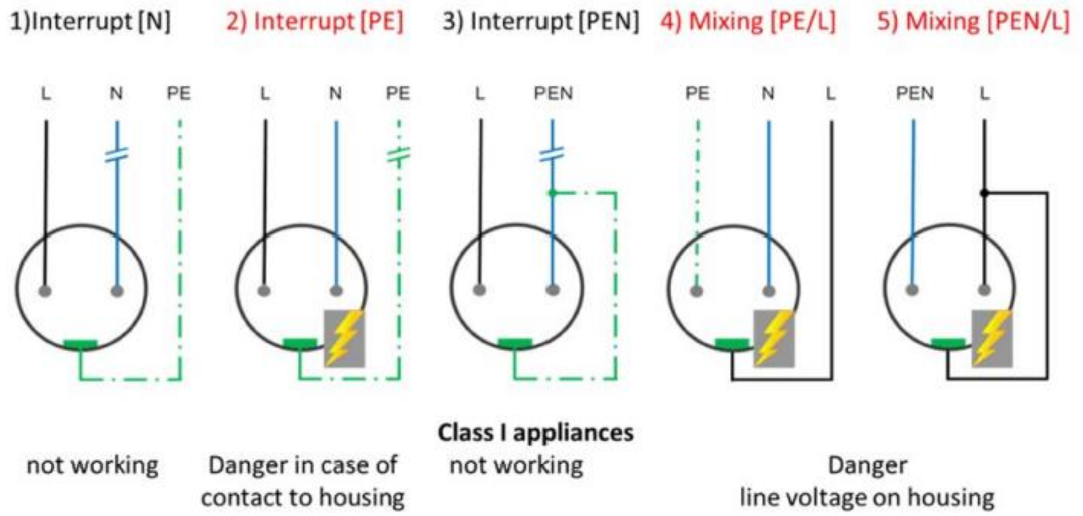
Table 3 - Overview of charging modes based on (RVO, 2019; The Driven, 2018)

	Mode 1	Mode 2	Mode 3	Mode 4
Is used for electric passenger cars	No	Yes	Yes	Yes
Type of charging	Private	Private	Private and public	Private and public
Charging point	230 V outlet	230 V outlet	Charging station	Charging station
Charging capacity	2.3 kW (single phase, 10A)	In practice: 2.3 kW (single phase, 10A) In theory: 7.4 kW (single phase, 32A) 22 kW (triple phase, 32A)	Private charging stations usually 3.7 or 11 kW Public charging stations: 11 kW or 22 kW Sometimes 43 kW	50 kW - 350 kW
Communication between EV & charging point	No	Via ICCB	Via BMS	Via BMS
Turns off when battery reaches full charge	No	Yes	Yes	Yes
Limits current level	No	Yes	Yes	Yes
Location of AC to DC transformer	In the car	In the car	In the car	In the charging station

Most of the time, private charging involves AC charging. We will illustrate possible faults involving electrical wiring in homes based on Figure 6 (Hanauer, 2018):
1. A defective phase wire or neutral conductor: this can result when a connection becomes detached over time. This is a visible flaw and can easily be remedied by an electrician.
2. A defective ground wire: this is not visible and, as a result, may be present for a longer period prior to discovery and can lead to electric shocks. This risk can be eliminated by installing a residual-current device.
3. In older homes, the ground wire and neutral conductor may be connected to one another. If this neutral connection or either one of the wires becomes damaged, the charging point will no longer work. An electrician can easily repair this fault.
4. Incorrect installation of the phase wire and ground wire (4) or the ground wire and neutral conductor (5) can create a hazard. In these situations, the installation of a residual-current device will have no effect because the current flowing through all wires is the same.

The figure above illustrates why charging cables with built-in control and protection are necessary to ensure safe charging, and why Mode 1 charging of electric cars has been outlawed in many countries (Hanauer, 2018; The Sun, 2019). We will therefore exclude Mode 1 charging from consideration for the remainder of this section. Modes 2 and 3 are currently in use for home charging. These charging modes involve the kind of built-in control system we mentioned.

Figure 6 – Potential failure mechanisms in home charging stations, where N = neutral conductor, L = phase wire and PE = ground wire



Source: (Hanauer, 2018).

The following parties are involved in the operation of charging stations:
- TSO: system administrator (TenneT).
- DSO: regional electricity grid operator.
- Charge Point Operator (CPO): a company that keeps charging points in working order and guarantees the network continues to operate as it should (Virta, 2018). A CPO provides the charging points and arranges their installation and maintenance, as well as the distribution of electricity to the charging stations. CPOs also operate a breakdown service (Allego, 2019). Not all charging stations are managed by a CPO. Some private

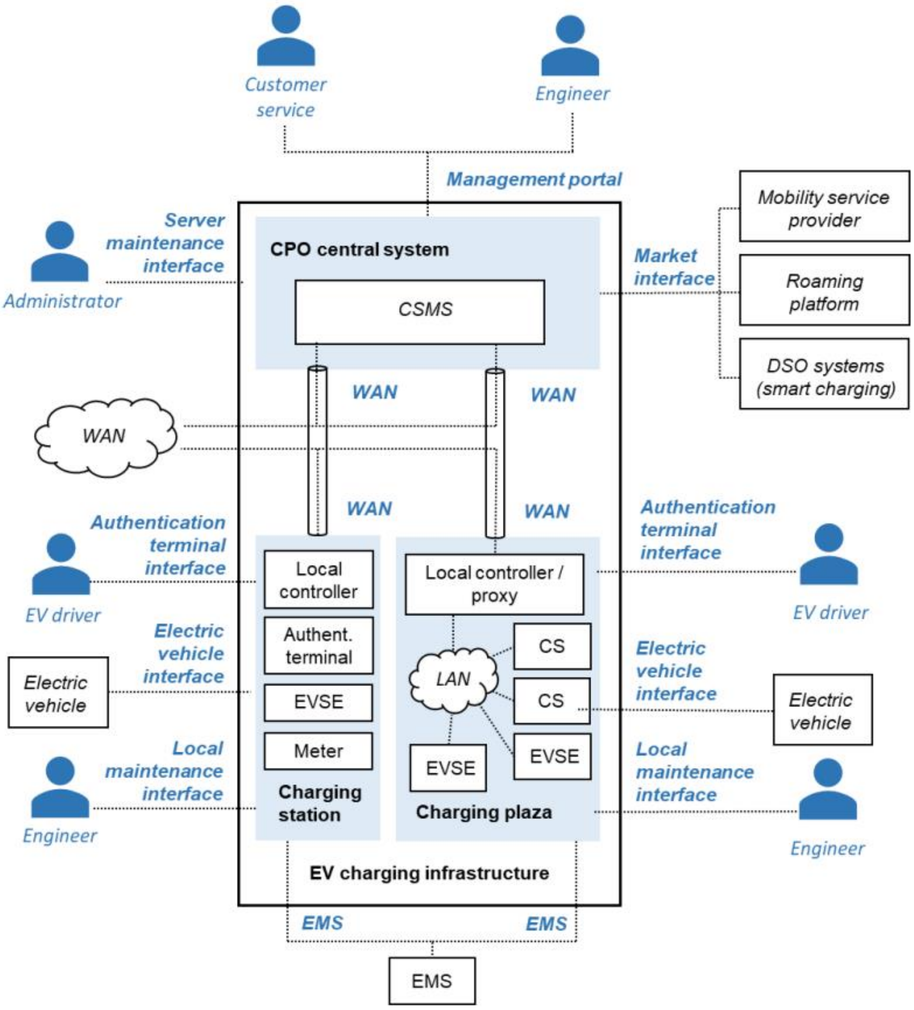
citizens choose to purchase a charging station without a hosting subscription from a CPO.

— (E)Mobility Service Provider (EMSP): a company that sells products and services — such as charging passes and subscriptions — to drivers of electric vehicles (Virta, 2018; Allego, 2019).
  An EMSP offers access to a number of charging stations within a given area and helps EV drivers find charging stations and begin charging; it also facilitates the payment transactions. In most cases, an EMSP offers assistance only to registered clients (Virta, 2018).

While a single business can be both a CPO and an EMSP, this is not always the case (Virta, 2018; Allego, 2019).

The Charging Station Management System (CSMS) is the system in which data from charging stations and points is collected in the back-office system of a CPO. In Figure 7, we see that the CSMS is connected via internet or GPRS to local monitors, safety systems and meters in charging stations and points, which are in turn connected to an electric car whenever it is plugged into the charging point.

Figure 7 – Digital architecture of charging stations



Source: (ElaadNL, 2019).

Areas for attention when using cables and designing, installing and using charging points

Safety risks in connection with the charging infrastructure depend on usage, the physical characteristics of the charging infrastructure and the digital aspects of the charging infrastructure. There is a physical component to the safety risks of all charging modes, although Mode 3 and Mode 4 are safer than Mode 2 because they feature a greater number of built-in safety systems. Digital security risks (such as the risk of hacking) are an issue only with Mode 3 and Mode 4 due to the digital components in the charging infrastructure and car. Safety risks related to use are mainly an issue with private charging points that use Mode 2, with the primary risk being that the charging cable may be connected to a household electrical system that is not suitable for supplying the require voltage level for a longer period of time.

In Section 4.9, we will address the international guidelines in effect for charging infrastructure. In addition, we provide an overview of the safety risks we found in the literature based on guidelines for the use of charging cables and charging stations which were established in New Zealand. These guidelines were selected because they offer effective insight into existing safety risks. The guidelines apply for modes 1 through 4, up to a maximum charging capacity of 150 kW. These guidelines are in keeping with the international guidelines described in Section 4.9 and have also been supplemented with national guidelines pertaining to connections and maintenance requirements (Worksafe, 2019). A list of situations that may pose risks to safety is included in the guidelines as well. This list offers an idea of the applicable safety risks and is in keeping with other literature we found:

- Using adapters which were not brought to market by either the manufacturer of the vehicle or a manufacturer of security devices for electric cars (Worksafe, 2019).
- Using a regular wall outlet (Worksafe, 2019).
- Using two or more power cables connected together to form a single extension cord (Worksafe, 2019).
- Using a portable power outlet (Worksafe, 2019).
- Using an extension cord (Worksafe, 2019; IFV, 2020b).
- Using a single outlet to charge more than one vehicle at the same time (Worksafe, 2019).
- Using devices that are not certified to be compatible with a 230V and 50 Hz power supply (Worksafe, 2019).
- Using a charging point intended for electric vehicles to charge any electric device other than an electric car (Worksafe, 2019).

Wear and tear to charging cables and/or the use of an extension cord result in additional risks. These risks are the threat of fire and electric shocks (IFV, 2020b). Rain may increase these risks because a short circuit can occur at the site of damage to the cable and/or the point of connection with the extension cord. A study conducted by Electrical Safety First (ESF) revealed that 74% of the 1,500 users surveyed has on occasion used an extension cord to charge their vehicle (The Sun, 2019).

Having reviewed the literature, we also found the following aspects that must be taken into account to ensure safe design, installation and use of charging stations:

- Collisions: the installation of collision protection around charging points on the street and in parking garages is important in order to reduce the chances of an incident (IFV, 2020c). There are a variety of practical solutions on the market to ensure collision protection (Boplan, 2018; Oplaadpaal-kopen.nl, 2020)[23]. In the event of a collision with a public charging station, the charging station will automatically switch off if the sensor that monitors the upright position of the station (provided one is present) determines this is necessary and sends a signal to the CPO.
- Cutting off power when an incident occurs: in case of an incident, it must be possible for incident managers to disconnect the electric cars from the charging point and to switch off power to the system. Charging points equipped with sensors to detect temperature deviations or when the charging point is askew can automatically switch off when an incident occurs. This can be achieved by installing an emergency ‘off’ switch/button, for instance, but also by means of security sensors that send messages between an electric car and charging points in order to ensure the safety of the connection, the energy transfer and the act of disconnecting the two (Milicic, et al., 2016; IFV, 2020b).
- Physically restricting the degree to which moisture may come into contact with electrical components in order to prevent short circuit (Milicic, et al., 2016; IFV, 2020b).

[23] Collision protection can be achieved by installing horizontal plastic bumpers in front of the charging points, placing safety plinths or wheel stoppers in the parking space next to a charging point or by installing stainless steel tubing around the charging point.

- Monitoring: by monitoring the current moving through the charging cable and the connection with the ground, the systems in charging points can ensure that the charging points automatically switch off when a connection becomes loose or the voltage becomes too high (Worksafe, 2019; Hanauer, 2018).
- Installation: the New Zealand guideline recommends positioning the contact outlet of a Mode 3 or Mode 4 charging station at least 800 mm above ground or floor level (Worksafe, 2019). Installation of charging points should be carried out exclusively by competent, certified installers (Worksafe, 2019; Allego, 2019).
- Maintenance: regular inspection and maintenance reduces the likelihood that safety risks will occur (Worksafe, 2019; Allego, 2019; Wang, et al., 2019).
- Flame arcs: in the event of a short circuit, a spark is generated which may lead to a flame arc. The risk of an arc occurring depends on the quantity of energy (Wang, et al., 2019).
- Fire safety (Wang, et al., 2019).

When charging via Mode 3 or Mode 4, risks to digital security are present in addition to the physical safety risks. Charging points are often connected to the internet or using GPRS, for example, making them a potential target for cyber attacks (ElaadNL, 2020; Wang, et al., 2019). Together with the ENCS[24], ElaadNL has drawn up security requirements for a safe digital charging infrastructure. This documents sets out measures for mitigating risks across eight different categories (ElaadNL, 2019). These categories provide an effective overview of cyber security risks:

1. Access control: this entails granting access rights to users and verifying the users' identities in Figure 7 (ElaadNL, 2019).
2. Cryptography: this is deployed to encrypt information for users (human and digital), to verify firmware and to protect the confidentiality and integrity of communication between parties (ElaadNL, 2019).
3. Physical security: securing the physical access to components such as memory cards and processors (INCIBE, 2020).
4. Operations security: this refers to safety aspects that make it possible to operate the charging station(s). A key concern here is designing for the future (such as sufficient RAM and flash memory to implement updates), system back-ups, monitoring and creating logbooks (ElaadNL, 2019). This applies to payment transactions as well (inNOVE, 2020);
5. Communication: ensuring the communication is secure (ElaadNL, 2019).
6. System development and maintenance: security must be taken into account when designing the charging infrastructure and corresponding digital architecture (ElaadNL, 2019).
7. Information security for CPOs: third parties must never be able to access vital data belonging to/intended for CPOs (ElaadNL, 2019).
8. Continuity of information security: this pertains to the need to minimise the impact in the event of security system failure (ElaadNL, 2019).

Practical testing

We found no mention in the literature of practical tests involving collisions with or fires at charging stations. As a result, we are unable to form a conclusion regarding the actual risks that occur in connection with charging electric cars.

[24] ECNS stands for 'European Network for Cyber Security'.

Interviews

In the interviews, it was indicated that there are major differences in safety between the various charging methods. Mode 3 and Mode 4 charging were mentioned as being quite safe, while Mode 2 charging was not. The power outlets used in combination with Mode 2 chargers are not suitable for being used for much longer periods than usually would be the case, which yields additional risks. This risk occurs on the power supply side and not the vehicle side. With Mode 3 charging, a system is built into the charging point that enables it to switch itself off in the event of a problem. There is also a detection system which ensures that, if an unsuitable cable is plugged in, a lower current will be dispensed.

According to the parties interviewed, users do not require any additional knowledge in connection with Mode 3 charging. However, knowledge levels related to Mode 2 charging, using Mode 2 charging in combination with an extension cord and using old plugs should be enhanced. Since not all car manufacturers provide a Mode 2 charging cable as a standard accessory with the purchase of an electric car, additional knowledge of Mode 2 charging will become less relevant as time goes on, however. User instructions already specify that adapters are not permitted, while the ANWB advises against using equipment such as a cable reel when charging. Knowledge would also be welcome concerning the risks of damaged connectors with any of the charging modes.

The risks specific to fast charging are the strong current and the high voltage being used. In addition, fast charging results in greater heat development in the charger, the connector, the cable and the battery pack itself. Managing that heat is vital, with a cooling circuit built into the car in order to actively draw away the heat being one way of doing so. New cars are usually equipped with such a system and older models may or may not have one built-in. When fast charging, thermal management is essential in order to combat battery ageing. The major risk in connection with this heat development is fire.

During slow charging, the charger is subjected to lower voltage. For AC charging, the cable is not connected to the battery but rather to the on-board charger, which can detect problems. In the case of rapid charging, the charger runs certain checks.

To maintain safety, it is important that quality is assured. CPOs are responsible for the installation of public charging points. When a private charging station is installed, the responsible party is usually the owner or manager of the building. Most CPOs do not employ installers of their own; instead, they screen potential contractors to ensure those installers are certified.

Charging station manufacturers provide training for installers to facilitate the safe installation of charging points. Such training courses also address communication with the back-end. In the Netherlands, installers must be familiar with the applicable legislation (see Section 4.9), yet there is no agency that oversees the installation of charging points, whether public, semi-public or private. In other countries, such as Belgium, such an agency does exist. There, the installation of charging stations must be approved by an independent company. A potential disadvantage of such approval is that it might entail high costs. Likewise, insurers do not always assess whether installation has been carried out properly. Insurers decide for themselves and on a case-by-case basis whether an inspection will take place.

One of the parties with whom we spoke in the interviews was the MRA-E.[25] We will provide an overview here to illustrate how they manage the charging infrastructure:
- Contract managers oversee the safety of public charging points.
- The MRA-E ensures quality by enforcing requirements for the installation procedure of public charging points. The charging points must pass what is known as a factory acceptance test and the installers must submit proof of their certification. Upon delivery, the operator or contractor must draw up a delivery document and confirm that the process has complied with the requirements.
- The MRA-E establishes the requirement that a charging station must require little maintenance, yet contains no additional requirements in connection with maintenance.

The CPOs interviewed have arranged the inspection and maintenance of their charging stations in different ways:
- Two of the CPOs conduct annual visual inspections and carry out preventative maintenance on the charging points. In addition, inspections — and any repairs needed — are carried out whenever the charging point sends a signal to the operator.
- Another CPO (for fast chargers) ensures that the charging stations are cleaned every three weeks. During this cleaning, everything is inspected. Users can also submit an alert via an app or by phone in the event something is amiss (such as when the connector is damaged or charging is unsuccessful). Possible causes of failure to charge include a dirty or cracked car inlet.

The CPOs use certified installers to install their charging stations. In some cases, these installers are employees and sometimes they are hired contractors. During installation, the installer will inspect the emergency button (if present), the charging process and the cable connection.

The responses given in the interviews varied with regard to fire safety when connecting to the charging point. We were told that in the event of an incident (a fire or collision), the charging point will automatically switch off the power if the charging point is equipped with sensors to detect temperature deviations or when the point is askew. While public charging points have such sensors in place, they are not always present in private charging stations. The BMS in the car will also automatically switch off the voltage if it receives a deviating signal. We also heard of an actual situation in which this automatic disconnection did not occur and it was necessary to cut the power to the charging point before the fire could be extinguished. The ANWB has received calls for assistance where it was impossible to disconnect the car from the charging point. The type of charging point involved in those instances is unknown. Fast-charging stations are often equipped with an emergency button to disable the voltage; this is the case with some AC charging stations as well. In the interviews, we heard no mention of cases in which an attempt to disable the voltage was unsuccessful.

Municipal authorities determine the locations of public charging points. When plans for construction are made, the charging infrastructure is generally not evaluated by a fire prevention committee.

The requirements for charging points are established when issuing tenders and differ from one municipality to the next. These requirements are subject to change over time. Such requirements may concern: the size of the charging point; its resistance to vandalism; water ingress; capacity; disruption-related aspects; maintenance; costs; ICT security and so on.

[25] MRA-E stands for 'Metropolitan Region Amsterdam - Electric'.

Where new charging techniques are concerned, charging via lampposts is considered safe so long as these are equipped with a complete Mode 3 charging point. Induction charging appears to be a more distant goal and is expected to become profitable only after self-driving cars are introduced.

The most important message to emerge from the interview with fast-charging specialists is that charging stations are equipped with many systems intended to ensure safety. These systems conduct continuous checks and if a deviation occurs in the charging station or the charging process, charging is stopped immediately. The systems are designed in such a way that they can be updated in order to guarantee safety. The specialists indicated that users pose a greater risk than the charging station itself, due to the risks of collision, vandalism or improper use of connectors. Data[26] from a CPO shows that collisions with fast-charging stations are a frequent occurrence. To reduce this risk, CPOs use an island configuration for their stations and place them further away from the road. In the event of a collision despite these measures, the main power line must be disconnected, either physically or remotely. While emergency services personnel cannot always access this power line, they can contact the CPOs. The specialists had no knowledge of any cases of electrocution or fire in connection with charging an electric car.

An additional point to emerge from the interviews is that charging electric vehicles other than cars poses a greater risk than charging electric cars. This has to do with the fact that, while legislation is in place for electric cars, this hardly does not exist for electric bicycles, for instance. As a result, the likelihood of thermal runaway in electric bicycles is estimated to be considerably greater. An additional risk occurs when other electric cars (such as a Biro) make use of Mode 3 charging points. In such cases, the charging point receives a signal that Mode 3 charging is taking place, while this is not the case, as the Biro uses only certain components of Mode 3 and not its safety aspects.

Conclusion

In this section, we addressed the following points:
- System architecture of the charging infrastructure: the four charging modes consist of various components, with Mode 3 and Mode 4 having a larger number of built-in safety systems.
- Safety risks of charging infrastructure: safety risks differ from one charging mode to another. A distinction can be made between risks due to (potentially improper) use, risks resulting from physical characteristics of the charging infrastructure and risks due to digital characteristics of Mode 3 and Mode 4.
- Practical testing: no practical tests were found in which the safety of the charging infrastructure (either physical or digital) was tested. We are therefore unable to quantify the risks identified in this chapter.

Charging infrastructure is complex and is made up of many components, both physical and digital. This complexity yields challenges in terms of mitigating risks. We were unable to answer all of the specific questions under consideration by means of the literature study and the interviews we conducted. Based on the questions put forth by the client prior to this study, and based on information from the interviewees, we have observed that a need does exist for answers to these specific questions. An example of a question that we were

[26] This data is in the CPO's possession and is not accessible to the public. The conclusion put forth by the CPO in the interview is based on their own data.

unable to answer but that was frequently discussed is: What can be done to ensure the safety of charging-point installation at private homes?

In the literature, we found no practical tests relating to the safety of the charging infrastructure, either physical or digital. We are therefore unable to quantify the risks identified in this chapter. Our impression, based on this literature study and the interviews, is that Mode 3 and Mode 4 charging is safe thanks to the built-in systems. While all charging modes are to some degree vulnerable to collisions, a charging point with a built-in sensor that detects when it is askew will automatically switch itself off in the event of a collision. Faulty connectors can also give rise to risks or cause a charging point to fail to begin the charging process (built-in safety system). Once again, the actual risk is the product of the chance that a given incident will occur and the effect if it does occur. Based on the interviews (and therefore based on data from the CPOs), the chance of risks occurring would seem to be present to some degree, yet the effects are small should those risks occur.

On the basis of the literature and the interviews, we can conclude that proper installation is important in terms of safety. Governments set requirements in this area when issuing tenders. Oversight of installation is regulated differently in different countries; in the Netherlands, there is no independent inspection following installation. Each CPO applies its own protocol for oversight to ensure proper installation and for carrying out preventative maintenance and visual inspections. The frequency with which visual inspections of charging stations are carried out varies from every three weeks (for fast-charging stations) to once a year for the CPOs we interviewed.

4 Laws and regulations

In this chapter, we describe the laws and regulations or standards and certification we found in the literature, or that was mentioned in interviews, in connection with each of the nine safety aspects. It is evident from both the literature and the interviews that a great many regulations exist and that an increasing number of standards have been formulated in recent years, specifically with regard to electric cars and battery packs. Even today, these standards are being further developed and/or formalised in regulations. New standards are being developed as well in order to guarantee the safety of electric cars.

A large portion of the regulations in question apply to both electric and conventional cars. Day-time running lights, for instance, have been required on new vehicles of all types since 2011 (EC, 2020a) and regulations are currently being developed for semi-automatic brake support (AEBS) (UNECE, 2019). In this chapter, we will discuss the major directives, regulations and guidelines which are either currently in effect or in development and relate specifically to electric cars. Based on our literature study and the interviews, we will also indicate in the conclusion to each section whether a gap in regulation exists in connection with each theme.

4.1 Vehicle safety

All vehicles in Europe must be equipped with a type approval certificate that meets the EU's guidelines. These guidelines have been defined for each category of vehicle (RDW, 2020). In the Netherlands, a type approval can be requested from the Netherlands Vehicle Authority (RDW).

The Road Traffic Act 1994 is in force in the Netherlands. While this Act has not been amended since the previous fact sheet was created, small adjustments have been made to the regulations it covers. The following regulations apply to electric cars (TNO, 2014) (RDW, 2020):
- Uniform regulations for the approval of electric cars (VN/ECE Regulation no. 100 (ECE 100), which was updated in 2015).
- Testing and requirements in connection with electromagnetic compatibility (EMC, UN guideline/ECE Regulation R10 or for the L category vehicles 97/24; guideline 72/245/EEG is no longer in force) (EUR-Lex, 2014).
- Testing and requirements with regard to road handling (policy rule on road handling).
- Requirements pertaining to cables, facilities for disconnecting high voltage and the placement of the battery pack. (Appendix IV, Annex 4, Vehicle directive).
- Since 2011, all high-voltage cables must be orange so that they can be quickly and easily identified by technicians and emergency services workers. High-voltage cables made prior to that year may have a different colour.

The ECE 100 Directive was updated in 2015. This directive sets out uniform regulations for the approval of vehicles, including specific requirements for the electric powertrain for vehicles in categories M (passenger cars and buses) and N (commercial vehicles) (EU, 2018; RDW, 2020). The latest version includes new testing requirements for manufacturers of rechargeable batteries (TUV SÜD, 2014). A new approval schedule has been added as well (European Road Safety Observatory, 2018). According to the DEKRA, in practice, manufacturers supplement the ECE 100 with additional requirements of their own and more safety measures are actually applied than are called for in the ECE 100.

International regulations with regard to electric cars are currently in development as well. Within the United Nations (UN), for instance, various working groups are focusing (or have focused) on existing and additional measures to ensure the safety of electric cars:

- IWG Electric Vehicle Safety (EVS);
- IWG Electric Vehicles and the Environment (EVE);
- IWG on Cyber Security and (OTA) software updates (CS/OTA);
- IWG Vehicle Interior Air Quality (VIAQ).

Topics of discussion include the ‘long-term fire-resistance test’, the ‘rotation test’ and the ‘REESSS Overcurrent protection’. These will potentially be added to the Global Technical Regulations[27] (GTRs) number 20 (Electric Vehicle Safety) in a subsequent phase (UNECE, 2020).

In the Netherlands, the NEN committee NEC 69 (electric cars) supervises international standardisation for electric cars in global and European standards committees.
The committee also serves as a participatory platform for (NEN, 2018c):

- CLC/TC 69X: ‘Electrical systems for electric road vehicles’ with as working area: ‘To prepare European standards related to electrical systems for road vehicles, totally or partly propelled from self-contained power sources’.
- IEC/TC 69: ‘Electric road vehicles and electric industrial trucks’ with as working area: ‘To prepare international standards for road vehicles, totally or partly electrically propelled from self-contained power sources, and for electric industrial trucks’.

Conclusion

Based on the literature reviews and the interviews, no questions remain unanswered with regard to the legislation relevant to the vehicle safety of electric cars.

4.2 Battery damage

In recent years, a variety of standards have been developed which specifically describe tests of the battery pack in vehicles. A distinction is made between testing at the level of the vehicle, battery pack, module or cell. Tests conducted at these different levels may have varying results. For example: the consequences for a battery pack may be different when a collision test is carried out at the battery pack level, as compared to a collision test at the vehicle level, as a result of the vehicle’s composition. The current standards exist at a variety of levels. In (Ruiz, et al., 2018), a comparison is made between these standards. In Table 4, we present an overview of this comparison with regard to the standards which apply in the Netherlands (NEN, 2018d; 2019e; Ruiz, et al., 2018).

In addition to these standards, the national PGS-37 guideline, which sets out requirements with regard to the storage of Li-ion batteries, will enter into effect in January 2021 (Publicatie gevaarlijke stoffen, 2020). The purpose of this guideline is to enhance safety in areas surrounding application of the batteries; it is not intended solely for electric cars. Prior to establishing the guideline, a policy memo containing recommendations was issued in July 2020. The memo will be revoked once the PGS-37 guideline enters into force. (Staatscourant, 2020)

[27] Directive that contains regulations governing type approvals.

Table 4 - Overview of content of standards for battery packs in vehicles based on (Ruiz, et al., 2018). V = vehicle level, A = battery pack level, M = module level and C = cell level

	ISO 12405-4	IEC 62660-2:2019	ECE 100	Need for regulation, based on literature and interviews
Mechanical				
Mechanical shock	A	C	C/M/A/V	
Drop test				X
Penetration test				
Immersion	A			
Crush/crash	A/V	C	C/M/A/V	
Rollover				
Vibration test	A	C	C/M/A	
Electric				
External short circuit	A	C	C/M/A	
Internal short circuit		C		
Overloading/discharging	A	C	C/M/A/V	
Environment				
Thermal stability		C		X
Thermal shock and cycles	A	C	C/M/A	
Overheating			C/M/A/V	
Extreme low temperature				X
Fire	A/V		C/M/A/V	
Chemical				
Toxic gases				X
Flammability				

The interview with the DEKRA painted the same picture as in Table 4. During that interview, it was asserted that the testing programmes for battery packs have improved in the past 10-15 years, resulting in a reduced likelihood of thermal runaway. Other parties, however, indicated that there is insufficient clarity regarding thermal runaway (see below). The testing programmes show positive results in connection with the BMS performance. One question remaining in this regard has to do with the reliability of the BMS over the course of the service life, or in other words: Does the BMS continue to function optimally as the system/battery ages? This point was raised in more than one interview and is a question to which we were unable to find a conclusive answer in the literature.

The tests in the standardisation procedures in Table 4 are static. Based on the literature and interviews, we have identified a need for dynamic testing to be carried out:

- In the event of a collision, the battery pack moves in the direction of the impact zone. Tests conducted according to the regulations in Table 4 did not take this movement into account (Ruiz, et al., 2018).
- With regard to working on the car, the standards do not mention dynamic loads when installing a battery pack and when the battery pack is dropped on the ground. The latter may occur when the battery is being replaced.

Furthermore, a number of relevant aspects in connection with electric cars are not currently being addressed in legislation, such as toxic emissions, flammable emissions and cold temperatures which may result in a short circuit (Ruiz, et al., 2018). There is also a lack of regulations concerning thermal stability. Many interview subjects indicated a need for this due to the risk of thermal runaway. We are not aware of any existing regulations on measures to mitigate thermal runaway.

In the Netherlands, the NEN committee NEC 21-35 (cells and batteries) is developing national standards and influencing the development of international and European standards for cells and batteries. The committee is participating in the development of (NEN, 2018a):
- IEC/TC 21: secondary cells and batteries (including safety, testing, safe application) (IEC, 2020a);
- IEC/TC 35: primary cells and batteries (including specifications, dimensioning, safety aspects) (IEC, 2020b).

Conclusion

Based on the literature study and the interviews, we have identified an additional need for battery-pack regulations with regard to:
- thermal stability (there is a previously existing IEC standard);
- extreme low temperature;
- toxic gases;
- regulations based on the results of dynamic testing.

There is a particular need for regulations concerning thermal stability due to the risk of thermal runaway. We have found no regulations that relate to measures intended to mitigate thermal runaway. There is also some ambiguity with regard to the reliability of the BMS as the system ages.

4.3 No sound

European regulations mandate that all new electric and hybrid cars must have an Acoustic Vehicle Alerting System (AVAS) (Regulation 2017/1576). This system generates warning signals from the moment the car starts until it reaches a speed of around 20 km/h.
The system has been mandatory in all new electric-type and hybrid-type cars since 1 July 2019. From 1 July 2021, it will be required in all new electric cars. Drivers will, however, be able to deactivate it system if they feel it is necessary (BBC, 2019; EC, 2019a).

Conclusion

Based on the literature reviewed and the interviews conducted, no unanswered questions remain with regard to the laws and regulations concerning the absence of sound in electric cars. The expectation is that the installation of an AVAS is sufficient to mitigate the risks to safety (see also Section 3.4).

4.4 Fire safety

The topic of fire safety touches upon many other forms of safety. There are specific requirements with regard to the battery pack, as discussed in Section 4.2. Requirements also apply in connection with the fire safety of charging infrastructure, as is addressed in Section 4.9. Fire safety also touch upon the vehicle safety requirements covered in Section 4.1. We did not encounter any other laws and regulations in connection with fire safety.

Conclusion

We see no need for additional fire-safety regulations in connection with electric cars. It might, however, be worthwhile to investigate which additional requirements could be established for car manufacturers and whether these requirements would merit being included in compulsory regulations.

4.5 Vehicle safety in enclosed spaces

All parking garages in the Netherlands must comply with the Buildings Decree 2012 (*Bouwbesluit 2012*) (Rijksoverheid, 2011). The provisions set out in the Buildings Decree 2012 apply to existing and new structures. The Buildings Decree 2012 includes performance requirements for parking garages, such as in connection with the maximum size of fire compartments. These provisions from the Buildings Decree 2021 meet the NEN 1010 standard regarding the safety of electrical facilities, which also includes requirements for charging points. Requirements for compulsory construction of charging infrastructure for electric vehicles were added to the Buildings Decree 2012 in March 2020 (Rijksoverheid, 2020). Currently, the obligation applies only in cases of extensive renovations to or new construction of buildings with parking facilities larger than ten parking spaces (but it will be extended to include existing buildings in a few years' time):

- For non-residential construction, at least one charging point must be installed and wiring put in place for 20% of the parking spaces.
- In the case of residential construction, this is merely a matter of running wiring to the site so that a charging point can be installed.
- From 2025, existing non-residential construction with parking facilities of more than twenty parking spaces must include (at least) one charging point.

This will fulfil the obligations pursuant to the European guideline EPBD III with regard to the energy performance of buildings (RVO, 2020). Besides the requirement set out in the Buildings Decree 2012 that electrical installations (including charging points) must meet the NEN 1010 standard, no specific fire-safety requirements have been included in relation to charging or parking electric cars in parking garages. The current Buildings Decree is expected to be subsumed into the Structures (Living Environment) Decree in 2022, when the Environmental and Planning Act enters into force.

The Ministry of the Interior and Kingdom Relations (BZK) has tasked the Dutch NEN standardisation institute to develop an NEN standard for the integral fire safety of parking garages. To that end, the Ministry is also exploring possible adjustments to building regulations. The new standard is expected to begin to apply in 2021, after which it can be incorporated into the building regulations. While this new version will most likely apply only to new construction, municipalities may choose to make it compulsory for existing buildings as well. The new version will address electrically propelled vehicles (and other vehicles with alternative propulsion). Its precise content, however, was not revealed by the literature and interviews.

Regional differences also exist in terms of requirements and provisions; municipal authorities currently do not apply identical requirements to parking garages in which charging points are installed, for example.[28]

[28] The municipality of Rotterdam stated that they require the installation of sprinkler systems, although this is not yet mandated in other cities.

Conclusion

It is our impression that the regulations concerning fire safety and other safety issues in parking garages related to vehicles may be insufficient at present. This applies to all cars in general and not exclusively to electric vehicles. The Ministry of the Interior and Kingdom Relations has authorised drafting a standard for comprehensive fire safety in relation to parking garages. We do not know what the content of the standard will be.

4.6 Incident management

In 2019, the Directorate-General for Public Works and Water Management (Rijkswaterstaat) — in cooperation with the police, fire services, a salvage company and the ANWB — drafted a guideline for primary safety measures in the event of traffic incidents (REVI: *richtlijn eerste veiligheidsmaatregelen bij verkeersincidenten*). This guideline is intended for police, fire services, ambulance care workers, road operators, salvage companies, the ANWB road assistance personnel and the Royal Netherlands Marechaussee. The guideline distinguishes the following four categories of incidents involving electric cars (Rijkswaterstaat, 2019):
- Category A: no damage;
- Category B: minor auto-body damage only;
- Category C: airbags have deployed;
- Category D: serious deformation of roll cage.

The guideline states that only vehicles in category D: 'serious deformation of roll cage' potentially pose an immediate threat. In rare instances involving such deformation, it is possible for the battery pack to ignite and therefor the vehicle body as well. Personal protection equipment (PPE) is required when dealing with electric cars in this category. In case of a fire involving an electric car, but where the battery pack is not on fire, the vehicle may be approached in the same way as a conventional car. When the battery pack is on fire, the incident manager must remain upwind and leave any effort to extinguish the fire to the fire services (Rijkswaterstaat, 2019).

The ISO 6469-4:2015 standard sets out safety requirements for electric cars following an accident. The standard does not describe a procedure for crash testing, nor does it contain extensive information for emergency services/aid workers, salvager personnel and technicians (NEN, 2015b; ISO, 2015).

Conclusion

We did not identify a need for additional laws or regulations.

4.7 Maintenance and safety

A revised version of the NEN 9140 standard was released in May 2019; this new version focuses more specifically on the automotive sector. Among the additions to the standard are two flow charts containing work procedures, one for roadside assistance services and one for employees of repair and maintenance companies. The standard establishes which individuals in the workshop are permitted to work on electric cars. The standard distinguishes between the following categories:
- ev-VOP: *ev-Voldoende Opgeleid Persoon* (EV-Sufficiently Qualified Person);
- ev-VP: *ev-Vakbekwaam Persoon* (EV-Competent Person);
- ev-WV: *ev-Werkverantwoordelijke* (EV-Person Responsible for the Work).

The ev-WV is responsible for ensuring safety during work on electric cars which may involve an electrical hazard. The ev-WV will provide Personal Protection Equipment (PPE) to colleagues and ensure proper use of this equipment (Innovam, 2020). Manufacturers have regulations concerning work on their products as well.

An Industry Standard for Safely Working on Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV) in Garage Workshops (*Veilig werken aan Elektrische Voertuigen (EV) en Hybride Elektrische Voertuigen (HEV)*) also exists, while car manufacturers also have their own EV-related requirements for employee training, workplace design and working safely on electric cars.

It is unclear whether hobbyists are generally familiar with these areas for attention and standards. By 'hobbyists' we mean both consumers who enjoy repairing and/or modifying cars and small garages without EV-certified employees.

Conclusion

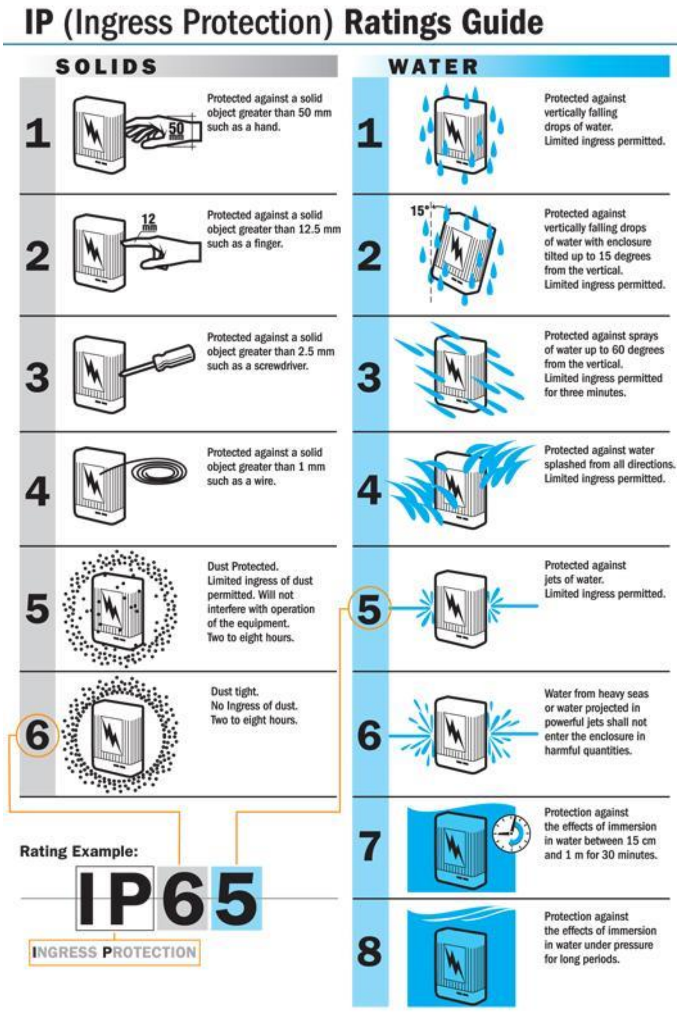
Our perception is that the standards and corresponding training programmes for garage staff are sufficient for them to work safely on electric cars. It is unclear whether hobbyists are generally familiar with these areas for attention and standards, however, which may result in potential risks.

4.8 Immersion in water

Most standards testing does not include a test involving the immersion of the vehicle battery pack in water as a standard component (Ruiz, et al., 2018). The high-voltage system of electric cars is insulated and designed in such a way that the system cannot deliver electric shocks or electrify the surrounding water. The design of the vehicles is therefore safe in case of immersion in water. Since 2014, ISO 12405 has included a test in which the battery pack is fully or largely immersed in water. This test has not been described in detail and its primary conclusion is that a short circuit may result in the release of potentially hazardous gases (NEN, 2018d; NFPA, 2017).

In Europe, the Ingress Protection (IP) rating system (see Figure 8) is used to specify how electronics are protected from external influences. The electronic components in an electric car must meet or exceed the IP66 standard. This means that the components must be completely protected from the ingress of dust and against water which comes in contact with the components at high pressure (NEN, 2019c; NEMA enclosures, 2013; Gaton, 2018; The Enclosure Company, sd).

Figure 8 – IP ratings guide



Source: (NEMA enclosures, 2013).

Conclusion

Based on the literature and interviews, the regulations pertaining to immersion in water appear to be sufficient.

4.9 Charging infrastructure

Charging infrastructure is a complex system that is made up of different physical and digital components. Charging facilities can also be either private and public, each with its own distinct regulations. As a result, the laws and regulations governing charging infrastructure are quite extensive.

All physical components of the charging infrastructure must be certified, from connector and cables to the charging point in which all components are connected. This results in a chain responsibility to ensure the safety of the system as a whole.

Within laws and regulations relating to charging infrastructure, we distinguish the following categories.
- Physical components (charging cables, connectors): these standards set out the requirements which individual components must meet.
- Charging stations: these standards include descriptions of the requirements for charging stations in general and the specific requirements for AC and DC charging stations.
- Installation: standards are available with regard to the installation of charging points, whereby a distinction is made between private and public charging points.
- Information exchange: this entails a description of the safety requirements with which the communications between the vehicle, the charging station and the operators must comply in order to ensure a secure exchange of information.

Appendix C contains an overview of the regulations for each category.

In 2018, the TRAN Committee[29] presented the results of a study aimed at charging infrastructure. The study explored which potential adjustments to existing laws and regulation might be in order to ensure a safe charging infrastructure for road users. One of its findings was that the technical standards for charging points are effective in ensuring sufficient quality.

While many protocols exist to safeguard the communication between the charging station and the vehicle, not all of these protocols support future developments such as smart charging (Ecofys ; Navigant Research, 2018).

In the Netherlands, NEN 1010 applies to the installation of private charging stations. This standard requires the presence of a residual-current device connected to the charging point. For private charging facilities, there are no requirements relating specifically to installation. For public charging facilities, on the other hand, NEN 3140 — a guideline for low-voltage and installation responsibility — is in effect. No regulations exist with regard to inspection of the installation of charging points (either public or private) once the process has been completed. This was noted as an area of concern in numerous interviews, particularly in relation to the expected increase in the number of charging points.

According to the majority of the parties interviewed, the NEN 1010 standard is not sufficient with regard to the installation of private charging stations and very little oversight of that installation takes place. The charging points are covered by the regular home insurance and the installation must comply with NEN 1010, which requires the charging point to be grounded. The installer must also verify aspects such as the capacity of the grid connection. While the terms and conditions of most insurance policies do not include any additional requirements, a number of insurers have added conditions pertaining to proper installation.

Conclusion

Besides the need for additional requirements regarding the installation of private charging points, we encountered no need for additional regulations on the basis of the literature and interviews. A question remains as to whether the concern regarding inspection of installation following completion may be alleviated through additional regulatory measures.

[29] TRAN stands for 'Transport and Tourism'. The TRAN Committee falls under the responsibility of the European Parliament.

5 Knowledge gaps

One objective of this study was to create an inventory of knowledge gaps in relation to safety risks associated with the use of electric vehicles. This proved to be no easy matter, as a great many, often dissimilar and extremely specific or situational questions emerged in the course of the study. In general, the existing literature fails to supply answers to such questions. These as of yet unanswered specific questions, however, might potentially prove vital with regard to identifying possible safety risks.

In order to arrive at a list of knowledge gaps (despite the aforementioned challenge), we attempted to assign priority to the questions that occupy experts and to include the most pressing of these in the list of knowledge gaps. Initially, priority was assigned by checking whether the same (or same type of) question was addressed by more than one interview subject. The more parties addressing the same or similar question, the greater the likelihood that we have classified the query as a gap in knowledge. Next, we evaluated whether it would be feasible to research these questions. In other words, we formed an expert opinion as to whether an answer to a question could be found by conducting research (or by other means), bearing in mind that the effort expended should be proportional to the potential safety risk. The resulting list of knowledge gaps was discussed in the sounding board group and additions were made as deemed necessary and/or desirable.

In the remaining portion of this chapter, we will discuss the major knowledge gaps one by one. For each knowledge gap, we will also provide general suggestions for potential solutions and recommendations as to how the knowledge gap might be eliminated.

Knowledge gap 1: Vehicle safety in relation to acceleration capability

As concerns vehicle safety, the literature shows comparatively little attention for the relatively strong acceleration performance of electric cars. This factor would seem to have a fundamental impact on traffic safety and the severity of injuries in case of accidents, for instance when traffic conditions are congested. At this time, no clear picture of the risks exists. Since there is unlikely to be a record of how quickly the car accelerated from standstill prior to the incident, a study based on data and statistics would prove difficult.

An alternative research method would be to design a behavioural study in which subjects are observed while driving electric and conventional cars and the handling characteristics are recorded in a log (along with the vehicle characteristics such as weight). This would allow a representative random sample of participants to be used to analyse whether driving behaviour in an EV is influenced by the greater acceleration capability and/or the weight of the vehicle, or by other factors.

Knowledge gap 2: Measures to mitigate thermal runaway

Our research shows that (due in part to the potential risks) there is a need for more knowledge regarding the effects and effectiveness of measures intended to mitigate thermal runaway. Many available studies include a description and exploration of the thermal runaway process. However, most studies looking for ways to limit safety risks only

offer potential solutions and (as far as we were able to determine) have yet to be actually implemented in battery packs.
We have identified the following next steps:

- Investigate the extent to which battery manufacturers take mitigating (or mitigation) measures into account when developing batteries.
- Invest in testing to turn potential solutions into actual concrete solutions which can be built into battery packs.
- Work with battery manufacturers, incident managers and the automotive industry to formulate international safety requirements with regard to thermal runaway; these might include explicitly quantifying the amount of time between the occurrence of thermal runaway and its spread to adjacent cells.

In this study, we have restricted our attention to literature and/or knowledge extending to the level of cells in the battery and the level of the battery pack itself. Such batteries and cells are themselves made up of many smaller components, about which additional literature is available. This literature addresses topics such as thermal stability in connection with the use of various materials, for instance. To supplement this study, more extensive knowledge regarding batteries at the component level could provide greater insight into the risks and therefore into potential measures to mitigate thermal runaway. To that end, we feel it is also important to consider the effects of production errors in batteries and of battery ageing, and how these factors affect the chances that thermal runaway will occur.

In our opinion, an inventory conducted among car manufacturers, and of the ways in which they implement measures to prevent thermal runaway, would be of added value, since car manufacturers purchase from battery-pack manufacturers, and can therefore set requirements for these. The extent to which that is now the case — and the directions being explored by car manufacturers — remain unclear at this time. Some car manufacturers do produce their own battery packs, however, making them both producer and customer. In such cases, both the requirements formulated and what constitutes compliance with these are an internal affair.

Knowledge gap 3: The effects of ageing

Although there are more electric cars on the road today than there were at the time the 'Fact sheet on electric vehicles and safety' (TNO, 2014) was drafted, there are still relatively few old electric cars on our streets. As a result, relatively little is known (on the basis of statistics) about how the ageing of electric vehicles affects their safety. There are three aspects in particular for which we feel it is relevant to compile additional data:

1. The quality of the battery pack when purchasing a second-hand electric car.
2. How ageing influences the likelihood of thermal runaway occurring.
3. The reliability of the BMS over the course of the life span.

Assessment of potential risks related to the ageing of the battery pack and the BMS could be made part of the mandatory annual vehicle inspection (APK) in the Netherlands, including the establishment of requirements for battery pack performance. Opinions expressed during the interviews varied on the subject of whether or not this is feasible. This might be an area which calls for further research.

We are in favour of including the effect of ageing on thermal runaway in research aimed at expanding insight into the likelihood of thermal runaway and the effects of mitigating measures in terms of preventing thermal runaway (see Knowledge gap 2).

Knowledge gap 4: Risks in enclosed spaces

There is currently some debate in the Dutch media and among politicians regarding the risks associated with fires in or near electric cars when the cars are located in enclosed spaces. In most cases, these discussions concern additional risks that might be present when electric cars are parked in parking garages, although they might also refer to safety in tunnels. With regard to risks in enclosed spaces, there are multiple aspects where additional knowledge is desired:

1. Investigate whether greater structural damage occurs — and then potentially the severity of that damage — in the event an electric car is involved in a fire in an enclosed space.
2. The best way to fight fires in enclosed spaces.
3. A decision-making framework in order to weigh the advantages and disadvantages of potential solutions to the risks posed by fires in electric cars in enclosed spaces.

For Point 1, the potentially extensive collateral damage of a fire is important, as parking garages are often located in residential areas or even directly underneath homes. In theory, fire can lead to structural damage which (in combination with the fire itself) can cause additional damage for nearby residents. Assuming a fire in an electric car can inflict relatively greater amount of damage than a fire in a conventional car, this collateral damage may be greater as well. At this time, further knowledge is required to rule out the possibility that electric cars may cause greater damage.

With regard to Point 2, it is at this time still insufficiently clear whether the fire behaviour in an electric car results in a greater or lesser risk as compared to the fire behaviour in a conventional car. In enclosed spaces, the consequences can potentially be much more severe than they might have been out of doors. There is also insufficient knowledge available with regard to effective fire-fighting in electric car fires: both the interviews and the literature show that many solutions are not yet being implemented because they are difficult to implement, in some cases due to high costs. Currently, fires are extinguished or prevented by applying a great deal of water or through the use of immersion or salvage containers. This is a costly undertaking, as an electric car is a total loss once it has been immersed and the containers are not convenient for use in all cases.

With regard to Point 1 and Point 2, we perceive a number of potential solutions for learning more about the consequences of fires in enclosed spaces:

- Experimental research: the fire services could build test locations or (scale) models involving electric cars and set and analyse fires within them under controlled conditions. Such research can entail high costs. These experiments could also be used to examine the effectiveness of fire-extinguishing tools.
- Computer simulations: computer simulations could be used to explore the effects of fires in terms of structural damage, smoke development and specific fire-fighting methods.

Point 3 is more general in nature and stems from the need to be able to reasonably weigh the safety risks of electric cars and the benefits of measures to combat those risks against the disadvantages associated with those measures. In the case of major infrastructure projects, a social cost-benefit analysis is required by law in the Netherlands prior to starting the project. This analysis must include properly weighing the advantages (benefits) of a measure against the associated disadvantages (costs). A social cost-benefit analysis also assigns a price to matters that cannot normally be expressed directly in monetary terms. This enables decision-makers to better compare the pros and cons of a given project.
At this time, it is not possible to effectively weigh the costs and benefits of mitigating

measures in connection with safety risks in electric cars. The recent report from the Institute for Safety (IVF), for instance, offers a series of possible solutions for managing risks and allowing potential incident management to proceed more smoothly (IFV, 2020b). This report provides no insight into the costs of implementation, however, nor does it weigh the costs and benefits of effectively minimised risks against the necessary investments.

Knowledge gap 5: Oversight of charging point installation

During the interviews, a long and extremely wide-ranging list of detailed and/or specific questions was asked regarding the installation and maintenance of charging points. As it turned out, it was not possible to sufficiently answer these individual questions based on the literature study. There is a lack of knowledge concerning the extent to which, after installation, the installation of charging points is inspected to ensure their safe operation and use.

We have identified the following methods for gaining insight into whether the extent to which inspection takes place following installation is, indeed, sufficient:

- In this study, we spoke with a number of CPOs and were able to form an initial impression of the charging-point installation process. More in-depth interviews with a larger number of CPOs could serve to refine this impression. It could also clarify whether all CPOs share a common approach. Following the interviews, the information obtained can serve as a basis for evaluating whether the current extent of inspections and oversight after installation is sufficient. It is important, for the purposes of this study, to distinguish between private and public charging facilities. To that end, it is also important to note that not all private charging stations have a CPO (as described in Section 3.10).
- A comparison can be made between different countries and the chosen methods for arranging oversight of charging-point installation. A comparison with the situation in the Netherlands, in which costs and benefits are weighed against one another, can prove useful in this regard.

6 Conclusion

6.1 Main conclusion

On the whole, electric cars do not seem to pose a greater safety risk than conventional vehicles. The same safety risks that apply to electric cars often apply to conventional cars as well. In addition, both conventional and electric cars must comply with numerous existing national and international safety regulations.

One safety risk the study found is thermal runaway, the process whereby a high temperature or internal resistance in the cells of battery packs can cause a fire and the release of toxic gases. Another safety risk is car fires inside parking garages, which poses a risk for both electric and conventional vehicles. The actual risk is the product of the chance that a given incident will occur and the effect if it does occur. The literature and practical tests do not suggest that these safety risks are very likely. There is also no evidence at this time to suggest that the effects would be significantly greater. In the future, statistics and practical data will be needed to determine the accuracy of these conclusions.

If thermal runaway leads to a fire, there is not necessarily a higher safety risk than for a conventional car. Cases involving an electric vehicle do, however, call for a different approach to incident management. More specifically, this applies to fires in a parking garage. This is because battery fires can last a long time, and batteries can reignite. Also, it is not always immediately clear where the battery pack is located in the car. As a result, a large volume of water is needed to put out a fire, it is difficult to tow the car away and responders must locate the battery pack before they can take action. There are other questions for which there is no answer yet. What happens when the battery pack gets older? How reliable is the system that checks for voltage and temperature in the battery pack as it gets older?

The persons who were interviewed by CE Delft asked some of the same questions about possible safety risks in electric cars as the media and politicians. CE Delft found that the actual added risk of electric cars was low. It based this conclusion on current knowledge and applicable regulations. Additional experimental or practical research may answer some of the remaining questions.

6.2 Further conclusions

In this section, we provide an overview of our conclusions in connection with each theme.

Vehicle safety

Crash tests show that electric cars are at least as safe as conventional cars. It is not so much the electric powertrain, but rather differences in the design of the car and the functioning of the AEBS that impact the safety performance of electric vehicles. By law, electric cars must meet the same safety standards as conventional cars. As is the case with conventional cars, the shape and design of the car will affect the safety of cyclists and pedestrians should an incident occur. The systems built into electric cars (such as the AEBS) ensure that injuries will be kept to a minimum in the event of an unsafe situation. It is not possible to critically assess the safety of a car (electric or conventional) based on a single factor such as its mass. Instead, vehicle safety depends on the relationships between various factors.

Battery damage

Damage to the battery yields a risk that thermal runaway will occur. Based on practical testing, however, this risk appears to be slight because the likelihood of its occurrence is low. Yet on the other hand, because little testing has been carried out, this cannot be established with certainty. Various possibilities for mitigating measures were found in literature, most of which were aimed at either preventing thermal runaway or keeping it from spreading to other cells, as well as reducing heat in the battery pack, module or cells. Furthermore, little is known regarding the relationship between ageing of the battery pack and the likelihood of thermal runaway.

No sound

Based on the literature and interviews, the expectation is that the AVAS system will effectively limit risks to safety resulting from a lack of sound when the vehicle is travelling at speeds lower than 20 km/h. At speeds greater than 20 km/h, the AVAS system is unnecessary because the difference in sound produced by an electric vehicle and a conventional car decreases as speed increases. From 50 km/h, the difference disappears entirely and tyre noise becomes the primary sound heard.

Fire safety

In case of a fire, aspects such as the temperature, the intensity of the fire, the fire load and the heat radiation are similar in both electric and conventional cars. A fire in an electric car does, however, behave differently (slower development, long duration). While the substances released are largely the same as well, in the case of an electric car, more hydrogen fluoride is released, which may cause skin irritation.

Based on the literature and practical testing, there is no reason to assume that the chance of a fire is greater in electric cars than in conventional cars. The real-world data we found supports this assertion. The actual risk is the chance that a given incident will occur multiplied by the effect if it does occur. On the basis of the literature, it can reasonably be assumed that the chance of its occurring is slight. This automatically results in a smaller risk. The data from literature also creates the impression that the effect of a fire in an electric car is no greater than that of a fire in a conventional car. By beginning to compile statistics on the subject, it may be possible in future to further substantiate this impression with real-world data.

Safety in enclosed spaces

In general, the fire safety risks in parking garages have increased in recent decades. This development is taking place independently of the introduction of electric cars. Neither actual events nor the studies and publications available give reason to believe that electric cars result in an increased risk of fire in parking garages (i.e. multi-storey and underground car parks). The limited number of practical tests and research aimed at recent fires in such car parks present the same picture. Here, too, the actual risk is the chance that a given incident will occur multiplied by the effect if it does occur.

Due to the limited number of tests conducted in practice and the lack of statistical data, assertions in this area cannot be made with certainty, so it is important to compile statistics and investigate the causes of the fires in order to provide a broader factual basis for this discussion. It is possible that insufficient laws and regulations exist in connection with fires in parking garages. At the behest of the Ministry of BZK (Ministry of the Interior and Kingdom Relations), the NEN is working to draft a standard for comprehensive fire safety in parking garages that will effectively address the potential risks.

Incident management

Incident management is different for an electric car as compared to a conventional car. This has to do with the difference in fire behaviour in an electric vehicle and with the risk that a fire will reignite. Incident managers face a challenge in connection with determining whether the vehicle involved is an electric car and then locating the position of the battery pack within the vehicle. To that end, they can make use of several different applications (e.g. one that provides vehicle information when the registration number of a car is scanned), along with tools such as a thermal imaging camera (used to identify the position of the battery pack). Technical developments also tend to progress more rapidly than the level of knowledge among emergency services personnel.

In the Netherlands, there are currently few salvage companies that specialise in the salvage of electric cars. The methods used when there is a fire in an electric car or an unstable battery pack are quite costly (large quantity of water to put out a fire, immersion and salvage containers). Salvage companies are working with insurers and fire services to draft a protocol for safely salvaging unstable and/or burning electric cars. This protocol will include (among other things) objective criteria for determining when immersion in a container is necessary and when other methods can be deployed.

Maintenance and safety

There are training and education courses available in the Netherlands for roadside assistance, emergency services and garage personnel with regard to working on and around electric cars, as well as guidelines pertaining to that work. However, it is unclear whether hobbyists are aware of the relevant areas for attention and standards. In addition to guidelines, another avenue that could be considered is to inform and raise awareness among consumers about the safety risks of working on electric cars, as these involve a high-voltage system.

Immersion in water

There are various standards for batteries under water. As a result, the batteries of electric cars are designed to continue working even if completely immersed. The standards make a distinction between the battery being fully submerged in water and its being partially submerged. A potential difference between these two scenarios is that no oxygen can reach the battery when the car is completely submerged, while in the case of partial immersion, this might still be possible. Salty or polluted water also entail greater risks in connection with fire safety as such water conducts electricity better. This is not expected to cause a great risk, however, since guidelines were developed for situations where flooding occurs too. In the event of a flood, cars — and therefore their battery packs — will not always be completely submerged.

Charging infrastructure

The complex nature of the charging infrastructure yields challenges in terms of mitigating risks. We were unable to answer all of the specific questions under consideration by means of the literature study and the interviews we conducted. Based on this literature study and the interviews, we feel that Mode 3 and Mode 4 charging is safe thanks to the built-in systems, and that the existing regulations and technical standards for charging points are sufficient to ensure a safe charging infrastructure. Although all charging modes are vulnerable to collisions to some extent, ones with built-in sensors that detect when they are askew will automatically switch off if a collision occurs. Faulty connectors can also give rise to risks or cause a charging point to fail to begin the charging process (built-in safety system). Here too, the actual risk is the product of the chance that a given incident will occur and the effect if it does occur. Based on the interviews (and therefore based on data from the CPOs), the chance of risks occurring would seem to be present to some degree, yet the effects are small should those risks occur. In addition, we have observed that while proper installation is important in terms of safety, there is no centrally organised oversight of charging point installation. A residual-current device is required when installing private charging stations and — as well as other factors — installers must take the capacity of the grid connection into account.

6.3 Answering the research questions

What relevant research results have been published in the Netherlands and abroad with regard to safety and the use of electric vehicles?

For this study, we consulted 280 sources for the literature study and conducted interviews with 25 parties. The field of electrically powered transportation is undergoing tremendous development, with a wide range of information available as a result. The results of our inventory of this information are presented in Chapter 3 and Chapter 4.

Which laws and regulations, standards, safety requirements and quality marks exist in connection with electrically powered transportation and safety? Are these regulations being met with compliance? Are they being enforced?

Existing legislation concerning electric cars is extensive and mostly coincides with that pertaining to conventional cars. Legislation drafted specifically for electric cars generally concerns the electrical components and corresponding high voltage present in the car, as well as to the battery pack and the charging infrastructure. Our impression is that there is good compliance. The CPO clients and the car manufacturers often set additional safety requirements that must be met as well.

Enforcing regulations concerning the installation of public charging points perhaps might offer room for improvement. Inspections of installation are currently being carried out by the installer and the CPO itself. More in-depth interviews with a larger number of CPOs could allow better evaluation as to whether the current extent of inspections and oversight after installation suffices. No inspections are carried out by an independent party. As far as we have been able to ascertain, no regulations exist concerning the installation of private charging stations.

Do the existing laws and regulations suffice?

Most legislation applies to both electric and conventional vehicles. For electric cars, additional regulations exist in connection with electromagnetic components, battery packs and charging infrastructure.

Existing regulations are sufficient in the majority of areas. There is, however, a need for additional laws and/or regulations in connection with the following points:

- Battery packs: thermal stability, extreme low temperature, toxic gases and dynamic testing. There is a particular need for regulations pertaining to thermal stability due to the possible risk of thermal runaway. We have found no regulations concerning measures intended to mitigate thermal runaway. This might be a useful supplement to regulations pertaining to thermal stability, in the event such regulations are developed.
- Fire safety: the regulations pertaining to fire safety appear to suffice. Manufacturers do, however, place additional requirements on the safety of electric cars (in addition to ECE 100). A possible direction for further study might involve an inventory of these additional requirements and whether they include fire safety as well.
- Parking garages: It is our impression that the regulations concerning fire and other safety in parking garages (i.e. multi-storey and underground car parks) in connection with vehicles may be insufficient at present. However, this applies to all cars in general and not exclusively to electric vehicles. The Ministry of the Interior and Kingdom Relations has authorised drafting a standard for comprehensive fire safety in relation to parking garages. We do not know how the standard will be drawn up or what it will entail. When formulating the standard, taking the potential risk associated with conventional and electric cars into account is to be recommended.
- Installation of private charging stations: the regulations for the installation of private charging stations mandate (among other things) the inclusion of a residual-current device. The installer must also verify aspects such as the capacity of the grid connection. A possible direction for further study might involve identifying the specific additional requirements necessary in order to ensure the safe installation of private charging stations.

What is the course of the procedures within the EV safety domain? For example: how does information reach the security regions?

For the purposes of this study, ‘processes’ refers to the cooperation between the various parties who manage and/or encounter the safety risks associated with electric cars. It primarily entails the coordination between parties involved in incident management.

The process with regard to incident management is illustrated by Figure 5 in Section 3.7. This figure shows what happens when an incident occurs. The reporting of incidents involving an electric car proceeds in the same way as that of any other incident. There is no special reporting code when calling 112, for instance. Incident managers do, however, appreciate knowing when an incident involves an electric car so that they can prepare accordingly. In incidents involving an electric car, other tools will be used, such as an app to determine the location of the battery pack within the car.

The literature study and interviews seem to indicate that not everyone who deals with electric-vehicle safety in a professional capacity has a clear picture of all parties involved and their respective responsibilities. An organisation chart identifying and describing the parties and their responsibilities would be useful.

Which topics still need to be addressed and what knowledge is still lacking in connection with electrically powered transportation and safety?

In the chapter on knowledge gaps, we address this at length. In addition to those gaps, a number of questions remain unanswered as well. For instance:
- What kind of developments are taking place among battery pack manufacturers?
- How might incident management for electric cars be organised even more efficiently?
- What is the statistic likelihood that thermal runaway will actually occur? (The initial results of tests in practice are positive. Additional research could provide evidence to support this conclusion.)
- Which risks exert an influence on the safety of the battery pack during its service life and who bears responsibility for these risks?
- How can the level of knowledge among users be enhanced and which knowledge is required in order to do so for each target group?

Certain knowledge questions remained unanswered as well. This pertains to the following questions:
- Does the greater acceleration capability of electric cars result in additional risks to safety?
- Which mitigating (or mitigation) measures are effective in preventing or inhibiting thermal runaway?
- How does ageing affect the likelihood that thermal runaway will occur?
- How does ageing affect the reliability of the BMS?

In the chapter on knowledge gaps, we offer several suggestions for enhancing insight into these topics.

What recommendations can be made in light of the study results and the knowledge gaps identified?

Through this study, we have provided effective insight into the potential safety risks of electric cars. Based on our research, we can conclude that electric cars do not pose a greater safety risk than conventional vehicles. In Chapter 5, we also identified a number of knowledge gaps which we addressed in greater detail, and for which we have provided recommendations on how they might be eliminated.

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A List of parties interviewed

Table 5 contains a list of the organisations and businesses which were interviewed for the purposes of this study.

Table 5 - List of parties interviewed

Interview	Parties
1	ANWB
2	RAI Vereniging
3	Haaglanden security region
	Brabant-Zuidoost security region
	IFV (Institute for Safety)
4	ElaadNL
	DOET
5	Police
	Fire services
6	Municipality of Rotterdam
7	Vreugdenhil salvage company
8	Directorate-General for Public Works and Water Management (Rijkswaterstaat) (incident management adviser)
9	Van Peperzeel BV (member of NEC 21-35 'Cells and batteries' committee)
	Alfen (chair of NEC 69 'Electric cars)
10	Vexpan
	Q-Park
11	Dutch Association of Insurers
	AON
12	MRA-E
13	Allego
	EV Box
14	DEKRA
15	TU/e (Eindhoven University of Technology)
16	FastNed
	ABB

B List of interview questions

This appendix contains the list of interview questions as communicated to the interview subjects. The questionnaire is extensive and contains both general and specialised questions on a variety of topics, so not every question was addressed in every single interview. Prior to the start of each interview, interviewees were informed which questions were relevant in their case.

General questions

- Which aspects of safety in connection with electric cars do you deal with in your work?
- What is your company or organisation's perception of safety and electric cars? How does it compare to the safety of conventional cars?
- What are the most important safety risks you encounter in day-to-day practice? How great are the risks in reality? Are there statistics and/or source data available?
- Do you know of any reliable statistics concerning incidents involving electric cars? If not, do you think such statistics should be compiled?
- What kind of developments are taking place among insurers in relation to EVs?
- [At the end of the interview] What do you expect from the government, sector organisations and/or other parties with regard to EV safety?
- [At the end of the interview] What do you consider to be the most important gaps in knowledge in connection with EV safety?
- [At the end of the interview] Are there other matters you feel are important, but that have not yet been addressed in this interview?

Laws and regulations

- Which laws and regulations govern the work you do? Are these international and/or national?
- Are there any rules and/or directives in effect locally (such as in the security region and/or at a municipal/provincial level) that deviate from these? If so, why?
- Is (sufficient) compliance with laws and regulations being practised? Who ensures this compliance?
- Are the laws and regulations clear and/or comprehensive? If not, what aspects are lacking?
- What other standards, safety requirements and quality marks do you know of in connection with electric vehicles and safety?
- Do any of these laws, standards and quality marks conflict with one another? If so, which ones and in what way?
- Which agencies do you cooperate with? Are these government and/or non-government?
- Which agencies are tasked with overseeing your work? To whom do you render account?
- Can you draw an organisation chart of the organisations and/or agencies involved in EV safety?
- What could be improved? Are there too many or too few parties?
- Is there sufficient capacity for handling safety-related issues?

Specific questions for each theme

Cluster 1: Vehicle safety, Sound, Maintenance & safety

- Can you describe your general experience with and/or impression of the safety of electric vehicles, including fire safety? What is the basis for that impression?
- Is the safety of EVs comparable to that of conventional cars? Do you feel that additional attention to EV safety is justified, or not? Why?
- How do manufacturers ensure the safety of vehicles, including fire safety? Which measures are taken in connection with EVs? Does this involve extra ones? What does safety testing involve? Specifically in connection with:
  - fire;
  - electrocution;
  - road handling;
  - sound;
  - interior air quality;
  - cyber security.
- Do type approval requirements adequately ensure the safety of EVs? And are the requirements for individual approval or structural changes sufficient?
- What is the status of the R100 battery test? Does it function properly? What problems are adequately or inadequately resolved with this test?
- Are there different types of Li-ion batteries in use and do these lead to different kinds (and magnitudes) of risk? Take for instance the charging method (Mode 1, 2, 3 or 4).
- Should safety guidelines be adjusted in connection with new developments such as solar panels on roofs?
- What statutory requirements exist with regard to the sound production of electric cars? Are there any new developments in this area?
  - Is this standard on all new cars?
- What specific risks are associated with retrofitted EVs? How does the number of retrofitted EVs compare to the number of factory-built EVs?
- Fire regulations mention specific risks associated with EVs: toxic smoke, intensity and duration of a potential fire, 1000 Volt gloves, not touching cables after immersion in water, and so on. How does this relate to the vehicle safety requirements? And how do these risks compare to those associated with conventional cars? Is a separate approach for EVs called for?
- Research (SWOV) into the accident risk in the Netherlands is fairly old (2011). Do you know of any new insights? What new insights are needed? Is the AVAS system sufficient?
- Do insurance policies for EVs differ from those offered for conventional passenger cars?

Cluster 2: Immersion in water, Damage to battery, Invisible damage to battery

- Are there effective protocols with regard to incident management for EVs? Are these sufficiently known to all parties and/or emergency services?
- Does a special code exist for reporting an incident with an electric car when calling 112? If not, would such a code have added value?
- When responding to a call, are emergency services personnel being informed quickly enough of any specific methods for when an EV is involved?
- As an emergency services worker, where do you turn for specific instruction (e.g. recommendations from the manufacturer) on what to do in case of incidents?
- Are you familiar with the Rescue Sheet website?

- As an emergency services worker, are you informed of instructions such as manufacturer recommendations in a timely manner?
- How often do Category D (serious deformation of roll cage) incidents occur?
- Are there specific risks associated with EVs in case of immersion in water? Are these risks manageable for emergency services?
- Immersion containers:
    - Is it currently possible to deploy immersion containers everywhere in the Netherlands?
    - An immersion container provides a kind of immersion in water. Do salvage companies have specific knowledge of what to watch out for in cases of full or partial immersion in water?
    - Are there alternatives, either existing or in development? Is wrapping (e.g. in a bag) an option?
- How do you handle invisible damage to the battery?
- Does deformation of batteries ever occur? Are the risks of this known?
- Does the temperature or outdoor temperature influence the risks of damage to the battery? Are there any other factors?
- Does the approach to managing incidents (including fires) differ from one type of car to another? (For instance because the battery pack is not always in the same location.) Do vehicles show a great deal of diversity? Is it easy to quickly identify the specific characteristics of a vehicle which are relevant for incident management?
- Are there systems (existing or in development) that make it possible for a user or incident manager to perceive the risks at a distance? (cf. Moditech)
- Does sufficient specialised salvage capacity exist for EVs in case of damage and/or fire? How is this being managed in connection with the growing number of EVs? Does supervision exist in this area?
- In your opinion, are there any other unknown aspects, potentially urgent or otherwise, pertaining to fires involving electric cars?
- Are there examples of cases in which the liability for damage to an EV was unclear?

Cluster 3: Fire safety, Enclosed spaces & Parking garages

- Do electric cars pose a greater fire safety risk than conventional cars with regard to:
    - the chance of a fire;
    - progression of the fire;
    - potential risks in case of fire;
    - options for risk-reducing measures.
- How has this been determined?
- Is there sufficient information available on fire safety in parking garages in combination with EVs? What is lacking? And does that knowledge exist in connection with conventional cars?
- Training programmes are being organised. What do these entail? Are multiple kinds of and/or different training courses available? Who is providing these? For which target groups are they intended?
- In your opinion, are there any other unknown aspects, potentially urgent or otherwise, pertaining to fires involving electric cars?
- How great do you estimate the risk of charging plugs and/or cables which (during charging) are ‘locked’ to the charging point in case of a fire? Are the unlocking techniques known and uniform for every vehicle?
- Is smoke development associated with EVs more hazardous than with conventional cars? What are the differences?
- To what extent does the need for a large quantity of water when fighting a fire present a bottleneck? What potential solutions are being considered? What alternative fire-

fighting methods are there on the market? Are fire services seriously considering these alternatives at this time?
- Are you familiar with chassis cooling? Is this used very often? To what extent is this a solution for fire-safety issues relating to EVs? Is this a necessary solution?
- Is there a fire risk associated with used batteries and/or wrecked vehicles? To what extent is this a problem?
- Are you aware of the differences in energy content between an EV and an ICEV with regard to the fire load?
- What do the protocols drafted by car manufacturers entail? How is this being shared and with whom?
- When exactly is the info sheet on ‘parking garages and electric cars’ expected to be published? Do you have an idea as to the fact sheet's content?
- Some of the recommendations from fire services (8 May 2020) can be said to be necessary in connection with ICEVs in parking garages as well. Are the current standards for parking garages sufficient to ensure safety in connection with conventional vehicles? Do electric cars in parking garages pose a greater risk to safety? If so, on which statistics/studies is this assertion based? In this regard, please distinguish between:
  - fire load;
  - release of toxic substances;
  - additional fire load resulting from plastic cars;
  - difficulties in fighting fires inside a garage.
- Who is liable in the event of an electric vehicle fire?
- Which liability-related complications may arise in connection with EVs in parking garages?
- Are car park owners and/or homeowners’ associations covered by insurance if a fire breaks out in an EV in their parking garage?
- Do you have an idea as to the risks in parking garages? What implications will this have for the insurance of the car park owner or homeowners’ association and the owner of the vehicle?
- Do insurers have requirements which parking garages must meet in connection with EVs? If so, what are these requirements? If not, should such requirements be introduced?
- Is liability in parking garages different when EVs are involved than in the case of conventional passenger cars?

Cluster 4: Charging infrastructure

- Which safety risks with regard to charging EVs are you aware of, and what is the likelihood that an incident will occur? At minimum, distinguish between the risk of fire, overheating, flooding and/or electrocution. How have these been identified? When an incident occurs, is it reported to a central registry?
- Which statutory requirements and protocols apply to the installation of a charging point? Who establishes these regulations and protocols?
- Do differences in safety exist between the various types of charging infrastructure (regular, home, fast)?
- Are there any (known) specific risks associated with:
  - Extended Private Connection?
  - Lamppost chargers?
  - Induction charging?
  - Other new or existing forms?
- Can the improper use of plugs and charging facilities (or combinations thereof) result in risks? If this is the case, which combinations (i.e. improper combinations of chargers,

extension cords and adaptors) does this involve? Are users clearly informed of the potential risks?

- What is the knowledge level among users? Are users being asked this and are their answers being recorded?
- Are records being kept of the cause (or suspected cause) of each incident?
- Are you familiar with the different charging modes that exist (Mode 1, 2, 3 and 4) and are.
- these modes mentioned in any requirements that you are aware of? Does sufficient knowledge exist with regard to safety risks of AC charging, as compared to DC charging (and any differences between those risks)?
- How great do you estimate the risk to be in connection with charging plugs and/or cables which (during charging) are ‘locked’ to the charging point in case of a fire? What solutions (e.g. automatic power shut-off, automatic unlocking in case of high temperature) can be envisioned?
- Are the charging and other protocols and regulations currently in use sufficient to ensure safety?
- What is the protocol for action in the event of damage to charging points caused by external factors such as a collision with an electric or conventional car, fireworks or vandalism?
- Are the current regulations and protocols actually being implemented? Does supervision of this implementation exist? If not, is this necessary and how might it be achieved?
- Are NEN 1010 and NEN 3140 sufficient with regard to the installation of charging points where it is possible to use the maximum current for hours on end?
- What steps are being taken to ensure the quality of the installation process?
- Is periodic maintenance being carried out on charging stations? What is necessary? What is actually happening? What are the remaining risks?
- How realistic is enforcement aimed at ensuring correct installation and use of charging facilities?

C Laws and regulations pertaining to charging stations

The following standards apply to physical components:
- IEC 62196 sets out requirements for plugs on electric cars.
  In recent years, the standard (which was established in 2014) has been expanded, with the most recent addition being made in March 2020 (NEN, 2014; 2017b; 2020a; IFV, 2020b).
- The IEC 62893 and IEC 62752 standards include requirements for charging cables. This standard, too, has been expanded in recent years (NEN, 2020c; IFV, 2020b).

We found the following regulations pertaining to charging stations:
- IEC 61851 sets out requirements for charging stations and charging points for electric vehicles, including the electromagnetic parameters. The standard covers both AC and DC charging. The standard sets out general requirements and has been expanded in recent years by the addition of specific requirements for AC and DC charging (NEN, 2017a; NEN, 2019a; IFV, 2020b).
- IEC 60362-7-22 contains safety requirements with regard to the electrical connections of charging infrastructure (IEC, 2018; IFV, 2020b).
- ISO 17409 sets out conditions for the connecting electric vehicles to the power supply. These conditions are established for charging modes 2, 3 and 4 (NEN, 2020b).

The following standards are in effect with regard to the installation of charging points:
- NEN 1010: applies to private charging stations. These must be equipped with a residual-current device.
- NEN 3140: applies to public charging stations. This is a low-voltage guideline (up to 1,000 V alternating current and 1500 V direct current) (NEN, 2015a).

With regard to information exchange, we are aware of the following standards and initiatives:
- ISO 15118-8:2019 applies to interaction between the electric car and the electricity grid (NEN, 2019b) (V2G clarity, 2019).
- IEC 63119-1:2019 is the first section of the standard pertaining to information exchange between electric cars, charging station providers (CSPs) and charging station operators (CSOs) via a roaming network. This first section contains a description of definitions, a system model, classifications, information exchange and safety mechanisms (IEC, 2019) (NEN, 2019a). Three other sections are expected to be published and will address topics including cybersecurity. These documents are expected to be delivered in March 2022 (RVO, 2019).
- The NEN committee on NEC 57 ‘Remote operation of energy supply systems’ focuses on themes including the development of protocols for communication between charging infrastructure and the grid structure that supplies its power. This is covered by the IEC/TC 57 standard ‘Power systems management and associated information exchange’ (IEC, 2020c; NEN, 2018b; NEN, 2018c).