D7.1–Gaps in regulatory framework prior to the demonstrator train test

WP 7–Normative Framework

Task 7.1–Identification of Gaps in regulatory framework

Author	Esteban Rodriguez Muñoz, CNH2 Beatriz Nieto Calderón, CNH2	
Phone number, E-mail	ERM: +34 926420682 – 155, Ej.rodriguez@cnh2.es BNC: +34 926420682 – 150, Beatriz.nieto@cnh2.es	
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Contributions Table	
Partner	**Contribution**
CNH2	Preparation of the deliverable and gaps analysis related to HRS
CAF	Gaps analysis related to the train
DLR	Gaps analysis related to TSI´s
ADIF	Preparation of the deliverable
RENFE	Review of the deliverable
IP	Preparation of the deliverable
STT	Gaps analysis related to the pantograph

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Executive Summary

This document is Deliverable D7.1: 'Gaps in regulatory frameworks prior to the demonstrator train test', that constitutes the first stage of the Legislative Gap Analysis, for the project 'FCH2RAIL: Fuel cell hybrid power pack for rail applications', under Grant Agreement No. 101006633[1].

In this document, each partner identifies their scope of work, the methodology they used to identify any gaps and the results of their analysis. A specific analysis of each of them is contained in a detailed document appended to this report.

The aim of this deliverable is to identify any gaps within the current regulatory framework, from a theoretical point of view, before testing and commissioning the demonstrator train on the railway, where next steps are followed:

- Evaluating the requirements associated with the integration of hydrogen in trains and railway systems.
- Identifying those codes that do not fully cover the railway specifications applicable to the project.
- Analysing and collecting the regulatory gaps extracted from the previous point.
- Identifying the TSI's that need to be reviewed and updated.

This document lists the gaps that were found and divides them into specific fields of application:

- Related to the train
- Related to the refueling station (HRS)
- Related to the pantograph
- Related to the infrastructure

The TSIs with the greatest probability of being affected by the changes implemented in train technology have also been evaluated by carrying out an analysis of the regulatory gaps from a general point of view, encompassing all the components that constitute the project within the railway sector.

Each partner's analysis will be reviewed following the completion of the demonstrator tests and a new version of this report will be issued in a second stage.

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Glossary of Terms

Abbreviations	Description
LGA	Legislative Gap Analysis
HRS	Hydrogen Refuelling Station
RCS	Regulations, Codes and Standards
FCHPP	Fuel Cell Hybrid PowerPack
FCH2RAIL	Fuel Cell Hybrid PowerPack for Rail Applications
H2	Hydrogen
HRP	Heavy Rail Pantographs (HRP) department of Stemmann-Technik (a Wabtec company)
IRIS	International Railway Industry Standard
TSI	Technical Specification for Interoperability
ENE	Energy (here related to EU 1301/2014)
ERA	European Railway Agency
ESS	Energy Storage System
FCS	Fuel Cell System
HSS	Hydrogen Storage System
LOC&PAS	Locomotives and Passenger Rolling Stock
NSA	National Safety Authority
QMS	Quality Management System
WP	Work Package

Acronyms	Description
CA	Consortium Agreement
GA	Grant Agreement
RSSB	Railway Safety & Standards Board

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Contents

1. Background

The aim of WP7 is to develop a normative framework for the use of hydrogen technology in various railway applications across Europe and to generate the necessary momentum in the railway community for this framework to be taken to the regulatory and standardisation bodies. The specific objectives of the Work Package are as follows:

- Identification of the key aspects of the standards and regulations that need to be dealt with by analysing the gaps in the current applicable regulatory and voluntary framework (TSI and EN).
- Proposal of a methodology for authorisation and testing of the prototype train developed in the project.
- Maximising the impact of the proposal by liaising with the relevant bodies (ERA, CEN and NSAs) and other stakeholders.

WP7 is split into three specific tasks:

- Task 7.1 Identification of Gaps in the Regulatory Framework
- Task 7.2 Propose Modifications to the Normative Framework
- Task 7.3 Networking Activities

The aim of the Legislative Gap Analysis corresponds to Task 7.1 and provides the necessary inputs to the subsequent task as represented in Figure 1.

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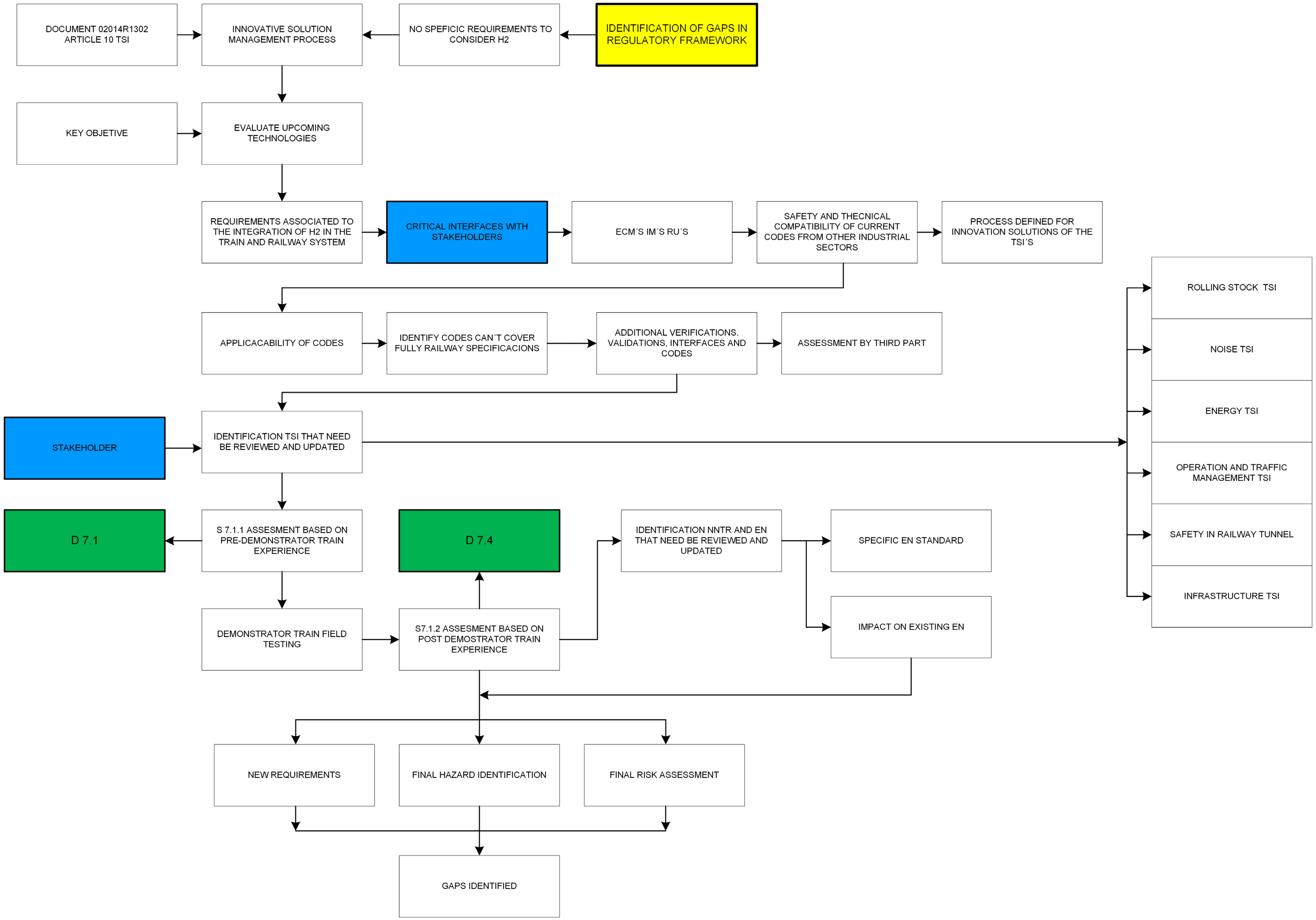

Figure 1 Task 7.1 Architecture

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2. Objective

The objective of the LGA is the identification of existing railway and non-railway regulations, codes and standards (RCS) that apply to the introduction of hydrogen technology into the railway environment to analyse the gaps in the current applicable regulatory and voluntary framework (TSI and EN).

Each partner in the project has examined its field of expertise and identified any gaps or issues associated with it:

- ADIF and IP have participated by identifying gaps related to the interaction between vehicle and infrastructure and providing the infrastructure manager point of view.
- RENFE has provided the operator point of view regarding technical and safety aspects.
- CAF, as railway vehicle manufacturer, has identified the consequences of integrating subsystems related to the use of H_2 in the integration of rail vehicles.
- DLR has reviewed the relevant TSIs and relevant railway regulations, such as EN and ERA regulations, for example, mainly from a railway systems point of view.
- STT has identified regulatory gaps for the interaction of pantograph H_2 system within the scope of this project.
- TME has contributed its experience and knowledge and provided a direct input into CAF's analysis.
- CNH2 has contributed its experience and specific knowledge in H_2, focussing on identifying legislative gaps related to the implementation of the Hydrogen Refuelling Station.

3. Scope

The scope of this work is to produce the Legislative Gap Analysis (LGA) based on the present normative framework for the safe use of hydrogen technology in various railway applications across Europe. It takes into account the European railwork network in the scope of the interoperability directive EU 2016/797 and the underlying regulations for vehicles, operations and infrastructure, such as the Technical Specifications for Interoperability (TSI).

This work has to be focussed on the vehicle and the integration of the Fuel Cell Hybrid Power Pack (FCHPP) within it, also considering the external vehicles interfaces and the impact of this technology on the operations, infrastructure (such as tracks, stations and refuelling points), the maintenance intervals, procedures and infrastructure, etc.

4. Methodology

The LGA must be based on the state of the art related to current legislation and standards that must be applied in the demonstration train.

Each partner may approach the resolution of the normative analysis under its own criteria and following the points that it considers necessary, defining the work methodology used specifically in the following analysis section.

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5. Analysis of Regulatory Gaps

5.1 Analysis related to the Train

5.1.1 Scope

The scope of this analysis is a H_2-powered rail vehicle and the integration of the FCHPP within it. It also considers the external vehicle interfaces and the impact of this technology on the infrastructure, operations, public, maintenance, etc.

The scope of this analysis has not been limited to the design and operation of the demonstrator vehicle, but also covers the integration of a FCHPP into a fully operational vehicle intended for use in a generic railway environment.

In this sense, three stages have been selected for undertaking the Legislative Gap Analysis:

1. Defines the approach, methodology and layout of the report. It includes analysis of design stage information, including inputs from the system and train hazard logs, supplied parts review, normative review and other external information.

2. 'Pre-Demonstrator Trial', including analysis of verification and validation activities in support of San Gregorio testing, update of the system and train hazard logs and the manufacturing process review.

3. 'Post-Demonstrator Trial', including the inputs and outputs from open line testing in Zaragoza, analysis of the vehicle safety case and maintenance aspects.

5.1.2 Methodology

Figure 2 below presents the strategy for gaps analysis in a diagram.

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CAF FCH2RAIL Task 7.1 & Task 7.2 Execution Strategy

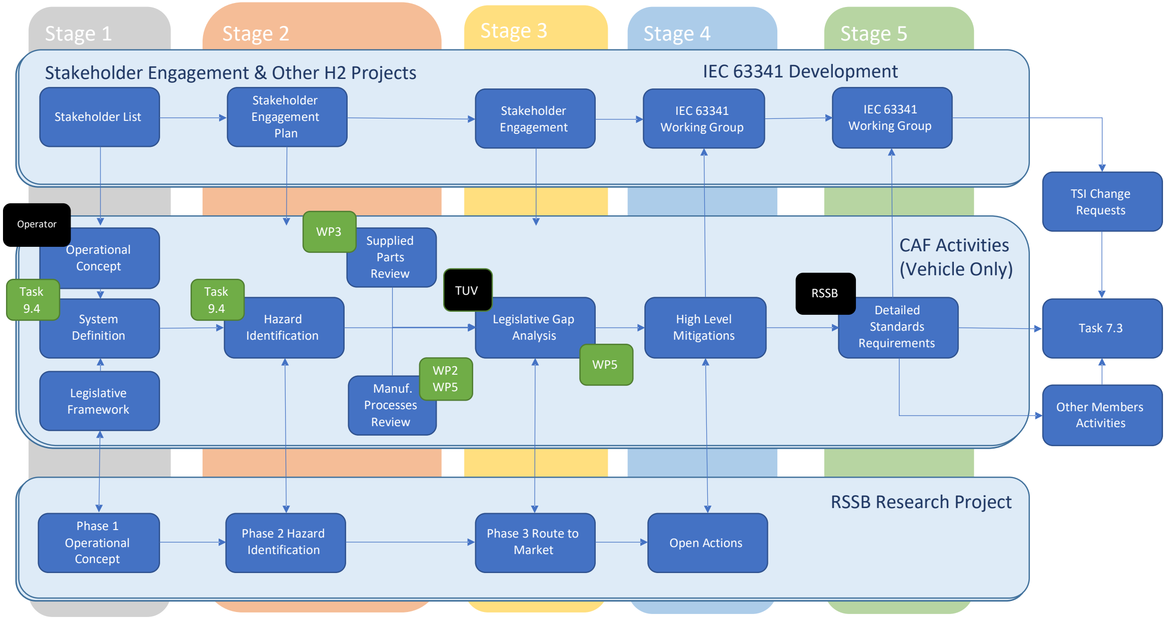

Figure 2: CAF´s Execution Strategy

The strategy is set out over five stages and considers input from stakeholders and other H_2-related projects, including outputs to the developing set of IEC63341 standards.

A research project undertaken by the UK Railway Safety & Standards Board (RSSB) is used to verify the approach and output at Stages 1 to 4. At Stage 5, CAF is seeking to work with the RSSB to identify the detailed standards requirements in support of the next stage of analysis.

The legislative gap analysis takes place at Stage 3, with inputs from hazard identification activities, a supplier parts review and a review of manufacturing processes. With the gaps identified at Stage 3, Stage 4 will propose high-level mitigations to address them in terms of which standards should be adopted, revised and re-issued to close the gaps. Stage 5 will provide the detailed requirements for inclusion in these standards.

Where the risks and mitigations identified by the hazard analysis produced in Stage 2 have been directly linked to the limited design and operation of the demonstrator vehicle, they have been reviewed and revisited.

The legislative gap analysis at Stage 3 was undertaken in five steps:

1. Determining generic hazards, related faults and related causes, which are to be expected with the applied technology.
2. Listing and categorising all Regulations, Codes and Standards (RCS) from input documents and amending those from RCS that may apply to generic application.
3. Analysing the RCS and, where applicable, allocating them to either:

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   a. Preferably preventing/avoiding causes from occurring or if not sufficiently achievable.
   b. Adequately limiting the severity or probability of the occurrence, and assessing its suitability.

4. Extracting lists of the applicable RCS that are suitable for preventing the cause or limiting the consequence:
   a. from the railway industry where no modification is required.
   b. from the railway industry where modification is required including a description of the identified gap.
   c. from other industries, including a description of the implications of their application.

5. Adding a list of those hazards where currently no applicable RCS exist (and the appropriateness of the specific safety measure has to be demonstrated).

5.1.3 Summary of Findings

The report in Annex A concludes that a total of 56 Regulations, Codes and Standards (RCS) of which more than half of the Railway Regulations Codes & Standards (RCS) have been allocated 200 times to 22 generic causes.

- 13 railway RCS that require no modification were identified as they adequately mitigate the related hazards when applied.

- 13 railway RCS that require modification were identified in order to achieve acceptable mitigation.

- 30 non-railway RCS were identified that are partly suitable for mitigating the related hazards although there were some implications or constraints that require amendment by railway RCS (such as EN 50155).

- 9 technical issues have been identified where currently no RCS exist.

If no applicable RCS exist and the requirement is not entirely specific but more generic, the generation of a new standard or amendment of existing ones may be appropriate. This applies to the gaps identified regarding hydrogen refuelling, since these aspects will be key for economic and successful application of the new technology.

5.2 Analysis related to the HRS

5.2.1 Scope

The scope of this analysis is based on the integration of an HRS in the railway sector, with the aim of supplying the powerpack that the train has integrated with pressurised gaseous hydrogen. The interfaces with the vehicle and its transit facility as well as the maintenance and commissioning programs of the HRS are also taken into account.

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The scope of the legislative gap analysis is centred on the following stages:

- Definition of the approach, methodology and design of the report, including the analysis of technical information in the design stage as well as the review of compliance with regulations adapted by manufacturers in the choice of supplied parts.
- General HRS requirements.
- Analysis and implementation of specific solutions for the adaptation of the HRS to the sites proposed for the testing and validation of the demonstrator train, taking into account the specific requirements of each one, and implementing general measures of application.

5.2.2 Methodology

The methodology implemented for analysis of the regulatory gaps is based on the following points described below:

a) Compilation of the Regulations, Codes and Standards (RCS) that apply to the design, testing, security measures and implementation of the necessary equipment for the development of the hydrogen, from a general point of view.
b) Study of the requirements associated with the integration of H_2 in train and railway systems.
c) Technical and safety compatibility of current application codes from other industries, such as SAE.
d) Applicability of the codes to the project.
e) Identification of those codes that do not fully cover the specifications of the railway sector.
f) Identification of verifications, validations, interfaces and additional codes.

As a result of the previous paragraph, Annex B reflecting the following points is presented:

1) Determination of the generic dangers, related faults and related causes, which are expected with the applied technology.
2) Enumeration and categorisation of regulations, codes and RCS standards applicable to the H_2 sector, from a general point of view.
3) Analysis of the RCS, where those that apply to the project itself are extracted.
4) From the previous point, RCS are classified according to:
    - RCS that do not require modification
    - RCS that require modification
5) List of hazards that are not covered by current regulations, where the failures that could result from not applying mitigating measures are associated with the hazard and the causes that generate it.

5.2.3 Summary of Findings

Starting from a total of 82 RCS in total, 45 RCS applicable to the project have been analysed, from which it can be concluded that:

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- 36 RCS do not need modification.
- 7 RCS need to be modified to adapt to project requirements.
- 3 technical problems have been found where currently there is no RCS that specifies how to mitigate the effects that may generate a hazard.

If there is no RCS that can be adapted to some of the project requirements, it would be convenient to expand and/or modify an existing one, specifying the nature of the problem associated with the use of hydrogen in the railway sector.

5.3 Analysis related to the pantograph

5.3.1 Scope

The scope of work is to execute the gaps analysis of the pantograph based on the present normative framework for the safe use of electrical railway technology and, where available, hydrogen technology in various railway applications across Europe. It considers the European railway network in the scope of interoperability directive EU 2016/797 and the underlying regulations for vehicles, operations and infrastructure, such as the Technical Specification for Interoperability (TSI) for Locomotives and Passenger rolling stock (TSI LOC&PAS), EU 1302/2014, for the energy of the rail system (TSI ENE), EU 1301/2014 and the relevant EN standards.

The gap analysis of the pantograph is focussed on the electrically actuated vehicle and the integration of a FCHPP. It should also consider the external vehicles interfaces and the impact of this technology on the operations, infrastructure (such as tracks, stations, the maintenance intervals, procedures and infrastructure), etc. if possible.

The GA should deliver the following results:

- Provide a baseline conformity matrix for the standards that are applicable.
- List the technical and risk areas where no specific railway requirement currently exists.
- Make reference where possible and applicable to related industry standards.

5.3.2 Methodology

The objective of the gaps analysis is the identification of the existing railway RCS that apply for a hybrid (H_2 and electrically actuated by a pantograph) demonstrator vehicle and its integration into the railway environment to analyse the gaps in the current applicable regulatory and voluntary framework (TSI and EN).

This is done by evaluating all RCS referenced as a code of practice to mitigate specific hazards and assess their suitability.

The gaps analysis is based on the relevant standards and guidelines for pantographs used in heavy railway applications.

Gaps analysis is performed in four main steps:

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1. Determining generic hazards, related faults and related causes, which are to be expected with the applied technology.

2. Listing and categorising all RCS from input documents and amending those in RCS may apply for the pantograph application.

3. Analyse the RCS and, if applicable, allocate to either:

- Preferably prevent/avoid causes to occur or, if not sufficiently achievable.
- Limit adequately the severeness or probability of the occurrence and assess their suitability.

4. Extract applicable RCS that are suitable to prevent the cause or limit the consequence:

- from the railway industry where no modification is required:
- from the railway industry where modification is required including a description of the identified gap.

5.3.3 Summary of Findings

The identified hazard, faults and causes are listed in Annex C, chapter 6, where the current project stage is represented and may be amended during the planned subsequent issues of the gaps analysis or execution of an analysis according EN 50126, EN 60812 or similar.

The severity and occurrence in the gaps analysis has to be assessed at a later stage.

From the gaps analysis already carried out, it can be concluded that the existing electrical European standards relating to the pantograph, mitigate the gaps.

Due to contact with the overhead contact line, the pantograph continuously causes arcing and abrasion of the wear material with varying intensity during operation. This creates dust made up of different carbon materials or metal alloys (mostly copper, copper, copper-steel alloys, etc.). Especially for metal alloys, the use of additional grease is required. Because of irregularities in the infrastructure, operation under icy overhead contact lines, etc., it is possible that larger particles of wear detach from the contact strip and contact components of the roof. Parts are subjected to high temperatures. The ignition energy, ignition temperature and other critical properties of hydrogen have to be considered. Due to the evolved system of railway infrastructure and pantograph-equipped vehicles as well as the financial consequences, one solution is not realistic.

Possible solutions could include:

- Fully controlled pantograph (closed loop regulation) to reduce the wear and arcing.
- Development of new wear materials with a lower wear rate.
- Development of a new overhead contact line system to reduce the arcing and wear.
- Battery-equipped vehicles with charging only when at a standstill.
- Modification of the contact strips to reduce the previously mentioned influences.

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At the moment, the only feasible short-term solution is to protect the fuel cell hybrid power pack against the previously mentioned influences.

Standards and guidelines for other vehicles such as cars, buses, etc. that are powered by hydrogen have to be checked according to their applicability to the planned hybrid vehicle. An innovative solution according to EU 1302/2014/EC in cooperation with a notified body is to be followed in order to find a solution regarding the modification of existing standards and guidelines or to create new ones.

5.4 Analysis related to TSI´s

5.4.1 Scope

Regarding the TSI's' gap analysis, a different method of study is carried out, from an overall railway system perspective. In this case, the goal is to identify potential problems that the introduction of the FCH2Rail train could impose on the different parts of the railway system.

5.4.2 Methodology

The Technical Specifications for Interoperability (TSI) serve this purpose from a regulation side – imposing the crucial requirements of railway subsystems to function in the European Union railway system. TSI´s most likely to be affected by the implemented changes in the train technology are analysed, and potential problems uncovered. The TSI´s analysed are shown in Table 1.

Short name	Full name
TSI LOC&PAS	Technical Specification for Interoperability for the "rolling stock subsystem - Locomotives and passenger rolling stock", adopted by Commission Regulation (EU) No. 1302/2014 of 18 November 2014 and amended by Commission Implementing Regulations(EU) 2016/919, 2018/868, 2019/776 and 2020/387 (TSI LOC&PAS)
TSI ENE	Technical Specification for Interoperability relating to the "energy" subsystem of the rail system in the union, adopted by Commission Regulation (EU) No. 1301/2014 of 18 November 2014 and amended by Commission Implementing Regulations (EU) 2018/868, 2019/776 and corrected by Corrigendum 1301/2014 (TSI ENE)
TSI INF	Technical Specification for Interoperability relating to the "infrastructure" subsystem of the rail system in the European Union, adopted by Commission Regulation (EU) No. 1299/2014 of 18 November 2014 and amended by Commission Implementing Regulation (EU) 2019/776
TSI NOI	Technical Specification for Interoperability relating to the subsystem "rolling stock - noise", adopted by the Commission Regulation (EU) No. 1304/2014 of 26 November 2014 and amended by Commission Implementing Regulation (EU) 2019/774
TSI SRT	Technical Specification for Interoperability relating to "safety in railway tunnels" of the rail system of the European Union, adopted by Commission Regulation No.

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	1303/2014 of 18 November 2014 and amended by the Commission Regulation (EU) 2016/912 and Commission Implementing Regulation (EU) 2019/776
TSI OPE	Technical Specification for Interoperability relating to the operation and traffic management subsystem of the rail system within the European Union, adopted by Commission Implementing Regulation (EU) 2019/773 and amended by Commission Implementing Regulations (EU) 2020/778 and 2021/2238
TSI PRM	Technical Specification for Interoperability relating to accessibility of the Union's rail system for persons with disabilities and persons with reduced mobility, adopted by Commission Regulation (EU) No. 1300/2014 and amended by Commission Implementing Regulations (EU) 2019/772 and 2022/721

Table 1: TSIs Analysed by DLR

The goal of the analysis is to discover requirements in the TSIs that may pose problems in compliance because of the innovations in our new type of train – either because the new technology involves a new or greater risk to the railway system, or because the train doesn't fit the categories mentioned in the regulations.

Generally, it is assumed that the requirements in the TSIs will be fulfilled in the design of the train wherever possible. Also, components not affected by the changes described in the system definition are assumed to fulfil the requirements of train control and signalling systems, for example.

5.4.3 Summary of Findings

The full list of findings, together with their place and exact wording in the TSIs, can be found in Annex D. It also contains the assessment and proposed subsequent steps for each finding. The chapter numbers given there refer to the annexes of the respective TSI´s, as they usually contain the technical requirements.

The following paragraphs summarise the results of the TSI analysis.

5.4.3.1 Environmental protection

The tests and a more detailed analysis have to determine if the train poses more danger to the environment after implementing the new technologies, especially with regard to:

- Electromagnetic compatibility
- Ground vibrations
- Noise

Concerning exhaust limits, there are requirements for diesel engines that the train very likely complies with. However, the hydrogen train is not a diesel train and, therefore, there is a gap concerning the exhaust that is not coming from diesel engines, that has to be closed. Analogous to this, noise limits for different use cases vary for the different train types, such as diesel units or electric units. Discussion is required of whether hydrogen trains would fit either of these categories, or if a new category needs to be created. In that case, the noise limits for the new train category would have to be introduced.

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5.4.3.2 Fire safety

Regarding fire safety, requirements for passenger trains are categorised into categories A and B. Trains have to be at least category A. The criteria for selecting category B don't take into account the higher risk arising from hydrogen trains, and the requirements for category A don't include all the fire-related risks of a hydrogen-related fire. One factor that influences the categorisation is the ability to run a burning train to a suitable firefighting point. For hydrogen trains, the suitability of a firefighting point could mean that, depending on the equipment and emergency operation plans of the infrastructure operator, the running capability has to be higher than with other types.

Tunnel structures have to withstand a fire of a certain temperature for a certain length of time. We doubt that these requirements are high enough to withstand a fire involving hydrogen, but that requires further research.

The same doubts exist regarding the requirements for containment of the fire in the train, especially in the event of burning electric and battery equipment.

General incidents in the tunnel are also divided into "hot" incidents (involving fire on a train) and "cold" incidents (e. g. collisions without fire). In case of a "cold" incidents, there is no time constraint for the evacuation of passengers. With hydrogen involved, all "cold" incidents should also be treated at least as seriously as "hot" incidents, especially regarding possible explosion risks due to leaking hydrogen without immediate flames. Furthermore, there are additional risks not stemming from fire or explosion hazards but from equipment leaking hydrogen after a collision, especially in a tunnel.

It needs to be analysed further if the required fire extinguishing equipment and operational procedures, e.g. portable fire extinguishers, are suitable for fires involving hydrogen.

5.4.3.3 Smoke control and ventilation

As a measure in the event of fire, the ventilation system must be shut off. If safe operation of the train requires ventilation, this measure will have to be reconsidered. One possibility could be to introduce two separate ventilation system categories.

5.4.3.4 Pantograph

Because of the gauge required between the pantograph and fixed installations on the roof and the construction of the pantograph itself, it is considered to be sufficient to provide enough insulation for all expected voltages. Pantograph system experts have to be consulted to determine if it is the case that hydrogen equipment is part of these fixed installations. For example, any possible undetected leakage in a hydrogen tank on the roof could cause a fire due to sparks flying from the pantograph.

5.4.3.5 Flammable liquids or gases

There is a chapter with requirements for flammable liquids and gases in the TSI OPE. However, there is no mention of hydrogen, so the dangers coming from hydrogen are probably not covered in this chapter. The requirement that "there will be measures preventing fire due to flammable liquids or gases" is too generic.

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5.4.3.6 Refuelling equipment

There are requirements for the refuelling equipment for diesel trains in the TSI OPE, and the TSI INF also only refers to this requirement. For refuelling other fuel types, new requirements will have to be added.

5.4.3.7 Space for persons with reduced mobility

The areas and amenities that have to be provided for persons with reduced mobility, e. g. wheelchair users, are described in the TSI PRM. In the prototype provided in this project, there are areas occupied by new technology equipment, but this train is not foreseen for use in regular operations. It is assumed that for later regular use of the train, however, the system design will be adapted in order to comply with the requirements in the TSI PRM.

5.5 Analysis related to Infrastructure

5.5.1 Scope

As in TRL Technology Readiness Level standardisation and regulatory framework will be the end of the process that starts as the innovation developments, from TRL 1: (Basic principles) to TRL 9 (system proven in an operational environment) that is the most mature technology. Following the same process, five steps in the process have been defined:

1. Definition
2. Prototype
3. Validation
4. Experience
5. Conclusions and standardisations

The reason for creating a regulation retrospectively is to ensure that a system does not limit technological development and allows progress to be made without the need for modification due to a lack of prior experience with the technology.

5.5.2 Methodology

The methodology to achieve the objectives is as follows:

- Identification of technical requirements that may limit the integration of new hydrogen technology in railroads.
- Identification of risks derived from the use of H_2 in railroads.

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- Establishing a regulatory framework or guidelines: Compliance with authorisation processes and identification of actions.
- Harmonisation of rolling stock requirements and guaranteeing interoperability of fixed installations.
- National position on European regulations, identifying RFIG particularities and defining national interests

One way of achieving these objectives is in three phases:

- Phase 1: Identification of risks and essential requirements affected.
- Phase 2: Definition of technical and evaluation requirements.
- Phase 3: Drafting of a national standard or guideline.

5.5.3 Summary of Findings

The gaps detected based on the knowledge and experience will be included in a second stage of the T7.1 development.

6. Conclusions

An in-depth review of the regulations, codes and application standards has been carried out with the aim of implementation of a new technology based on the integration of a hydrogen-powered fuel cell hybrid power pack for railway applications.

From this study, we can draw the following conclusions:

Regarding the train, numerous regulatory gaps have been found in both the specific regulations aimed at railway systems and those from other industries. In addition, technicalities have been discovered that have to be considered in the design, e.g. the effect of solar radiation falling on the train, which can trigger a fire and/or explosion as a result of the increase in temperature and pressure of the hydrogen stored in it, where no regulations have been found that contemplate mitigation actions to solve this problem. This same problem could be extrapolated to HRS storage.

Regarding the pantograph, numerous regulatory gaps have been found that highlight the interaction of the pantograph with the electrical power line generating a metallic powder in suspension as a result of friction, causing electric arcs that represent an ignition source and can cause a fire.

Regulatory gaps in relation to the HRS have been found, focusing on ISO 19880 regarding refuelling stations, where general guidelines have been drawn up regarding the points to be considered in the design and implementation of an installation for this purpose. However, there is a certain lack in addressing technical specifications from a more specific point of view, such as minimum safety distances or external containment elements against impact, for example.

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In addition, standards regarding hydrogen refuelling protocols for heavy-duty vehicle with high flow (HF) are lacking because, although SAE J2601-2 establishes the boundary conditions for refuelling heavy-duty vehicles with > 10 kg of hydrogen storage and/or mass flow rates of up to 7.2 kg/min, SAEJ2601-2 lacks the level of practical detail required for a full standard. The capacity for railway applications is planned to be greater than the capacity covered by existing protocols and ISO 19885-3 is a high-flow hydrogen refuelling protocol being developed under the supervision of the ISO/TC197 and could be a valid option for trains.

Related to TSI's: All the critical points related to the implementation of this technology in the railway sector have been analysed in a general way.

Most significant TSI´s have been analysed, where the most important points to be dealt with within the technical regulations reveal interoperability requiring some type of modification, matters such as enviromental protection, fire safety on tunnels or ventilation systems or even the addition of new requirements as in the case of refuelling equipment. Non additional requirements are listed in TSI PRM.

7. References

[1] European Comission, “Grant Agreement Number- 101006633 - FCH2Rail,” 2020.

[2] Consortium FCH2Rail Project, “Consortium Agreement FCH2Rail,” 2020.

A.1 List of Figures

A.2 List of Tables

ANNEX_A – CAF Report FCH2RAIL_LGA

ANNEX_B – CNH2 Report FCH2RAIL_LGA

ANNEX_C – STT Report FCH2RAIL_LGA

ANNEX_D – DLR Report FCH2RAIL_LGA

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ANNEX_A – CAF Report FCH2RAIL_LGA

Co-funded by the European Union

EDITION CONTROL

Edition	REASON	Date
_	First Planned Issue	13/04/22
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Prepared by:	Reviewed by:	Approved by:
Name: Paul Simmons Signature: Date: 28/09/22	Name: Eva Terron Signature: Date: 28/09/22	Name: Ainara Gonzalez Signature: Date: 28/09/22

Index:

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Verified:	Eva Terron
Approved:	Ainara Gonzalez
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1 Introduction

This document provides the second issue of the Legislative Gap Analysis (LGA), at Appendix A, in respect of the vehicle and the integration of the FCHPP within it; it also considers the external vehicle interfaces and the impact of this technology on the infrastructure, operations, the public, maintenance etc.

2 Glossary

Term	Meaning
EN	Euro Norm
FCHPP	Fuel Cell Hybrid Power Pack
LGA	Legislative Gap Analysis
RCS	Regulations Codes & Standards

3 Objective

The objective of this document is to provide the methodology and results of the Legislative Gap Analysis, in respect of the vehicle and the integration of the FCHPP, at its second issue (see Section 4).

4 Scope

The Legislative Gap Analysis will be presented in three distinct issues:

- Issue 1 - Defines the approach, methodology and layout of the report. It includes analysis of Design Stage information, including inputs from the System & Train Hazard Logs, Supplied Parts Review, Normative Review and other external information, including TUV experience.

- Issue 2 (this document) - 'Pre-Demonstrator Trial', includes analysis of Verification & Validation activities in support of San Gregorio testing, update of the System & Train Hazard Logs and the Manufacturing Process Review.

- Issue 3 - 'Post- Demonstrator Trial', includes the inputs and outputs from open line testing in Zaragoza, analysis of the vehicle safety case and maintenance aspects.

5 Methodology

The methodology used to undertake the LGA is fully described in the report at Appendix A.

In summary, the LGA has been undertaken in five steps, as follows:

1. Determine generic Hazards, related Faults and related Causes, which are to be expected with the applied technology,

2. List and categorize all Regulations Codes & Standards (RCS) from input documents and amend those by RCS which may apply for a generic application,

3. Analyse the RCS and if applicable, allocate either to:

    a. Preferably prevent/avoid causes to occur or, if not sufficiently achievable,

b. Limit adequately the severeness or probability of the occurrence, and assess their suitability.

4. Extract lists of applicable RCS, that are suitable to prevent the cause or limit the consequence:

a. from railway industry, where no modification is required,

b. from railway industry, where modification is required including a description of the identified gap,

c. from other industries, including a description of the implications of their application.

5. Add a list of those hazards where currently no applicable RCS exist.

5 Summary of Findings

The report at Appendix A concludes that a total of 56 Regulations, Codes and Standards (RCS) – of which more than half are Railway Regulations Codes & Standards (RCS) – have been allocated 200 times to 22 generic Causes.

- 13 Railway RCS were identified that require no modification as they adequately mitigate the related hazards, when applied.
- 13 Railway RCS were identified that require modification in order to achieve an acceptable mitigation.
- 30 Non-Railway RCS were identified that are partially suitable to mitigate the related hazards, however there were some implications or constraints, that require amendment by railway RCS, such as EN 50155.
- 9 Technical issues have been identified where currently no RCS exists.

If no applicable RCS exists and the requirement is not entirely specific but more generic, generating a new standard or amending existing ones might be appropriate. This applies for the gaps identified regarding hydrogen refuelling, since these aspects will be key for an economic and successful application of the new technology.

Appendix A – Legislative Gap Analysis – FCH2RAIL Work Package 7.1 Ref: CZ98349T Revision 2.1

LEGISLATIVE GAP ANALYSIS

FCH2RAIL
Work Package 7.1

Report-No.: CZ98349T, Report Date: 2022-09-23

Revision: 2.1, Pages: 30

Customer:

CONTRUCCIONES Y AUXILIAR DE FERROCARRILES, S.A. (CAF)

Avenida Cataluña, 299

50014 Zaragoza

SPAIN

Order Date: 2021-05-12

Project No.: 717523125

Assessor:

M.Eng. Tolga Wichmann

Phone: +49 30 632230-37, Fax: -99

Mail: tolga.wichmann@tuvsud.com

Inspection body Rolling Stock:

TÜV SÜD Rail GmbH

Barthstraße 16

D - 80339 Munich

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Revision history

Revision	Status	Date	Author	Modified clauses	Modifications
0.1	Draft	2022-02-22	Tolga Wichmann	---	Initial
1.0	Released	2022-03-31	Tolga Wichmann	All	Review comments
1.1	Released	2022-04-06	Tolga Wichmann	All	Editorial changes and corrections, added ISO 17268, deleted UN 38.3
2.0	Released	2022-09-19	Tolga Wichmann	All	1.6, 1.7, 4, 5 – additional 13 RCS analysed
2.1	Released	2022-09-23	Tolga Wichmann	All	Editorial changes and corrections

1. Introduction

1.1. Assignment

TÜV SÜD Rail was assigned by CAF to perform a Legislative Gap Analysis within the framework of the European funding project, FCH2RAIL, where CAF together with its consortia members is developing and testing a HEMU demonstrator. The Legislative Gap Analysis is part of Work Package 7 (WP7) of the FCH2RAIL project.

The aim of WP7 is to develop a normative framework for the use of hydrogen technology in different kinds of railway applications across Europe, and to generate the necessary momentum in the railway community for this framework to be taken to the regulatory and standardization bodies [D01].

The specific objectives of this Work Package are as follows [D01]:

- Identification of the key aspects of the standards and regulations that need to be dealt with, by analyzing the gaps in the current applicable regulatory and voluntary framework (TSI and EN),
- Proposal of a methodology for authorization and test of the prototype train developed in the project,
- Maximize the impact of the proposal by liaising with the relevant bodies (ERA, CEN and NSAs) and other stakeholders.

WP7 is split into three specific tasks; Task 7.1 Identification of Gaps in the Regulatory Framework, Task 7.2 Propose Modifications to the Normative Framework and Task 7.3 Networking Activities. The goal of the Legislative Gap Analysis corresponds to Task 7.1 and shall provide the necessary inputs to the subsequent tasks [D01].

1.2. Scope

The scope of work is to produce the Legislative Gap Analysis (LGA) based on the present normative framework for the safe use of hydrogen technology in different kinds of railway applications across Europe. It considers the European railway network in the scope of the interoperability directive EU 2016/797 and the underlying regulations for vehicles, operations and infrastructure, such as the technical specification for interoperability (TSI) for locomotives and passenger rolling stock (TSI LOC&PAS), EU 1302/2014, for the energy of the rail system (TSI ENE), EU 1301/2014, and the infrastructure of the rail system (TSI INF), EU 1299/2014.

Whilst it should be focused on the vehicle and the integration of a Fuel Cell Hybrid Power Pack (FCHPP) within it, it should also consider the external vehicles interfaces and the impact of this technology on the operations, the infrastructure, such as tracks, stations and refueling points, the maintenance intervals, procedures, and infrastructure, etc.

The LGA shall deliver the following results:

- Provide a baseline conformity matrix, for the standards that are applicable and do not require modification,

- List the requirements in existing standards which require modification.
- List the technical and risk areas where no specific railway requirement currently exists,
- Make reference, where possible, and applicable to related industry standards.

1.3. Planned Issues

The Legislative Gap Analysis runs in parallel with the project as it depends on the results of documents that are produced along the progress of the project. For this reason, there will be two intermediate issues of the LGA before it will be released in the final version.

- First Issue: Defines, approach, layout and includes analysis of Design Stage information, including inputs from System & Train HL, Supplied Parts Review, Normative Review and other external information, as well as TUV experience.
- Second Issue: Pre-Demonstrator Trial run, including analysis of V&V in support of San Gregorio testing, update of the System & Train HL and the Manufacturing Process Review. LGA assumed to be 80% complete at this point, depending on the maturity of the delivered evidence by then.
- Final Issue: Post-Demonstrator Trial, including outputs and return of experience from the trial, analysis of the vehicle safety case and maintenance aspects.

1.4. Management system

The assessment was executed under application of the valid quality management system [M1] of the inspection body TÜV SÜD Rail GmbH accredited according to DIN EN ISO/IEC 17020:2012 [M2].

Table 1: Management System

Ref.	Designation	Title
[M1]	QMS	Quality management system of TÜV SÜD Rail GmbH
[M2]	D-IS-11190-01-00	Accreditation according to DIN EN ISO/IEC 17020:2012 as a Type A inspection body. The accreditation is only valid for the scope of accreditation listed in the document annex D-IS-11190-01-00.

1.5. Abbreviations

Table 2: Abbreviations

Abbreviation	Definition
CAF	CONTRUCCIONES Y AUXILIAR DE FERROCARRILES
CEN	European Committee for Standardization
EMC	Electromagnetic Compatibility
ENE	Energy (here related to EU 1301/2014)

Table 2: Abbreviations

Abbreviation	Definition
ERA	European Railway Agency
ESS	Energy Storage System
FCHPP	Fuel Cell Hybrid Power Pack
FCS	Fuel Cell System
H2	Hydrogen
HSS	Hydrogen Storage System
INF	Infrastructure (here related to EU 1299/2014)
LGA	Legislative Gap Analysis
LOC&PAS	Locomotives and Passenger Rolling Stock (here related to EU 1302/2014)
NSA	National Safety Authority
QMS	Quality Management System
RCS	Regulations, Codes and Standards
TSI	Technical Specification for Interoperability
WP	Work Package

1.6. Documents

The input documents from the different stages of the project have been reviewed by TÜV SÜD and, if considered relevant for the assignment, have been added to the list of documents of this report.

Table 3: Documents

ID	Document Title	Doc./File ID	Author	Rev.	Date
[D01]	FCH2RAIL Remit for Third Party Support – Legislative Gap Analysis	CN9.96.002.00	CAF	A	2021-10-20
[D02]	SYSTEM DEFINITION - FCH2RAIL – BI-MODE FCH TRAIN DEMONSTRATOR (CIVIA H2)	C.N9.96.950.00	CAF	B	2021-05-15
[D03]	Hazard Log FCH2Rail – Civia H2	C.N9.96.908.00	CAF	D	2022-09-02
[D04]	Legislative Framework - Generic EU EMU	---	CAF	---	2021-10-21
[D05]	ESSENTIAL OUTSOURCED ITEM SPECIFICATION (EEFAE) – FUEL CELL SYSTEM – FCH2RAIL PROJECT	C.N9.94.113.01	CAF	---	27.01.2021
[D06]	ESSENTIAL OUTSOURCED ITEM SPECIFICATION (EEFAE) – FUEL CELL COOLING SYSTEM – RENFE H2 PROTOTYPE	C.N9.94.111.03	CAF	A	22.04.2021

Table 3: Documents

ID	Document Title	Doc./File ID	Author	Rev.	Date
[D07]	ESSENTIAL OUTSOURCED ITEM SPECIFICATION (EEFAE) – FUEL CELL HYDROGEN STORAGE SYSTEM – RENFE H2 PROTOTYPE	C.N9.94.113.02	CAF	---	15.03.2021
[D08]	Fuel Cell Module Type Test Plan	---	CAF	---	---
[D09]	FCH2RAIL CAF Normative Review	---	CAF	---	2021-11-16

1.7. Regulations, Codes and Standards

The Regulations, Codes and Standards (RCS), which have been analysed for gaps and their suitability to mitigate specific hazards, have for the most part been referenced by the input documents [D02], [D03], [D04], [D05], [D06], [D07], [D08], [D09] and are listed below in table 4. This table will extend in the planned second and third issue of the LGA.

Further RCS – mostly from other industries – which have been identified by TÜV SÜD as being potentially applicable and suitable to mitigate the identified hazards and were not taken into the analysis up to now, can be found in appendix II. For further information on the list of RCS, please refer to section 4.2.

All standards listed below are referenced in the original EN/IEC/ISO-version and not in the national version to avoid any translation issues or national forewords.

Table 4: Regulations, Codes and Standards

No.	Standard	Date	Title
[R01]	1999/92/EG	1999-12-16	DIRECTIVE 1999/92/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 1999 on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres
[R02]	2006/42/EC	2006-05-17	DIRECTIVE 2006/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006 on machinery, and amending Directive 95/16/EC
[R03]	2014/34/EU	2014-02-26	DIRECTIVE 2014/34/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres
[R04]	2014/68/EU	2014-05-15	DIRECTIVE 2014/68/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 May 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment
[R05]	2014/30/EU	2014-03-29	DIRECTIVE 2014/30/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility (recast)

Table 4: Regulations, Codes and Standards

No.	Standard	Date	Title
[R06]	EC 79/2009	2009-01-14	REGULATION (EC) No 79/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 January 2009 on type-approval of hydrogen-powered motor vehicles, and amending Directive 2007/46/EC
[R07]	EN 1127-1	2019	Explosive atmospheres - Explosive prevention and protection - Part 1: Basic concepts and methodology
[R08]	EN 1779	1999	Non-destructive testing - Leak testing - Criteria for the method and technique selection
[R09]	EN 12663-1	2010 A1: 2014 2015 prA2:2021	Railway applications - Structural requirements of railway vehicle bodies - Part 1: Locomotives and passenger rolling stock
[R10]	EN 15085-1	2013	Railway applications - Welding of railway vehicles and components - Part 1: General
[R11]	EN 15227	2020	Railway applications - Crashworthiness requirements for rail vehicles
[R12]	EN 17124	2018	Hydrogen fuel - Product specification and quality assurance - Proton exchange membrane (PEM) fuel cell applications for road vehicle
[R13]	EN 17127	2018	Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols
[R14]	EN 45545-1	2013	Railway applications - Fire protection on railway vehicles - Part 1: General
[R15]	EN 45545-2	2020	Railway applications - Fire protection on railway vehicles - Part 2: Requirements for fire behaviour of materials and components
[R16]	EN 45545-3	2013	Railway applications - Fire protection on railway vehicles - Part 3: Fire resistance requirements for fire barriers
[R17]	EN 45545-4	2013	Railway applications - Fire protection on railway vehicles - Part 4: Fire safety requirements for rolling stock design
[R18]	EN 45545-5	2013 A1:2015	Railway applications - Fire protection on railway vehicles - Part 5: Fire safety requirements for electrical equipment including that of trolley buses, track guided buses and magnetic leviation vehicles
[R19]	EN 45545-6	2013	Railway applications - Fire protection on railway vehicles - Part 6: Fire control and management systems
[R20]	EN 45545-7	2013	Railway applications - Fire protection on railway vehicles - Part 7: Fire safety requirements for flammable liquid and flammable gas installations
[R21]	EN 50121-3-1	2015	Railway applications - Electromagnetic compatibility - Part 3-1: Rolling stock - Train and complete vehicle
[R22]	EN 50121-3-2	2016	Railway applications - Electromagnetic compatibility - Part 3-2: Rolling stock - Apparatus

Table 4: Regulations, Codes and Standards

No.	Standard	Date	Title
[R23]	EN 50122-1	2022	Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 1: Protective provisions against electric shock
[R24]	EN 50124-1	2017	Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment
[R25]	EN 50124-2	2017	Railway applications - Insulation coordination - Part 2: Overvoltages and related protection
[R26]	EN 50125-1	2014	Railway applications - Environmental conditions for equipment - Part 1: Rolling stock and on-board equipment
[R27]	EN 50128	A2:2020	Railway applications - Communication, signalling and processing systems - Software for railway control and protection systems
[R28]	EN 50129	2018 AC:2019	Railway applications - Communication, signalling and processing systems - Safety related electronic systems for signalling
[R29]	EN 50153	2014/A2:2020	Railway applications - Rolling stock - Protective provisions relating to electrical hazards
[R30]	EN 50155	2017	Railway applications - Rolling stock - Electronic equipment
[R31]	EN 50215	2010	Railway applications - Rolling stock - Testing of rolling stock on completion of construction and before entry into service
[R32]	EN 50343	2014 A1:2017	Railway applications - Rolling stock - Rules for installation of cabling
[R33]	EN 60068-2-11	1999	Environmental testing - Part 2: Tests; test Ka: Salt mist
[R34]	EN IEC 62619	2017	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications
[R35]	EN IEC 62928	2018	Railway applications - Rolling stock - Onboard lithium-ion traction batteries
[R36]	EU 406/2010	2010-04-26	COMMISSION REGULATION (EU) No 406/2010 of 26 April 2010 implementing Regulation (EC) No 79/2009 of the European Parliament and of the Council on type-approval of hydrogen-powered motor vehicles
[R37]	EU 1302/2014	2020-03-11	COMMISSION REGULATION (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the ‘rolling stock — locomotives and passenger rolling stock’ subsystem of the rail system in the European Union
[R38]	EU 2021/535	2021-04-06	COMMISSION IMPLEMENTING REGULATION (EU) 2021/535 of 31 March 2021 laying down rules for the application of Regulation (EU) 2019/2144 of the European Parliament and of the Council as regards uniform procedures and technical specifications for the type-approval of vehicles, and of systems, components and separate technical units intended for such vehicles, as regards their general construction characteristics and safety

Table 4: Regulations, Codes and Standards

No.	Standard	Date	Title
[R39]	IEC 60079-10-1	2020	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres - Edition 3.0
[R40]	IEC 60529	1989 A1:1999 A2:2013	Degrees of protection provided by enclosures (IP Code)
[R41]	IEC 61373	2010	Railway applications - Rolling stock equipment - Shock and vibration tests
[R42]	ISO 11114-1	2020	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 1: Metallic materials
[R43]	ISO 11114-2	2022	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 2: Non-metallic materials
[R44]	ISO 11114-4	2017	Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 4: Test methods for selecting steels resistant to hydrogen embrittlement
[R45]	ISO 11114-5	2022	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 5: Test methods for evaluating plastic liners
[R46]	ISO 14687	2019	Hydrogen fuel quality - Product specification
[R47]	ISO 17268	2017	Gaseous hydrogen land vehicle refuelling connection devices (ISO 17268:2012)
[R48]	ISO 19453-6	2020	Road vehicles - Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles - Part 6: Traction battery packs and systems
[R49]	ISO 19880-1	2020	Gaseous hydrogen - Fuelling stations - Part 1: General requirements
[R50]	ISO 20485	2018	Non-destructive testing - Leak testing - Tracer gas method
[R51]	ISO/TR 15916	2015	Basic considerations for the safety of hydrogen systems
[R52]	SAE J2601-1	2020-05	Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles
[R53]	SAE J2601-2	2014	Fuelling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles
[R54]	SAE J2799	2019	Hydrogen Surface Vehicle to Station Communications Hardware and Software
[R55]	UN ECE R 10	2012-09-20	Regulation No 10 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility
[R56]	UN ECE R 134	2019-05-17	Regulation No 134 of the Economic Commission for Europe of the United Nations (UN/ECE) - Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fuelled vehicles (HFCV)

TÜV SÜD Rail and further involved corporations from the TÜV SÜD Group carry accreditations to most of the aforementioned RCS. However, the accredited scope from TÜV SÜD has not been specifically marked here, since this report does not refer to any assessment activities dedicated to a specific object.

2. Objective

The objective of the LGA is the identification of the existing railway and non-railway RCS that apply for a vehicle with an FCHPP and its integration into the railway environment to analyse the gaps in the current applicable regulatory and voluntary framework (TSI and EN).

This shall be done by evaluation of the input documents with regards to all RCS referenced as a code of practice to mitigate specific hazards and assess their suitability. Since the inputs from CAF refer to the specific application for the CIVIA demonstrator, TÜV SÜD shall, based on its hydrogen project experience and expert knowledge, enhance the analysis to generalise the results for generic hydrogen vehicles as well as for a wider range of interfaces with the infrastructure and environment.

3. Method

The LGA is performed in five main steps:

1. Determine generic Hazards, related Faults and related Causes, which are to be expected with the applied technology,
2. List and categorize all RCS from input documents and amend those by RCS which may apply for a generic application,
3. Analyse the RCS and if applicable, allocate either to:
    a. Preferably prevent/avoid causes to occur or, if not sufficiently achievable,
    b. Limit adequately the severeness or probability of the occurrence,

   and assess their suitability.
4. Extract lists of applicable RCS, that are suitable to prevent the cause or limit the consequence:
    a. from railway industry, where no modification is required,
    b. from railway industry, where modification is required including a description of the identified gap,
    c. from other industries, including a description of the implications of their application.
5. Add a list of those hazards where currently no applicable RCS exist (and the appropriateness of the specific safety measure has to be demonstrated).

The applied level of detail is similar to the project Hazard Log [D03].

4. Findings

4.1. Generic Hazards, Faults and Causes

The identified Hazard, Faults and Causes, which are listed below, are numbered so that they can be quickly allocated during the analysis. They represent the current project stage and may be amended during the planned second and third issue of the LGA.

There is no assessment of severity and occurrence done within the LGA, as this was already done by CAF in the Hazard Log [D03]. It does, however, have an influence on the priority rating of identified needs for modification (see appendix V).

The following five main top-level **Hazards** have been identified (mainly based on [R51] and [D03]):

- **H1** **Fire hazards** (such as a hydrogen jet-flame or a vehicle on fire)
- **H2** **Explosion hazards** (such as detonation or deflagration)
- **H3** **Pressure related hazards** (such as burst or flying away parts)
- **H4** **Electrical hazards** (such as electrocution)
- **H5** **Health related hazard** (such as intoxication, burn or hearing damage)

Taking into account the typical components and functions of an FCHPP, which mainly consists of a hydrogen storage system (HSS), a Fuel Cell System (FCS) and an energy storage system (ESS) [D01], the following 14 generic **Faults** were identified, that may lead to the above-mentioned top-level hazards (mainly based on [R06], [R36], [R51], [R56] and [D03]):

- **F1** **Leakage** (of hydrogen)
- **F2** **Venting** (of hydrogen)
- **F3** **Bursting** (of pressure equipment)
- **F4** **Overpressure** (of pressure equipment, especially tanks)
- **F5** **Overtemperature** (of pressure equipment or batteries)
- **F6** **Component defect** (of pressure equipment, other than tanks)
- **F7** **Output overvoltage / over current** (of batteries or fuel cells)
- **F8** **Internal short circuit** (of batteries or fuel cells)
- **F9** **Loss of electrical isolation** (of any electrical component)
- **F10** **Loss of mechanical integrity** (of equipment racks or fixations)
- **F11** **Loud noise** (caused by a leak of pressurized gas or explosion)
- **F12** **Spark generation** (electrical, mechanical)
- **F13** **Degassing / Thermal Runaway** (of batteries)
- **F14** **Insufficient Ventilation** (in confined spaces with hydrogen equipment)

For preventive mitigations, the following 22 generic **Causes** or triggers of these failures were analyzed in a next step (mainly based on [R51] and [D03]).

- **C1** **Fire / Ignition source** (from the FCHPP or an adjacent area)
- **C2** **Thermal impact / over temperature** (from sun radiation / operational heat)
- **C3** **Cold impact / under temperature** (from cold weather or cold gas)
- **C4** **Operational shock / vibration** (during normal railway operation)
- **C5** **Electromagnetic emission / interference**
- **C6** **Hydrogen purity / particle ingress**
- **C7** **Hydrogen incompatibility** (leading to hydrogen embrittlement)
- **C8** **Corrosion** (dusts, aerosols, humidity, chemicals)
- **C9** **Human error** (manufacturing, operation, maintenance)
- **C10** **Improper mechanical design** (includes also tightness, ventilation, etc.)
- **C11** **Improper electrical design** (including functional safety)
- **C12** **Crash / Derailment / mechanical impact**
- **C13** **External short circuit / arcing** (from a defective component or outside)
- **C14** **Input over voltage / over current** (due to variations in the power supply)
- **C15** **Clogging / aerodynamic effects** (of natural or forced ventilation)
- **C16** **Over filling / charging** (of tanks by refueling station / batteries by converter)
- **C17** **Excessive mass flow** (from refueling station)
- **C18** **Deep discharge** (of hydrogen tanks or batteries)
- **C19** **Falling objects** (such as stones or tree branches)
- **C20** **Vandalism / Terrorism** (any kind of intentional damage)
- **C21** **Residual voltage** (from batteries, capacitors or electrostatic charge)
- **C22** **Wear, poor / improper maintenance**

Each cause can be allocated to one or several faults and each fault can be allocated to one or several hazards. A list of allocations can be found in appendix I.

4.2. Input RCS-List

The Regulations, Codes and Standards (RCS), which have been identified so far as potentially applicable and suitable to mitigate hazards, can be found in appendix II.

Up to the current stage, a total of 142 RCS are listed, which were derived from the input documents [D02], [D03], [D04], [D05], [D06], [D07], [D08], [D09] or identified by TÜV SÜD in an internal investigation. The list provides the code, the full title and current release date. It also pre-classifies the RCS with regards to their general topic (e.g., Fire Safety, Explosion Protection, Pressure Equipment), their type and their origin from the railway industry (or not). Four different main types of RCS were defined:

- **Test standard** (Describing a test procedure or alternative validation method)
- **Design standard** (Providing requirements regarding technical characteristics,

safety, etc.)

- **Process / Quality standard** (Defining a process to follow or organizational structures to apply)
- **Legislation** (Conditions to obey, mostly European directives or regulations)

The list also marks those standards that have gone through the legislative gap analysis up to this stage, which is 56 out of 142 RCS. Table 4 in section 1.7 of this report lists those 56 RCS. The RCS that have been applied as a risk acceptance criterion in the Train Hazard Log of CIVIA H2 [D03] were linked with the safety related requirements in a separate column in appendix II.

4.3. Analysis

The analysis was done in a separate spread sheet, which can be found in appendix III.

It lists the generic hazard causes on the left side and allocates applicable RCS in the next column. Each hazard cause is repeated as many times as applicable RCS for mitigation can be allocated.

In the next column, the relevant section or clauses of each RCS is listed.

The suitability for mitigation of the hazard is assessed in a narrative way and in additionally with a qualitative classification in “Low”, “Medium” and “High” – where a high suitability means that the RCS is likely to prevent the hazard cause or limit the consequence adequately.

The judgement of suitability of a standard is based on the generic hazard cause, combined with the experience of a typical system concept and design. In a specific case, the applicant may come to a different conclusion, depending on features of the individual design solution.

The identified gap, if any, is briefly described in a separate column and finally, each allocation is evaluated whether it is a Railway RCS without any need for modification, a Railway RCS with the need for modification or Other suitable RCS.

The next sections will collect the findings of the analysis sheet. To review the detailed justifications, please refer to the Analysis spread sheet in the appendix.

4.4. Railway RCS without modification

The following RCS can be applied for mitigation without any need for modification. Their suitability was mostly rated high.

Table 5: Railway RCS without modification

	Standard	Applicable to mitigate hazard causes	Suitability for mitigation
1	EN 12663-1	C4 Operational shock / vibration C10 Improper mechanical design C12 Crash / Derailment / mechanical impact	High

Table 5: Railway RCS without modification

	Standard	Applicable to mitigate hazard causes	Suitability for mitigation
2	EN 15085-X	C10 Improper mechanical design	High
3	EN 45545-4	C1 Fire or Ignition Source (internal, external)	Medium
4	EN 50121-3-1	C5 Electro magnetic emission / interference C11 Improper electrical design	High
5	EN 50121-3-2	C5 Electro magnetic emission / interference C11 Improper electrical design	High
6	EN 50122-1	C13 External short circuit / arcing	Low
7	EN 50124-1	C11 Improper electrical design C13 External short circuit / arcing	High
8	EN 50124-2	C13 External short circuit / arcing	High
9	EN 50125-1	C1 Fire or Ignition Source (internal, external) C2 Thermal impact / over temperature C3 Cold impact / under temperature C8 Corrosion (dusts, aerosols, humidity, chemicals) C11 Improper electrical design C13 External short circuit / arcing	High
10	EN 50128	C11 Improper electrical design	High
11	EN 50129	C11 Improper electrical design	High
12	EN 50153	C11 Improper electrical design C13 External short circuit / arcing C21 Residual voltage	High
13	EN 50343	C11 Improper electrical design C13 External short circuit / arcing	High

4.5. Railway RCS with need for modification

The following Railway RCS are partially suitable for mitigation as certain gaps have been identified, which are listed here below. The suitability for mitigation and the priority to close the gap was also evaluated and can be reviewed in the appendix.

Table 6: Railway RCS with need for modification

No.	Standard	Causes where Gaps have been identified	Suitability for mitigation	Identified Gap
1	EN 15227	C12	High	EN 15227 does not refer to the component arrangement in deformation zones of the car body. As this is not in the sense of this standard, the existing and future standards for hydrogen and traction battery systems, such as IEC 62928, IEC 63341-1 and IEC 63341-2, shall prohibit the

Table 6: Railway RCS with need for modification

No.	Standard	Causes where Gaps have been identified	Suitability for mitigation	Identified Gap
				arrangement of any hydrogen or battery components in the deformation zones of the car body.
2	EN 45545-1	C1 C20	High	Running capability requirements in 5.2.3, Table 1 (harmonized with TSI LOC&PAS) currently do not reflect the time beyond evacuation of passengers and the catastrophic impact of a further developing fire on Traction Batteries and/or Hydrogen Storage Systems.
3	EN 45545-2	C1	High	No specific requirement set for typical combustible materials of an alternative propulsion system, such as CRP of Type 3 or Type 4 hydrogen tanks (currently fulfilling R9, acc. to clause 4.2 l), because samples for flame spread test cannot be produced from the cylindric tanks).
4	EN 45545-3	C1	High	No specific requirement for hydrogen tank systems and its piping to protect it from onboard fires (optionally external fires), protect the structure (e.g., car body roof) from collapsing after extended heat impact, causing further critical damage on hydrogen tanks. No specific requirement for protection of passenger and staff areas from fires starting in the hydrogen tank system and its piping.
5	EN 45545-5	C1 C11 C13	Medium	No consideration of Lithium-Ion-Batteries, Fuel Cells and Hydrogen Storage Systems as well as the corresponding railway application standards, which already exist. It does not require electrical components to comply with shock and vibration requirements acc. to EN 61373 or alternatively fulfil railway suitability requirements of EN 50155.
6	EN 45545-6	C1	High	There is no consideration of Lithium-Ion-Batteries, Fuel Cells and Hydrogen Storage Systems with regards to fire detection and functional reaction upon fire detection.
7	EN 45545-7	C1	Low	The standard was not intended for hydrogen gas installations and requires a comprehensive update and normative references to future standards, such as IEC 63341-1 and 2.
8	EN 50155	C2 C3 C4 C8 C10 C12	High	The scope of EN 50155 is limited to electric and electronic components and there is currently no equivalent standard requiring these tests for hydrogen systems and components. Either the scope of EN 50155 is extended to non-electrical component testing or other still to be developed standards, such as IEC 63341-1, IEC 63341-2 and IEC 63341-3 adopt the international hydrogen standards and directives and define additional requirements. The shock and vibration test is needed to test the mechanical integrity of racks and housings, hydrogen

Table 6: Railway RCS with need for modification

No.	Standard	Causes where Gaps have been identified	Suitability for mitigation	Identified Gap
				components and fittings as well as the function of mechanical or electro-mechanical safety components of the hydrogen gas system. The function test is only required by EN 50155 (chapter 13.4.11.3 and 13.4.11.4), hence testing acc. to IEC 61373 only, would not cover this aspect. In order to prove enhanced tightness (no leakage under all expectable operational stress scenarios), the entire gas system must undergo a functional inspection and a pressure and tightness test before and after the shock and vibration test, which is not part of IEC 61373. The future standards for hydrogen application in railway, such as IEC 63341-1, IEC 63341-2 and IEC 63341-3, shall adopt IEC 61373 and EN 50155 and define additional requirements.
9	EN 50215	C11	Medium	EN 50215 adresses testing of thermal combustion engines, but not for hydrogen fuel cells, hydrogen storage systems and high voltages batteries. The standard should be updated to cover state of the art railway propulsion technology.
10	EN 50553	C1	High	Running capability requirements (defined by EN 45545-1 and TSI LOC&PAS) currently do not reflect the time beyond evacuation of passengers and the catastrophic impact of a further developing fire on Energy Storage System (ESS) and/or Hydrogen Storage Systems (HSS). The definition of Type 2 and Type 3 fires (chapter 5.2) requires an update to cover new hazards from TB and HSS as well as Fuel Cells or Hydrogen Combustion Engines. The requirements to achieve conformity in the decision boxes (chapter 6) must be updated to cover the new technologies and define new functional requirements.
11	IEC 61373	C1 C4 C10 C12	High	The shock and vibration test is needed to test the mechanical integrity of racks and housings, hydrogen components and fittings as well as the function of mechanical or electro-mechanical safety components of the hydrogen gas system. The function test is only required by EN 50155 (chapter 13.4.11.3 and 13.4.11.4), hence testing acc. to IEC 61373 only, would not cover this aspect. In order to prove enhanced tightness (no leakage under all expectable operational stress scenarios), the entire gas system must undergo a functional inspection and a pressure and tightness test before and after the shock and vibration test, which is not part of IEC 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt IEC 61373 and EN 50155 and define additional requirements.

Table 6: Railway RCS with need for modification

No.	Standard	Causes where Gaps have been identified	Suitability for mitigation	Identified Gap
12	EN IEC 62928	C1 C2 C4 C9 C12 C19	High	Neither the measurement of the toxicity and flammability of released gases during thermal runaway, nor a limitation of such is defined in IEC 62928 or IEC 62619 respectively. There are no functional requirement to minimize propagation (e.g. by continuous on board cooling). There are not requirements to support incident management, e.g. by informing fire brigades about the installed technology and provide means for an immediate and effective fire attack. IEC 62928 does not define requirements to protect the battery from excessive heat caused by sun radiation of waste heat from adjacent components. This also applies for future standards IEC 63341-1, IEC 63341-2 and IEC 63341-3 with regards to fuel cells and hydrogen storage systems. Especially hydrogen tanks with dark carbon fibre corpuses quickly heat up from sun radiation. IEC 62928 and there referenced standards IEC 61373 and IEC 60571 (IEC pendant to EN 50155) respectively do not define any functional tests during random vibration, as required by EN 50155, 13.4.11. IEC 62928 should prohibit integration of battery cases in the primary and secondary crash deformation zones of the car body. This also applies for future standards IEC 63341-1, IEC 63341-2 and IEC 63341-3 with regards to fuel cells and hydrogen storage systems. IEC 62928 should define requirements for mechanical protection of the battery case, especially when arranged on the car body roof or under floor.
13	EU 1302/2014	C1 C2 C3 C10 C11 C12	Low	TSI LOC&PAS needs to be revised e.g., by adding generic requirements for alternative propulsion with traction batteries and/or hydrogen and define a minimum set of safety requirements, such as - consideration of potential fire sources from new technologies in 4.2.10.3.4. (3), to be harmonized with EN 45545-3 - consideration of additional running time for vehicles with hydrogen or lithium-batteries in 4.2.10.4.4., to be harmonized with EN 50553 - new fire risk areas from new technologies in 6.2.3.23., to be harmonized with EN 45545-6 - new shock and vibration testing of safety relevant components, - new EMC testing of safety relevant components, - new requirements for hydrogen compatibility, - new corrosion protection of safety relevant materials

Table 6: Railway RCS with need for modification

No.	Standard	Causes where Gaps have been identified	Suitability for mitigation	Identified Gap
				and components, - new requirements to limit human error, - new requirements for enhanced tightness of hydrogen installations, - new electrical safety requirements for vehicles that are independent from catenary (by extending the scope of clause 4.2.8.4.), - new requirements for arrangement of hydrogen storage and traction battery systems outside of crash deformation zones (e.g. in clause 4.2.2.5.), - new requirements to prevent deep discharge of Type 4 hydrogen storage and traction battery systems, - new requirements for protection from falling objects on sensitive components, - new security measures of sensitive equipment, - new maintenance requirements e.g. by referencing to existing and future standards, such as IEC 62928, IEC 63341-1, IEC 63341-2, IEC 63341-3, etc. In addition the interfaces between the infrastructure and the vehicles, such as electrants and hydrogen filling stations, needs to be defined and aligned with other subsystems of the railway system. This includes the hydrogen purity, gas temperature, filling rate, nozzle, etc.

4.6. Applicable RCS from other industries

The following RCS are adopted from other industries for mitigation. The following table lists only the standard, the allocated hazard causes and the suitability for mitigation. Important hints regarding the applicability for railways and potential gaps when adopting these RCS are provided in the Remarks-column.

Table 7: Applicable RCS from other industries

No.	Standard	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
1	1999/92/EG	C9 C10 C13 C15 C21 C22	Medium	ATEX directive 1999/92/EG excludes vehicles for transportation. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage (depending on a dedicated hazard analysis). Furthermore, it is, together with its harmonized standards, a comprehensive rule to assess potential formation of explosive atmospheres. If it can be demonstrated that the probability of a significant release of hydrogen is low, the on-board hydrogen system is not classified as an explosive zone acc. to Annex I. Generic

Table 7: Applicable RCS from other industries

No.	Standard	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				requirements for organizational and workers safety measures are provided in Annex II.
2	2006/42/EC	C1 C2 C3 C4 C5 C7 C8 C9 C10 C11 C21	Low	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1 must be considered.
	2014/30/EU	C5	Medium	2014/30/EU specifically describes principal requirements for electrical devices with regards to electro magnetic compatibility and is the basis for product certification in this field. Depending on the test and assessment basis of the related certification, it may be possible to assess fulfillment of the requirements from EN 50121-3-2 on component basis. Adopting components with 2014/30/EU certification requires assessment with the requirements from EN 50121-3-2.
3	2014/34/EU	C9 C10 C11 C13 C14	Medium	ATEX product directive 2014/34/EU itself does not apply for railway vehicles. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage. Furthermore, it is, together with its harmonized standards, a comprehensive rule to assess explosive protection safety systems and devices suitable to work inside explosive atmospheres or outside with a safety related control function. If it can be demonstrated that the probability of a significant release of hydrogen is low, the on-board hydrogen system is not classified as an explosive zone, which would not require any components of the vehicle to fulfil ATEX product directive.
4	2014/68/EU	C10	High	Pressure Equipment Directive (PED) regulates in particular stationary installations as well as installations for industrial trucks under internal pressure >0,5 bar. It excludes road vehicles and their components but does not explicitly exclude railways in its scope of application. PED defines essential requirements for the design and manufacturing process of pressure vessels, components and assemblies as well as equipment with safety function. Besides many generic non-prescriptive requirements, PED defines a test pressure ratio of 1.43 of the maximum possible operating pressure (PS) for end-of-line testing, which means for a nominal working pressure (NWP) at 15 °C of 350 bar a test pressure of

Table 7: Applicable RCS from other industries

No.	Standard	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				438 bar (at 85°C) x 1.43 = 626 bar. There is currently no standard, which is harmonized with PED, that applies to Type 3 and Type 4 hydrogen pressure vessels at NWPs of 350 or 700 bar, which complicates a CE-marking acc. PED for these vessels. Furthermore, as assembly certification acc. to PED requires all components to be compliant with PED. If the vessel follows automotive regulations, such as EC 79 or R 134, it is formally not possible for the Notified Body PED to certify the assembly.
5	EC 79/2009	C1 C2 C3 C4 C7 C8 C10 C12 C16	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Tightness of tanks and components and their media compatibility under the given operating conditions is sufficiently proven by EC 79 type approval. Adopting components with EC 79 type approval requires a comparison with the boundary conditions of railway application and closure of these gaps with additional tests and design rules from existing and still to be developed railway standards, such as IEC 63341-2: - shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11. - validation of fixations acc. to EN 12663-1, 6.5.2 - consideration of the deformation zones acc. to EN 15227, where components must not be arranged. - EMC tests acc. to EN 50121-3-2. It also requires an assessment of mechanical stress due to thermal expansion, especially with regards to longer pieces of pipes, in order to avoid mechanical stress on pipes, fittings and components. The minimum allowable residual pressure of large heavy duty tanks is defined with 2 bar acc. to EU 406, which is too low for Type 4 tanks and may lead to damages of the liner. The integrator needs to be aware of this characteristic and provide vehicle side protection measures to avoid deep discharge. Type 1 to 3 tanks are not affected.
6	EU 406/2010	C1 C2 C3 C4 C7 C8 C10 C12 C16	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Tightness of tanks and components and their media compatibility under the given operating conditions is sufficiently proven by EC 79 type approval. Adopting components with EC 79 type approval requires a comparison with the boundary conditions of railway application and closure of these gaps with additional tests and design rules from existing and still to be developed railway standards, such as IEC 63341-2: - shock and vibration tests acc. to EN 61373 including

Table 7: Applicable RCS from other industries

No.	Standard	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				function tests acc. to EN 50155, 13.4.11. - validation of fixations acc. to EN 12663-1, 6.5.2 - consideration of the deformation zones acc. to EN 15227, where components must not be arranged. - EMC tests acc. to EN 50121-3-2. It also requires an assessment of mechanical stress due to thermal expansion, especially with regards to longer pieces of pipes, in order to avoid mechanical stress on pipes, fittings and components. The minimum allowable residual pressure of large heavy duty tanks is defined with 2 bar acc. to EU 406, which is too low for Type 4 tanks and may lead to damages of the liner. The integrator needs to be aware of this characteristic and provide vehicle side protection measures to avoid deep discharge. Type 1 to 3 tanks are not affected.
	EU 2021/535	C7	High	EU 2021/535 regulates the type approval for road vehicles and does not apply for railway vehicles. It requires materials of the hydrogen storage system to be compatible with hydrogen by refering to several international and north american standards. For metallic materials it refers to test according ISO 11114-4. It closes the gap from R134 after withdrawal of EC79, since R134 does not specify requirements for hydrogen compatibility.
7	EN 1127-1	C10	High	EN 1127-1 defines the term "enhanced tightness" in clause 3.2 and Annex B, meaning that an installation does not permeate or leak sufficient amounts of medium to create an explosion zone under all operating conditions, which is the basic design goal of any hydrogen installation.
	EN 1779	C9	High	EN 1779 provides a number of leak testing methods and their criteria for correctly choosing the right method. It serves to choose and conduct the correct leak testing methods after assembly, maintenance or during regular inspection in order to avoid leaks in operation.
	EN 17124	C6	Low	EN 17124 defines methods how to check the quality of the hydrogen especially used with PEM-fuel cells and delivers also some information about the effect of impurities. It serves for availability and reliability of the power generation function of the fuel cells rather than mitigating a safety hazard.
8	EN 17127	C16 C17	Medium	EN 17127 defines requirements for hydrogen refuelling of road vehicles at pressures of 350 bar and 700 bar, for vehicles with EC 79 or R 134 type approved tanks and a maximum mass flow of 120 g/s. For the refuelling protocol the standard refers to SAE J2601-1 (not

Table 7: Applicable RCS from other industries

No.	Standard	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				applicable for railways), for the communication protocol to SAE J2799 and for the dispenser to ISO 17268. This communication protocol includes safety related stop signals in case of any criticality, such as over pressure or over temperature.
9	ISO 17268	C17	Low	ISO 17268 provides a comprehensive set of requirements for safe and reliable design of refuelling connectors. The current state of the art in railway application foresees different connectors, which are not in the scope of ISO 17268, that foresee a larger bore than the H35HF to allow higher flow rates for fast refuelling. These connectors are not compatible with EN 17127 and SAE J2601-1 / 2.
10	EN 60068-2-11	C8	High	EN 60068-2-11 provides a test method for salt spray testing of components. This test can be applied on specific sensitive components and materials, which may corrode due to salty air (e.g., operation close to sea)
11	IEC 60079-10-1	C10 C15	High	IEC 60079-10-1 comprehensively provides rules for definition of zones with explosive atmospheres, assess releases, assess dilution and ventilation and define the topological limits of a zone. It contains additional information for the assessment of hydrogen in an informative Annex H, which makes reference to ISO/TR 15916.
12	IEC 60529	C8	High	EN 60529 provides test methods and classifications for tightness degree of component housings and enclosures. It may be applicable to electrical components, such as batteries or control units but is rather unlikely for hydrogen components due to the need to active and passive ventilation.
	ISO 11114-1	C7	High	ISO 11114-1 applies to the compatibility of metal tanks and valves in contact with gases. It provides a list of gases and metals for tanks and valves, which are compatible with each other or require additional measures. The application of this standard provides basic material integrity with regards to hydrogen compatibility, especially with regards to pipes, fittings and valves, which are in contact with hydrogen.
	ISO 11114-2	C7	High	ISO 11114-2 applies to the compatibility of non-metallic materials, such as gaskets, in contact with gases. It provides a list of gases and plastics and elastomers, which are compatible with each other or require additional measures. The application of this standard provides basic material integrity with regards to hydrogen compatibility, especially with regards to gaskets inside any fittings, valves or flexible tubes, which are in contact with hydrogen.

Table 7: Applicable RCS from other industries

No.	Standard	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
	ISO 11114-4	C7	High	ISO 11114-4 provides test methods for steels that resist hydrogen embrittlement. The application of this standard provides basic material integrity with regards to hydrogen compatibility, especially with regards to pipes fittings and valves, which are in contact with hydrogen.
	ISO 11114-5	C7	High	ISO 11114-5 provides test methods for testing the integrity of plastic liners inside hydrogen tanks (Type 4). This new standard will become a mandatory validation method for liners of any type 4 tank and will serve to mitigate the probability of leakages.
13	ISO 14687	C6	High	ISO 14687 defines purities and test methods for different use cases of hydrogen (for gaseous hydrogen and PEM fuel cells in mobile application Type 1 D applies).
14	ISO 19453-6	C4	High	Shock and vibration testing acc. to ISO 19453-6 is typically used in the automotive industry. It is possible to assess conformity to IEC 61373 based on the test profile. However, IEC 61373 is more conservative in shock impulse, which lasts for 30 ms instead of 6 ms. If ISO 19453-6 test is combined with shock impulses of 30 ms in the shock test, it fully covers IEC 61373.
15	ISO 19880-1	C16 C17	Medium	ISO 19880-1 defines requirements for hydrogen refuelling of road vehicles at pressures of 350 bar and 700 bar. For the refuelling protocol the standard refers to SAE J2601-1 (not applicable for railways) and SAE J2601-2 (not prescriptive), for the communication protocol to SAE J2799 and for the dispenser to ISO 17268. This communication protocol includes safety related stop signals in case of any criticality, such as over pressure or over temperature.
	ISO 20485	C9	High	ISO 20485 provides rules and instructions for several leak testing methods, such as the sniffer method in clause 9.6. It serves to apply proper leak testing methods after assembly, maintenance or during regular inspection in order to avoid leaks in operation.
16	ISO/TR 15916	C1 C2 C6 C7 C8 C9 C10 C11 C13 C15 C21	Medium	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.).
17	SAE J2601-1	C2 C16	Low	SAE J2601-1 defines refuelling protocols for road vehicles with tank sizes between 49.7 and 248.6 litres,

Table 7: Applicable RCS from other industries

No.	Standard	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
		C17 C18		refuelled at a maximum flow rate of 60 g/s up to 350 or 700 bar and with precooled hydrogen at -20 to -40 °C. It is not applicable for refuelling of railway application hydrogen storage systems due to their volume and the intention to refuel at ambient gas temperatures.
18	SAE J2601-2	C2 C16 C17 C18	Low	SAE J2601-2 provides general rules for refuelling of heavy-duty road vehicles with a nominal working pressure of 350 bar and a maximum flow rate of 120 g/s. It would apply for railway vehicles, but the standard does not yet provide validated protocols for ambient temperature refuelling of heavy duty and railway hydrogen storage systems. It specifies a minimum initial pressure of 5 bar for refuelling. The minimum allowable residual pressure of large heavy-duty Type 4 tanks typically higher (around 10 bar). The integrator needs to be aware of this characteristic and provide vehicle side protection measures to avoid deep discharge. Type 1 to 3 tanks are not affected.
19	SAE J2799	C16 C17	Low	SAE J2799 defines the communication interface between road vehicle and filling station with hydrogen couplings acc. to SAE J2600. It foresees infrared (IR) transmitter on both sides. The communication is also used to transmit safety related information and signals. The communication via IR emitters has not been validated with regards to functional safety and security according to railway standards. State of the art technologies for sensing gas temperatures inside heavy-duty hydrogen tanks do not deliver reliable values during the refuelling process, which currently puts the transmittance of safety related stopping signals at question.
	UN ECE R 10	C5	Medium	The ECE R 10 describes tests in order to proove the electromagnetic compatibility of vehicles and components used in vehicles. It is possible to assess fulfillment of the requirements from EN 50121-3-2 on component basis. Adopting components with R 10 type approval requires assessment with the requirements from EN 50121-3-2.
20	UN ECE R 134	C1 C2 C3 C4 C5 C7 C8 C10 C11 C12 C14	High	UN ECE R 134 will substitute EC 79/2009 and EU 406/2010 in the near future. However, the scope of R 134 is limited to the hydrogen tank and the directly attached safety components, such as solenoid valve, check valve and TPRD, while EC 79 has a wider scope an also includes pipework, fittings and components up to the filling receptacle. The requirements defined by R 134 for the tanks are similar to EU 406/2010 but testing is mostly done in sequences where the test sample must undergo several different stresses to reflect a characteristic conservative load profile in road

Table 7: Applicable RCS from other industries

No.	Standard	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
		C16 C18		application, which serve to reduce or avoid leakage of hydrogen and remain burst pressure over the tanks live. Tightness of tanks and components under the given operating conditions is sufficiently proven by R 134 type approval. However, R 134 does not raise any requirements for hydrogen compatibility. Adopting components with R 134 type approval requires a comparison with the boundary conditions of railway application and closure of these gaps with additional tests and design rules from existing and still to be developed railway standards, such as IEC 63341-2: - shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11. - validation of fixations acc. to EN 12663-1, 6.5.2 - consideration of the deformation zones acc. to EN 15227, where components must not be arranged. - EMC tests acc. to EN 50121-3-2. It also requires an assessment of mechanical stress due to thermal expansion, especially with regards to longer pieces of pipes, in order to avoid mechanical stress on pipes, fittings and components. The minimum allowable residual pressure of large heavy duty Type 4 tanks is not clearly defined. The integrator needs to be aware of this characteristic and provide vehicle side protection measures to avoid deep discharge. Type 1 to 3 tanks are not affected from this.

4.7. List of Hazards where no applicable RCS exist

The following topics were identified, where, as far as known, no RCS could be allocated.

Table 8: List of Hazards where no applicable RCS exist

No.	Cause	related Faults	Description of technical issue
1	C1 Fire / Ignition source (internal, external)	F1 Leakage F2 Vent F3 Burst	There is no RCS that requires component and vehicle manufacturers to consider the possibilities for the fire brigades to effectively extinguish a fire, such as a battery fire. The physical integration typically does not allow any effective firefighting. There is also no requirement to consider the hazard for fire fighters in case of an emergency.
2	C2 Thermal impact / over temperature	F1 Leakage F2 Vent F3 Burst F4 Overpressure F5 Overtemperature	There is no RCS that defines adequate measures to prevent hydrogen tanks from excessive sun radiation or heat dissipation.

Table 8: List of Hazards where no applicable RCS exist

No.	Cause	related Faults	Description of technical issue
3	C11 Improper electrical design (including functional safety of E/E/PE systems)	F1 Leakage F2 Vent F12 Spark generation F14 Insufficient Ventilation	There is no RCS that defines requirements how to validate the correct placement of H2-Sensors inside a confined space. It is unclear which boundary conditions shall be tested or simulated to cover all potential operational situations. This is an important aspect when H2 sensors have a certain safety relevance as a result from the risk analysis and require functional safety analysis.
4	C15 Clogging / aerodynamic effects	F14 Insufficient Ventilation	There is no RCS that clearly defines measures to foresee inspection and cleaning of any ventilation system, especially when a tank system is placed inside a confined space.
5	C16 Over filling	F1 Leakage F2 Vent F3 Burst F4 Overpressure F5 Overtemperature	There is no RCS that adequately prevents heavy duty tank systems from over filling, especially when refuelling at ambient gas temperature is foreseen.
6	C17 Excessive mass flow	F1 Leakage F4 Overpressure F5 Overtemperature	There is no RCS that adequately prevents heavy duty tank systems from being refuelled with too high mass flows, which may lead to hot spots at the plastic liners of Type 4 tanks, especially when refuelling at ambient gas temperature is foreseen.
7	C18 Deep discharge	F1 Leakage F4 Overpressure F5 Overtemperature	There is no RCS that adequately prevents fast refuelling of Type 4 tanks with an SOC of less than 10 to 20 %. This may lead to liner damage and consequently leakage if not detected. Additionally, there is a risk of higher temperatures during fast refuelling at ambient gas temperatures of heavy-duty tanks as the temperature development increases with low SOCs.

Table 8: List of Hazards where no applicable RCS exist

No.	Cause	related Faults	Description of technical issue
8	C19 Falling Objects	F1 Leakage F3 Burst F6 Component defect F9 Loss of electrical isolation F10 Loss of mechanical integrity F11 Loud noise	There is no RCS that adequately prevents or limits damage to the hydrogen system from falling objects (e.g., object thrown from a bridge, branch hanging from a tree), especially when mounted on the roof of under floor (e.g., objects being catapulted against components).
9	C20 Vandalism / Terrorism	F1 Leakage F2 Vent F3 Burst F6 Component defect F9 Loss of electrical isolation F10 Loss of mechanical integrity F11 Loud noise F14 Insufficient Ventilation	There is no RCS that adequately protects a hydrogen system from vandalism or terrorism (including cyber-attacks). It requires a security assessment due to potential catastrophic consequence.

5. Conclusion

5.1. Summary of Findings

From the findings listed in section 4 of this report, it can be concluded that the existing electrical European standards, such as EN 50121-3-1 and 2, EN 50153 or EN 50155 adequately mitigate a wide range of hazard causes, especially with regards to flaws in the electrical design, functional integrity, or suitability for railway environment.

With only a few identified gaps, this also applies to the design standard IEC EN 62928 for Onboard lithium-ion traction batteries in rolling stock. This fairly new standard forms the blueprint for future standards for components of the FCHPP and gives an outlook how IEC 63341-1, IEC 63341-2 and IEC 63341-3 for FCS and HSS might close most of the existing gaps.

The TSI LOC&PAS currently reveals a large number of gaps for the assessment of an FCHPP in a locomotives or passenger rolling stock. This does not just apply for purely hydrogen related topics, such as Hydrogen Compatibility, Refuelling and Leak tight design, but also for the basic electrical and railway suitability requirements, such as EMC, shock and vibration, functional and electrical safety of sensitive components, etc.

The existing regulations for type approval of automotive hydrogen systems and components, such as EC 79/2009 and UNECE R 134 provide an adequate level of basic safety and can be adopted in railways in combination with railway suitability standards, mainly EN 50155. The Pressure Equipment Directive (PED) instead reveals gaps in the framework of harmonized standards, which complicates a conformity assessment for Notified Bodies of PED.

In numbers, a total of 56 Regulations, Codes and Standards (RCS) have been allocated 200 times to 22 generic hazard causes.

- 13 Railway RCS were identified that require no modification as they adequately mitigate the related hazards, when applied.
- 13 Railway RCS were identified that require modification in order to achieve an acceptable mitigation.
- 30 Other RCS were identified that are partially suitable to mitigate the related hazards, however with some implications or constraints, that require amendment by railway RCS, such as EN 50155.

Additionally:

- 9 Technical issues have been identified where no applicable RCS exist.

If no applicable RCS exists and the requirement is not entirely specific but more generic generating a new standard or amending existing ones might be appropriate. This applies for the identified gaps regarding hydrogen refuelling since these aspects will be key for an economic and successful application of the new technology.

But there is no explicit need to have a standard at hand to fulfil a requirement, it can be fulfilled just as defined. In this case the verification of the fulfilment is more demanding for the applicant.

5.2. Next Steps

There is one more issue of this LGA intended which will be released after the Demonstrator Trials have been finished and return of experience has been documented (details see chapter 1.3).

The next issue will, among other inputs, incorporate the documentation that is generated after demonstrator trials in the analysis of further gaps. In parallel it is planned to analyse the suitability for mitigation of further non-railway RCS from the list in appendix II. The next issue will also incorporate any feedback from CAF and the other stakeholders of the FCH2RAIL-Project on this report.

TÜV SÜD Rail GmbH

Berlin, 2022-09-23

Department Manager
Health, Environmental Safety, Incident

Digital unterschrieben von Corinna Trettin
Datum: 2022.09.23 09:27:50 +02'00'

M.Sc. Corinna Trettin

Project Manager / Senior Assessor

Tolga Wichmann
2022.09.23
09:00:05 +02'00'

M.Eng. Tolga Wichmann

6. Appendices

I **List of Generic Hazards, Faults and Causes**

II **List of input Regulations, Codes and Standards**

III **Analysis for Suitability of applicable RCS**

IV **List Railway RCS without need for modification**

V **List Railway RCS with need for modification**

VI **List of applicable RCS from other industries**

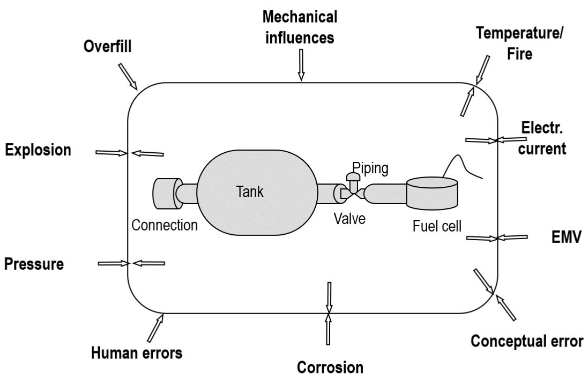
VII **List of Hazards where no applicable RCS exists**

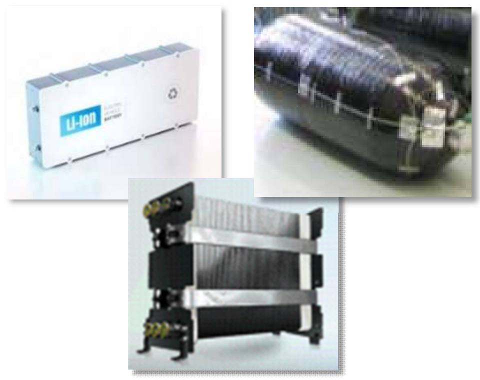
I List of generic Hazards, Faults and Causes

Hazard ID	**Main Generic Hazards:**	Related Faults:
H1	Fire hazards	F1, F2, F6, F7, F8, F9, F12
H2	Explosion hazards	F1, F2, F4, F5, F6, F12, F14
H3	Pressure related hazards	F3, F4, F5, F6, F10
H4	Electrical hazards	F7, F8, F9, F12
H5	Health related hazard	F5, F11, F13

Fault ID	**Generic Faults:**	Related Causes:
F1	Leakage	C1 to C4, C6 to C10, C12, C16 to C20
F2	Vent	C1, C2, C9, C16, C20
F3	Burst	C1, C2, C7, C10, C12, C16, C19, C20
F4	Overpressure	C1, C2, C3, C11, C16, C17
F5	Overtemperature	C1, C2, C13, C16, C17
F6	Component defect (other than tanks)	C1 to C16, C19, C20, C22
F7	Output over voltage / over current	C5, C11, C13, C14
F8	Internal Short circuit	C1, C2, C3, C4, C9, C10, C11, C12, C13, C14, C18
F9	Loss of electrical isolation	C1, C4, C8, C9, C10, C11, C12, C13, C14, C19, C20, C21
F10	Loss of mechanical integrity (not pressure related)	C1, C2, C3, C4, C7, C8, C9, C10, C12, C19, C20
F11	Loud noise (caused by a leak)	C1, C2, C4, C9, C12, C16, C19, C20
F12	Spark generation	C5, C11, C12, C13, C14, C21
F13	Degassing / Thermal Runaway (of batteries)	C1, C2, C3, C4, C9, C10, C11, C12, C13, C14, C18, C19
F14	Insufficient Ventilation	C11, C15, C20, C22

Cause ID	**Generic Causes:**
C1	Fire / Ignition source (internal, external)
C2	Thermal impact / over temperature
C3	Cold impact / under temperature
C4	Operational shock / vibration
C5	Electro magnetic emission / interference
C6	Hydrogen purity / particle ingress
C7	Hydrogen incompatibility
C8	Corrosion (dusts, aerosols, humidity, chemicals)
C9	Human error (manufacturing, operation, maintenance)
C10	Improper mechanical design
C11	Improper electrical design (including functional safety of E/E/PE systems)
C12	Crash / Derailment / mechanical impact
C13	External short circuit / arcing
C14	Input over voltage / over current
C15	Clogging / aerodynamic effects (of natural or forced ventilation)
C16	Over filling / charging
C17	Excessive mass flow
C18	Deep discharge
C19	Falling Objects
C20	Vandalism / Terrorism
C21	Residual voltage
C22	Wear, poor / improper maintenance





II List of input Regulation, Codes and Standards

T = Test standard
D = Design standard
P = Process / Quality standard
L = Legislation

No.	Standard	Title	Date	Topic	Category (T / D / P / L)	Railway application	Analysed	Ref. SRR from Hazard Log
1	1999/92/EG	DIRECTIVE 1999/92/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 1999 on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres	1999-12-16	ATEX	L		yes	
2	2006/42/EC	DIRECTIVE 2006/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006 on machinery, and amending Directive 95/16/EC	2006-05-17	Machine Directive	L		yes	
3	2010/35/EU	DIRECTIVE 2010/35/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 June 2010 on transportable pressure equipment	2010-06-16	Pressure Equipment	L			
4	2014/30/EU	DIRECTIVE 2014/30/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility (recast)	2014-03-29	Electrical Safety	L		yes	
5	2014/34/EU	DIRECTIVE 2014/34/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres	2014-02-26	ATEX	L		yes	
6	2014/68/EU	DIRECTIVE 2014/68/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 May 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment	2014-05-15	Pressure Equipment	L		yes	
7	AD 2000-Rules Framework (Germany)	Das AD 2000-Regelwerk konkretisiert alle grundlegenden Sicherheitsanforderungen, die nach der europäischen Druckgeräterichtlinie (DGRL) beachtet werden müssen	2020	Pressure Equipment	D			
8	ANSI / NACE TM0284	Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen Induced cracking.	2016	Piping	D			
9	ANSI C18.2M, Part 1	Portable Rechargeable Cells and Batteries - General and Specifications	2019	Battery	D			
10	ANSI C18.2M, Part 2	Portable Rechargeable Cells and Batteries - Safety Standards	2021	Battery	D			
11	ANSI HGV 2	Compressed Hydrogen Gas Vehicle Fuel Containers	2021	Containers	D			
12	ANSI HGV 3.1	Fuel System Components for Compressed Hydrogen Powered Vehicles	2015-02	Fuel Systems	D			
13	ANSI HGV 3.1	Fuel system components for compressed hydrogen gas powered vehicles	2015-02	Fuel Systems	D			
14	ANSI/CSA America FC 3	Portable Fuel Cell Power Systems	2004-01	Fuel Cells	D			
15	ANSI/CSA CHMC 1	Test Method for Evaluating Material Compatibility in Compressed Hydrogen Applications - Metals	2014	Hydrogen Compatibility	T			
16	ANSI/CSA HGV 4.10	Fittings for Compressed Hydrogen Gas and Hydrogen Rich Gas Miyestures	2020	Fittings	D			
17	ANSI/CSA HPRD 1	Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	2021	TPRD	D			
18	API RP 941	Steels for Hydrogen Service at Elevated Temperatures and Pressures	2020	Hydrogen Compatibility	D			
19	ASME B31.12	Hydrogen Piping and Pipelines - ASME Code for Pressure Piping	2019	Piping	D			
20	ASME B31.3	Process Piping	2018-01	Piping	P			
21	ASTM F1387-99	Standard Specification for Performance of Piping and Tubing Mechanically Attached Fittings	2012-01	Piping	D			
22	ASTM G129	Standard Practice for Slow Strain Rate Testing to Evaluate the Susceptibility of Metallic Materials to Environmentally Assisted Cracking	2021	Hydrogen Compatibility	T			
23	BGV D2	Working on Gas Pipelines	1988	Workers Safety	D			
24	CAN/CSA C22.2 No. 62282-2	Fuel cell technologies - Part 2: Fuel cell modules	2018-03	Fuel Cells	D			
25	CGA S-1.1	Pressure Relief Device Standards - Part 1: Cylinders for Compressed Gases	2019-01	Containers	D			
26	CGA TB-25	Design Considerations for Tube Trailers	2013-01	Tube trailers	D			
27	EC 79/2009	REGULATION (EC) No 79/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 January 2009 on type-approval of hydrogen-powered motor vehicles, and amending Directive 2007/46/EC	2009-01-14	Hydrogen Vehicles	L		yes	001, 046, 074
28	EN 1127-1	Explosive atmospheres - Explosive prevention and protection - Part 1: Basic concepts and methodology	2019	Explosion Protection	D		yes	001, 009, 074
29	EN 12245	Transportable gas cylinders – Fully wrapped composite cylinders;	2022	Container and assemblies	D			
30	EN 12663-1	Railway applications - Structural requirements of railway vehicle bodies - Part 1: Locomotives and passenger rolling stock	2010 A1: 2014 2015/prA2:2021	Mechanical Strength	D	yes	yes	001, 056, 111, 116, 117, 118
31	EN 13445-3	Unfired pressure vessels - Part 3: Design	2018	Containers	D			
32	EN 13480-1	Metallic industrial piping - Part 1: General	2017	Piping	D			
33	EN 1363-1	Fire resistance tests -- Part 1: General requirements	2021	Fire Safety	D	yes		
34	EN 15085-X	Railway applications - Welding of railway vehicles and components - series	2021	Mechanical Strength	D	yes	yes	
35	EN 15227	Railway applications - Crashworthiness requirements for rail vehicles	2020	Mechanical Strength	D	yes	yes	001, 116
36	EN 16404	Railway applications - Re-railing and recovery requirements for railway vehicles	2016	Rail System	D			
37	EN 17124	Hydrogen fuel - Product specification and quality assurance - Proton exchange membrane (PEM) fuel cell applications for road vehicles	2018	Fuel Cells	D			
38	EN 17124	Hydrogen fuel - Product specification and quality assurance - Proton exchange membrane (PEM) fuel cell applications for road vehicles	2018	Fuel Cells	T		yes	
39	EN 17127	Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols	2018	Refuelling	D		yes	
40	EN 1779	Non-destructive testing - Leak testing - Criteria for the method and technique selection	1999	Tightness Test	T		yes	
41	EN 45545-1	Railway applications - Fire protection on railway vehicles - Part 1: General	2013	Fire Safety	D	yes	yes	001, 023, 073, 137
42	EN 45545-2	Railway applications - Fire protection on railway vehicles - Part 2: Requirements for fire behaviour of materials and components	2020	Fire Safety	D	yes	yes	001, 023, 073, 137
43	EN 45545-3	Railway applications - Fire protection on railway vehicles - Part 3: Fire resistance requirements for fire barriers	2013	Fire Safety	D	yes	yes	001, 023, 073, 137
44	EN 45545-4	Railway applications - Fire protection on railway vehicles - Part 4: Fire safety requirements for rolling stock design;	2013	Fire Safety	D	yes	yes	001, 023, 073, 137
45	EN 45545-5	Railway applications - Fire protection on railway vehicles - Part 5: Fire safety requirements for electrical equipment including that of trolley buses, track guided buses and magnetic leviation vehicles	2013 A1:2015	Fire Safety	D	yes	yes	001, 023, 073, 137
46	EN 45545-6	Railway applications - Fire protection on railway vehicles - Part 6: Fire control and management systems	2013	Fire Safety	D	yes	yes	001, 023, 073, 137
47	EN 45545-7	Railway applications - Fire protection on railway vehicles - Part 7: Fire safety requirements for flammable liquid and flammable gas installations	2013	Fire Safety	D	yes	yes	001, 023, 073, 137
48	EN 50121-3-1	Railway applications - Electromagnetic compatibility - Part 3-1: Rolling stock - Train and complete vehicle	2015	Functional Safety	D	yes	yes	001, 101
49	EN 50121-3-2	Railway applications - Electromagnetic compatibility - Part 3-2: Rolling stock - Apparatus	2016	Functional Safety	T	yes	yes	001, 101
50	EN 50122-1	Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 1: Protective provisions against electric shock	2017	Electrical Safety	D	yes	yes	
51	EN 50124-1	Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment	2017	Electrical Safety	D	yes	yes	145
52	EN 50124-2	Railway applications - Insulation coordination - Part 2: Overvoltages and related protection	2017	Electrical Safety	T	yes	yes	
53	EN 50125-1	Railway applications - Environmental conditions for equipment - Part 1: Rolling stock and on-board equipment	2014	Functional Safety	D	yes	yes	001
54	EN 50126-1	Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1: Generic RAMS Process	2017	Functional Safety	P	yes		
55	EN 50126-2	Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 2: Systems Approach to Safety	2017	Functional Safety	P	yes		

No.	Standard	Title	Date	Topic	Category (T / D / P / L)	Railway application	Analysed	Ref. SRR from Hazard Log
56	EN 50128	Railway applications - Communication, signalling and processing systems - Software for railway control and protection systems	A2:2020	Functional Safety	P	yes	yes	
57	EN 50129	Railway applications - Communication, signalling and processing systems - Safety related electronic systems for signalling	2018 AC:2019	Functional Safety	P	yes	yes	
58	EN 50153	Railway applications - Rolling stock - Protective provisions relating to electrical hazards	2014/A2:2020	Electrical Safety	D	yes	yes	001, 100, 143
59	EN 50155	Railway applications - Rolling stock - Electronic equipment	2017	Functional Safety	T	yes	yes	
60	EN 50156-1	Electrical equipment for furnaces and ancillary equipment - Part 1: Requirements for application design and installation	2016	Electrical Safety	D			
61	EN 50163	Railway applications - Supply voltages of traction systems	2004/A2:2020	Electrical Safety	D	yes		
62	EN 50215	Railway applications - Rolling stock - Testing of rolling stock on completion of construction and before entry into service	2010	Commissioning	T	yes	yes	
63	EN 50343	Railway applications - Rolling stock - Rules for installation of cabling	2014 A1:2017	Electrical Safety	D	yes	yes	
64	EN 50547	Railway applications - Batteries for auyesiliary power supply systems	2013	Battery	D	yes		
65	EN 50553	Railway applications - Requirements for running capability in case of fire on board of rolling stock	2012/A2:2020	Fire Safety	D	yes		136
66	EN 60068-2-11	Environmental testing - Part 2: Tests; test Ka: Salt mist	1999	Electrical Safety			yes	
67	EN IEC 62619	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications	2022	Battery	D		yes	
68	EN IEC 62620	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for use in industrial applications	2015	Battery	D			
69	EN IEC 62660-2	Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 2: Reliability and abuse testing	2019	Battery	T			
70	EN IEC 62660-3	Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 3: Safety requirements	2017	Battery	D			
71	EN IEC 62864-1	Railway applications - Rolling stock - Power supply with onboard energy storage system - Part 1: Series hybrid system	2016	Battery	D	yes		
72	EN IEC 62928	Railway applications - Rolling stock - Onboard lithium-ion traction batteries	2018	Battery	D	yes	yes	
73	EN ISO 20485	Dichtheitsprüfung - Prüfgasverfahren	2018-05-01	Leackage	T			
74	EU 1299/2014	Commission Regulation (EU) No 1299/2014 of 18 November 2014 on the technical specifications for interoperability relating to the 'infrastructure' subsystem of the rail system in the European Union	2014-11-18	Rail system	L	yes		120
75	EU 1302/2014	COMMISSION REGULATION (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the 'rolling stock — locomotives and passenger rolling stock' subsystem of the rail system in the European Union	2020-03-11	Rail System	L	yes	yes	
76	EU 1303/2014	COMMISSION REGULATION (EU) No 1303/2014 of 18 November 2014 concerning the technical specification for interoperability relating to 'safety in railway tunnels' of the rail system of the European Union	2019-06-16	Rail System	L	yes		
77	EU 2015/1136	COMMISSION IMPLEMENTING REGULATION (EU) 2015/1136 of 13 July 2015 amending Implementing Regulation (EU) No 402/2013 on the common safety method for risk evaluation and assessment	2015-07-14	Rail System	L			
78	EU 2016/797	DIRECTIVE (EU) 2016/797 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 May 2016 on the interoperability of the rail system within the European Union	2016-05-11	Rail System	L	yes		
79	EU 2021/535	COMMISSION IMPLEMENTING REGULATION (EU) 2021/535 of 31 March 2021 laying down rules for the application of Regulation (EU) 2019/2144 of the European Parliament and of the Council as regards uniform procedures and technical specifications for the type-approval of vehicles, and of systems, components and separate technical units intended for such vehicles, as regards their general construction characteristics and safety	2021-04-06	Hydrogen Compatibility	L		yes	
80	EU 406/2010	COMMISSION REGULATION (EU) No 406/2010 of 26 April 2010 implementing Regulation (EC) No 79/2009 of the European Parliament and of the Council on type-approval of hydrogen-powered motor vehicles	2010-04-26	Hydrogen Vehicles	L		yes	
81	GTR 13	Global technical regulation on hydrogen and fuel cell vehicles	2013-07	Hydrogen Vehicles	D			
82	IEC 60077-1	Railway applications - Electric equipment for rolling stock - Part 1: General service conditions and general rules	2017	Electrical Safety	D	yes		
83	IEC 60079-10-1	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres - Edition 3.0	2020	Explosion Protection	D		yes	018
84	IEC 60529	Degrees of protection provided by enclosures (IP Code)	1989 A1:1999 A2:2013	Railway Suitability	T		yes	
85	IEC 60730-1 + AMD1	Automatic electrical controls - Part 1: General requirements	2015	Battery	D			
86	IEC 60730-2-14	Automatic electrical controls - Part 2-14: Particular requirements for electrical actuators	2017	Battery	D			
87	IEC 60730-2-15	Automatic electrical controls - Part 2-15: Particular requirements for automatic electrical air flow, water flow and water level sensing controls	2017	Battery	D			
88	IEC 60730-2-6	Automatic electrical controls - Part 2-6: Particular requirements for automatic electrical pressure sensing controls including mechanical requirements	2016	Battery	D			
89	IEC 60730-2-9	Automatic electrical controls - Part 2-9: Particular requirements for temperature sensing control	2016	Battery	D			
90	IEC 60952-2	Aircraft batteries - Part 2: Design and construction requirements	2013	Battery	D			
91	IEC 61373	Railway applications - Rolling stock equipment - Shock and vibration tests	2010	Mechanical Strength	T	yes	yes	001
92	IEC 62282-2-100	Fuel cell technologies - Part 2-100: Fuel cell modules - Safety	2020	Fuel Cells	D			
93	IEC 62282-3-100	Fuel cell technologies - Part 3-100: Stationary fuel cell power systems - Safety	2019	Fuell Cells	D			
94	IEC 62282-3-200	Fuel cell technologies - Part 3-200: Stationary fuel cell power systems - Performance test methods	2015	Fuell Cells	T			
95	IEC/WD 63341-1	Railway applications_Fuel Cell_Part1_Fuel cell Power System	not published yet	Fuel Cells	D	yes		014, 018, 065, 066, 068
96	IEC/WD 63341-2	Railway applications_Fuel Cell System Part2 Hydrogen Storage System	not published yet	Fuel Cells	D	yes		032, 038
97	IEEE 1478	IEEE Standard for Environmental Conditions for Transit Railcar Electronic Equipment	2013	Electrical Safety	D	yes		
98	ISO 11114-1	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 1: Metallic materials	2020	Hydrogen Compatibility	D		yes	
99	ISO 11114-2	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 2: Non-metallic materials	2022	Hydrogen Compatibility	D		yes	
100	ISO 11114-4	Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 4: Test methods for selecting steels resistant to hydrogen embrittlement	2017	Hydrogen Compatibility	T		yes	
101	ISO 11114-5	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 5: Test methods for evaluating plastic liners	2022	Hydrogen Compatibility	T		yes	
102	ISO 11623	Gas cylinders - Composite construction - Periodic inspection and testing (ISO 11623:2015)	2017	Containers	T			
103	ISO 12405-4	Electrically propelled road vehicles - Test specification for lithium-ion traction battery packs and systems - Part 4: Performance testing	2018-07	Battery	T			
104	ISO 12619-1	Road vehicles - Compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blend fuel system components - Part 1: General requirements and definitions	2014	Fuel Systems	D			
105	ISO 12619-12	Road vehicles - Compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blends fuel system components - Part 12: Gas-tight housing and ventilation hoses	2017	Hydrogen Systems	D			
106	ISO 14687	Hydrogen fuel quality - Product specification	2019	Hydrogen Quality	P		yes	
107	ISO 15649	Petroleum and natural gas industries - Piping	2001	Piping	D			
108	ISO 17268	Gaseous hydrogen land vehicle refuelling connection devices	2017	Filling	D		yes	085
109	ISO 19453-6	Road vehicles - Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles - Part 6: Traction battery packs and systems	2020	Battery			yes	
110	ISO 19880-1	Gaseous hydrogen - Fuelling stations - Part 1: General requirements	2020	Filling	D		yes	
111	ISO 19880-8	Gaseous hydrogen - Fuelling stations - Part 8: Fuel quality control	2019	Hydrogen Quality	P			
112	ISO 19881	Gaseous hydrogen - Land vehicle fuel containers	2018	Containers	D			
113	ISO 19882	Gaseous hydrogen - Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	2018	TPRD	T			
114	ISO 20485	Non-destructive testing - Leak testing - Tracer gas method	2018	Tightness Test	T		yes	

No.	Standard	Title	Date	Topic	Category (T / D / P / L)	Railway application	Analysed	Ref. SRR from Hazard Log
115	ISO 21087	Gas analysis - Analytical methods for hydrogen fuel - Proton exchange membrane (PEM) fuel cell applications for road vehicles	2019	Fuel Cells	D			
116	ISO 21266-1	Road vehicles - Compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blends fuel systems - Part 1: Safety requirements	2018	Fuel Systems	D			
117	ISO 23273	Fuel cell road vehicles - Safety specifications - Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen	2013	Hydrogen Vehicles	D			
118	ISO 24431	Gas cylinders - Seamless, welded and composite cylinders for compressed and liquefied gases (excluding acetylene) - Inspection at time of filling	2016	Containers	P			
119	ISO 4126-1	Safety devices for protection against excessive pressure - Part 1: Safety valves	2013/A2:2019	Safety valves	D			
120	ISO/TR 15916	Basic considerations for the safety of hydrogen systems	2015	Hydrogen Systems	D		yes	001, 003, 005, 011, 023, 029, 042, 059, 062, 063, 064, 065
121	ISO/TR 20491	Fasteners - Fundamentals of hydrogen embrittlement in steel fasteners	2019	Hydrogen Compatibility	D			
122	NFPA 130	Fiyesed Guideway Transit and Passenger Rail Systems	2020-01	Passenger Safety / Rail System	D	yes		
123	NFPA 2	Hydrogen Technologies Code	Revised and published in 2019 (dated 2020)	Hydrogen Systems	D			
124	NFPA 55	Compressed Gases and Cryogenic Fluids Code - Chapter 10 Gas Hydrogen Systems	Published 2019 (dated 2020).	Hydrogen fuel	P			
125	SAE J2464	Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing	2021	Battery	T			
126	SAE J2517	Performance Test Procedure of PEM Fuel Cell Stack Subsystem for Automotive Application	2016	Fuel Cells	T			
127	SAE J2572	Recommended Practice for Measuring Fuel Consumption and Range of Fuel Cell and Hybrid Fuel Cell Vehicles Fueled by Compressed Gaseous Hydrogen	2014-10	Hydrogen Vehicles	P			
128	SAE J2574	Fuel Cell Vehicle Terminology	2011-09	Fuel Cells	D			
129	SAE J2579	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles	2018-09	Fuel Cells	D			
130	SAE J2600	Compressed Hydrogen Surface Vehicle Fueling Connection Devices	2015-10	Filling	D			
131	SAE J2601-1	Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles	2020-05	Hydrogen Vehicles	D		yes	
132	SAE J2601-2	Fuelling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles	2014	Filling	D		yes	
133	SAE J2615	Testing Performance of Fuel Cell Systems for Automotive Applications	2011-10	Fuel Cells	T			
134	SAE J2719	Hydrogen Fuel Quality for Fuel Cell Vehicles	2020-03	Hydrogen fuel	P			
135	SAE J2799	Hydrogen Surface Vehicle to Station Communications Hardware and Software	2019	Functional Safety	D		yes	
136	SAE J2929	Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells	2013-02	Battery	D			
137	TRGS 722	Technische Regeln für Gefahrstoffe - Vermeidung oder Einschränkung gefährlicher explosionsfähiger Gemische	2021-02-01	Explosion Protection	D			
138	UL 1642	Lithium Batteries	2020	Battery	D			
139	UL 1973	Batteries for Use in Stationary, Vehicle Auyesiliary Power and Light Electric Rail (LER) Applications	2018-02	Battery	D			
140	UL 1998	Standard for software in programmable components	2018-01	Functional Safety	D			
140	UL 991	Standard for Tests for Safety-Related Controls Employing Solid-State Devices	2004-10	Functional Safety	T			
141	UN ECE R 10	Regulation No 10 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility	2012-09-20	Fuel Cells	L		yes	
142	UN ECE R 134	Regulation No 134 of the Economic Commission for Europe of the United Nations (UN/ECE) - Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fuelled vehicles (HFCV)	2019-05-17	Hydrogen Vehicles	L		yes	
142	UN38.3	Recommendations on the Transport of dangerous goods	6th revised edition	Battery	L			

III Analysis for Suitability of applicable RCS in mitigating Triggers / Causes

			Mitigation				Evaluation	
No.	ID	Trigger / Cause	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	C1	Fire / Ignition source (internal, external)	EC 79/2009	Annex IV to VI	EC 79/2009 applies for hydrogen road vehicles only. In combination with its implementing directive EU 406/2010, it is one of the most comprehensive regulations for hydrogen components in mobile application and provides - in combination with existing railway standards - an acceptable level of safety for railways. EC 79 requires numerous tests for hydrogen tanks and components in annexes IV and V and provides additional design rules in annex VI. There are specific requirements that directly or indirectly serve for protection against external fire sources, such as bonfire test for tanks with TPRDs and extreme temperature cycling tests. The detailed requirements are described in EU 406/2010.	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Adopting either one of them requires an assessment of the gaps with the boundary conditions from railway application and closing of these gaps with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-2.	Other RCS
2	C1	Fire / Ignition source (internal, external)	EU 406/2010	Annex IV, Parts 1 to 3, especially part 2, clauses 3.5. and 4.2.9. and part 3, clause 4.2.2.2.5.	EU 406/2010 is the implementing directive of the hydrogen road vehicle directive EC 79/2009. It is one of the most comprehensive requirements for hydrogen components in mobile application and provides - in combination with existing railway standards - an acceptable level of safety for railways. Design rules, tests, thresholds and pass fail criteria of gaseous compressed hydrogen tanks and components can be found in Annex IV, parts 1 to 3. Requirements for materials of hydrogen tanks, such as liner softening temperature, resin glass transition temperature are defined in chapter 3.5 of Annex IV, part 2. The bonfire tests is defined in chapter 4.2.4 and the extreme temperature cycling test (+85 °C to -40 °C) in chapter 4.2.9 of Annex IV, part 2. These tests directly serve to protect the tank from overpressure and burst due to heat and fire, with the trade off to create a several meter long upward directed hydrogen flame for several minutes. The TPRD triggering temperature is not defined but is generally, set at 110 °C with a tolerance of +/- 5 % acc. to chapter 4.2.2.2.5 of Annex IV, part 3. The location of TPRDs, TPRD vents and their triggering temperature require additional analysis when adopted in railway application. Further requirements and tests in Part 2 and 3 serve to reduce or avoid leakage of hydrogen from tank and components.	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Adopting either one of them requires an assessment of the gaps with the boundary conditions from railway application and closing of these gaps with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-2. Adopting TPRDs from automotive regulations requires assessment of the residual risks posed by their application, such as probability of unintended activation, breakage of life ports, activation by heat but without a flame, etc. This topic shall be discussed in the ongoing standardisation processes.	Other RCS
3	C1	Fire / Ignition source (internal, external)	UN ECE R 134	Chapters 5 to 7 and Annex 3 to 4	UN ECE R 134 will substitute EC 79/2009 and EU 406/2010 in the near future. However, the scope of R 134 is limited to the hydrogen tank and the directly attached safety components, such as solenoid valve, check valve and TPRD, while EC 79 has a wider scope an also includes pipework, fittings and components up to the filling receptacle. The requirements defined by R 134 for the tanks are similar to EU 406/2010 but testing is mostly done in sequences where the test sample must undergo several different stresses to reflect a characteristic conservative load profile in road application, which serve to reduce or avoid leakage of hydrogen and remain burst pressure over the tanks live. Transfering these test sequences to railways requires a more detailed analysis and comparison of load profiles. It is expected though that the safety level of tanks with an R 134 type approval provide at least the same level of safety compared to EC 79. The bonfire test is following a more conservative curve compared to EC 79. In combination with the tests for TPRDs, it directly serves to protect the tank from overpressure and burst due to heat and fire, with the trade off to create a several meter long upward directed hydrogen flame for several minutes. TPRDs shall protect the tank from overpressure when overheating and are mandatory without definition of a triggering temperature. They shall activate within 2 minuntes after application of a defined heat source (Annex 4, chapter 1.9). The location of TPRDs, TPRD vents and their triggering temperature require additional analysis when adopted in railway application.	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Adopting either one of them requires an assessment of the gaps with the boundary conditions from railway application and closing of these gaps with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-2. Adopting TPRDs from automotive regulations requires assessment of the residual risks posed by their application, such as probability of unintended activation, breakage of life ports, activation by heat but without a flame, etc. This topic shall be discussed in the ongoing standardisation processes.	Other RCS
4	C1	Fire / Ignition source (internal, external)	2006/42/EC	Annex 1, clause 1.5.6.	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1, especially 1.5 must be considered. Clause 1.5.6. generally, refers to fire hazard from the machine itself that shall be avoided, without being prescriptive.	Low	None	Other RCS
5	C1	Fire / Ignition source (internal, external)	ISO/TR 15916	all	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.). It provides guidance for fire protection throughout the complete document since hydrogen forms a combustible atmosphere in combination with air (3.6% LFL) and the components are sensitive to excessive heat and fire. It also includes the information that hydrogen is not flammable in a container because oxygen is missing.	Medium	None	Other RCS
6	C1	Fire / Ignition source (internal, external)	EN 45545-1	all	The general classifications (operation category, design category, etc.) also apply for hydrogen vehicles. With regards to running capability, the standard is limiting the running time of 4 or 15 minuten at 80 km/h to the maximum distances between two locations for safe evacuation, which corresponds with TSI. Since Lithium-Ion-Batteries and Tanks with compressed hydrogen have a high potential for catastrophic colleteral damage, an extended running time in a degraded mode is necessary to move the vehicle away from built-over areas, such as tunnels or roofed stations, to an area with sufficient distance from buildings and where fire brigades can reach the vehicle and reduce the extended impact of the incident as far as possible.	High	Running capability requirements in 5.2.3, Table 1 (harmonized with TSI LOC&PAS) currently do not reflect the time beyond evacuation of passengers and the catastrophic impact of a further developing fire on Traction Batteries and/or Hydrogen Storage Systems.	Modification
7	C1	Fire / Ignition source (internal, external)	EN 45545-2	all	Conformity to EN 45545-2 brings the probability of a propagating on board fire down to an acceptable minimum. The material requirements from EN 45545-2 are sufficiently generic and already successfully applied on existing FCPPs. In addition, the amount of combustible materials - except for the hydrogen tanks and the fuel cells - is fairly limited. In order to achieve clarity for the exact requirement sets to test e.g., for CRP hydrogen tanks, it would aid manufacturers and applicants to specifically mention them them in table 2.	High	No specific requirement set for typical combustible materials of an alternative propulsion system, such as CRP of Type 3 or Type 4 hydrogen tanks (currently fulfiling R9, acc. to clause 4.2 I), because samples for flame spread test cannot be produced from the cylindric tanks).	Modification
8	C1	Fire / Ignition source (internal, external)	EN 45545-3	Table 1	The fire barrier requirements from EN 45545-3 refer to Lithium-Ion-Batteries in the latest draft revision, but they do not sufficiently cover separations to hydrogen equipment. As hydrogen storage systems are sensitive to excessive heat, which may cause a venting of hydrogen to protect the tank from overpressure (the triggering temperature of TPRDs typically at 110 °C +/- 5 K) and at the same time a degrading structure of the tank, a protection from onboard fire sources is necessary. This applies to the integrity criterion E as well as the insulation criterion I. Further more, the structure that holds the tanks (e.g., car body roof) must not collapse under impact of a fire, even beyond the time needed to evacuate passengers (typically only 15 minutes) in order to avoid mechanical damage on the tanks and the piping. This fire barrier requirement shall also apply from the hydrogen storage to the passenger or staff area as there is a potential of an ignition of a hydrogen leak. A protection from external fire sources can be necessary, but depends on the individual risk analysis of the manufacturer and operator.	High	No specific requirement for hydrogen tank systems and its piping to protect it from onboard fires (optionally external fires), protect the structure (e.g., car body roof) from collapsing after extended heat impact, causing further critical damage on hydrogen tanks. No specific requirement for protection of passenger and staff areas from fires starting in the hydrogen tank system and its piping.	Modification
9	C1	Fire / Ignition source (internal, external)	EN 45545-5	5.2, 5.3, 5.4, 5.6, 6	The preventive fire safety requirements from EN 45545-5 for the electrical design of the high voltage and high-power equipment is generically written any applies also for alternative propulsion systems. The requirements for high-power cabling acc. to chapter 5.2 mainly apply to the vehicle. Requirements for ar protection acc. to chapter 5.3 applies to any high-power switch any may also apply to traction battery or fuel cell contactors. The requirements for auxiliary batteries and potentially explosive atmospheres in chapter 5.4 and 5.6 do not sufficiently reflect the specific features of the Lithium-Ion-Technology and Hydrogen Storage Systems. A reference to the existing code of practices, such as IEC 62928 and an update of chapters 5.4 and 5.6 would be necessary. Also fuel cells and hydrogen storage systems should be clearly mentioned inside the standard and a reference to the future standards IEC 63341-1 and IEC 63341-2 should be added. In addition, there is no requirement for electrical components to comply with shock and vibration requirements acc. to EN 61373 or alternatively fulfil railway suitability requirements of EN 50155. The requirements for maintainability in chapter 6 apply also for any component of an alternative propulsion system.	Medium	No consideration of Lithium-Ion-Batteries, Fuel Cells and Hydrogen Storage Systems as well as the corresponding railway application standards, which already exist. It does not require electrical components to comply with shock and vibration requirements acc. to EN 61373 or alternatively fulfil railway suitability requirements of EN 50155.	Modification
10	C1	Fire / Ignition source (internal, external)	EN 45545-6	5.2, 5.4	The requirements for fire detection from EN 45545-6 currently do not reflect the potential fire hazards from FCPPs. There no requirements for fuel cells, for traction batteries or (depending on risk analysis) for hydrogen storage systems with regards to fire detection (chapter 5.2) and their selective shut down upon fire detection (chapter 5.4). The foreseen functional measures should consider the behaviour of each component, e.g the consequence of a thermal runaway is reduced if liquid cooling equipment remains running as long as possible.	High	There is no consideration of Lithium-Ion-Batteries, Fuel Cells and Hydrogen Storage Systems with regards to fire detection and functional reaction upon fire detection.	Modification
11	C1	Fire / Ignition source (internal, external)	EN 45545-7	6	The requirements for flammable gas installations from EN 45545-7 is currently only partially applicable to hydrogen gas installations, since this standard was intended to address gasoline, petroleum, oil and natural gas installations and the corresponding tanks at much lower working pressures, e.g., for combustion engines, heating or cooking. It requires an extensive update or a reference to future standards, such as IEC 63341-1 and 2.	Low	The standard was not intended for hydrogen gas installations and requires a comprehensive update and normative references to future standards, such as IEC 63341-1 and 2.	Modification
12	C1	Fire / Ignition source (internal, external)	EN 50553	all	EN 50553 defines test and design requirements how to achieve the required running time with a fire on board. It is limited to TSI categories A and B, which means Operation Categories 2 and 3 acc. to EN 45545-1. The standard is limiting the running time of 4 or 15 minuten at 80 km/h to the maximum distances between two locations for safe evacuation, which corresponds with TSI. Since Lithium-Ion-Batteries and Tanks with compressed hydrogen have a high potential for catastrophic colleteral damage, an extended running time in a degraded mode is necessary to move the vehicle away from built-over areas, such a tunnels or roofed stations, to an area with sufficient distance from buildings and where fire brigades can reach the vehicle and reduce the extended impact of the incident as far as possible. In addition, EN 50553 limits the sources of a critical fire (Type 2 or Type 3) in technical areas to Diesel fuel systems and tanks as well as unprotected electrical lines. This definition requires an update to cover new hazards from Traction Batteries and Hydrogen Storage Systems connected with Fuel Cells or Combustion engines. The requirements to achieve running capability in the different decision boxes must be updated to cover the alternative propulsion systems and define new functional requirements, such as closure of On-Tank-Valves or opening of HV-battery switches.	High	Running capability requirements (defined by EN 45545-1 and TSI LOC&PAS) currently do not reflect the time beyond evacuation of passengers and the catastrophic impact of a further developing fire on Traction Batteries (TB) and/or Hydrogen Storage Systems (HSS). The definition of Type 2 and Type 3 fires (chapter 5.2) requires an update to cover new hazards from TB and HSS as well as Fuel Cells or Hydrogen Combustion Engines. The requirements to achieve conformity in the decision boxes (chapter 6) must be updated to cover the new technologies and define new functional requirements.	Modification
13	C1	Fire / Ignition source (internal, external)	EN 50155	11, 13	A major source of technical failures is malfunction caused by operational condition that go beyond the design criteria of the electrical / functional component. EN 50155 is a comprehensive standard covering all aspects of technical compatibility with the railway operational environment, such as climatic, environmental, mechanical and electrical aspects. This standard is also applied for mitigation of several other causes. It applies mainly to electric and electronic components.	High	None	No Modification
14	C1	Fire / Ignition source (internal, external)	IEC 61373	all	A potential source of technical failures is loosening, braking or displacement of mechanical or electrical connections due to shock and vibration. Improper electrical connections may lead to high contact resistance or arcing, improper mechanical connections may lead to leakage of flammable gases or malfunction of valves and components, which in its consequence can cause fires. Therefore, it is necessary to have all safety related components tested acc. to IEC 61373 and test their function acc. to chapters 6.3.2 and 8. However, the test procedure does not include any pressure or leakage tests as well as functional tests of mechanical safety components (e.g., Safety Valves, Excess Flow Valves) before and after the test. (EN 61373 is required by EN 50155)	High	The shock and vibration test is needed to test the mechanical integrity of racks and housings, hydrogen components and fittings as well as the function of mechanical or electro-mechanical safety components of the hydrogen gas system. The function test is only required by EN 50155 (chapter 13.4.11.3 and 13.4.11.4), hence testing acc. to IEC 61373 only, would not cover this aspect. In order to prove enhanced tightness (no leakage under all expectable operational stress scenarios), the entire gas system must undergo a functional inspection and a pressure and tightness test before and after the shock and vibration test, which is not part of IEC 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt IEC 61373 and EN 50155 and define additional requirements.	Modification
15	C1	Fire / Ignition source (internal, external)	EU 1302/2014	4.2.10.	The existing TSI for locomotives and passenger trains does not mention catenary free propulsion technologies other than Diesel engines. The requirements for fire safety and evacuation in chapter 4.2.10. are harmonized with EN 45545 but, with exception of EN 45545-2 and EN 50553, not as detailed and comprehensive as EN 45545 in all parts. In order to ensure an equal level of minimum safety, TSI LOC&PAS needs to be revised e.g., by adding a new requirements for alternative propulsion with traction batteries and or hydrogen (e.g., in chapter 4.2.10) and define a minimum set of safety requirements by referencing to existing and future standards, such as IEC 62928, IEC 63341-1, IEC 63341-2, etc. and harmonize with future revisions of EN 45545 and EN 50553.	Low	TSI LOC&PAS needs to be revised e.g., by adding new requirements for alternative propulsion with traction batteries and or hydrogen and define a minimum set of safety requirements by referencing to existing and future standards, such as IEC 62928, IEC 63341-1, IEC 63341-2, etc. Chapter 4.2.10, especially chapters 4.2.10.2.2. (to add requirements for hydrogen systems by referencing future IEC 63341-2), 4.2.10.3.4.(3) (to consider potential fire sources from new technologies, to be harmonized with EN 45545-3), 4.2.10.4.4. (to consider additional running time for vehicles with hydrogen or lithium-batteries, to be harmonized with EN 50553) and 6.2.3.23. (to add new fire risk areas from new technologies, to be harmonized with EN 45545-6)	Modification

			Mitigation				Evaluation	
No.	ID	Trigger / Cause	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
16	C1	Fire / Ignition source (internal, external)	EN IEC 62928	all	IEC 62928, especially with reference to IEC 62619, provides a comprehensive set of safety requirements for lithium-ion battery systems. Conformity to those requirements is considered as a basic safety evidence, provided that functional safety of the battery management system (for non-inherent safe batteries) is proven. With regards to the toxicity and flammability of the released gases during thermal runaway, neither IEC 62619 nor IEC 62928 define any limits or let alone any requirement for measurement of those. The pass fail criteria for the propagation test from IEC 62619, chapter 6.3.3 is limited to containment of flames but does not consider the flammability and toxicitiy of the emitted gases, which is an important aspect to determine the severity of potential hazards to passengers, uninvolved people or rescue forces (e.g., by simulation) in order to assess the required safety integrity of any battery management functions. In addition, there are no requirements defined to minimize the propagation by functional means (e.g., continuous on board cooling) and for fire fighting by rescue forces. Fire brigades need a reliable and safe confirmation that the batteries are diconnected from the rest of the vehicle before starting their fire attack. In addition, they need to know how to effectively cool the battery case or flood the battery case with water without endangering themselves. There are currently no requirements defined in any standard to support incident management when a thermal runaway has occurred. There are no requirements to provide basic information about location, handling, fire fighting and salvage of traction batteries to fire brigades.	High	Neither the measurement of the toxicity and flammability of released gases during thermal runaway, nor a limitation of such is defined in IEC 62928 or IEC 62619 respectively. There are no functional requirement to minimize propagation (e.g., by continuous on board cooling). There are no requirements to support incident management, e.g., by informing fire brigades about the installed technology and provide means for an immediate and effective fire attack.	Modification
17	C1	Fire / Ignition source (internal, external)	EN 50125-1	4.3, 4.9, 4.10	EN 50125-1 provides values for environmental conditions and limits the area of operation by classifying climate zones. Climatic conditions and influences, such as temperature, sun radiation and lightning strike may cause sensitive components, such as Lithium-Ion-Batteries with the potential to cause a thermal runaway under worst case climatic conditions defined by EN 50125-1 (see also operating temperature classes of EN 50155, chapter 4.3.2), to overheat, which must be considered in the technical design. (EN 50125-1 is referenced by EN 50155 and TSI LOC&PAS)	High	None	No Modification
18	C1	Fire / Ignition source (internal, external)	EN 45545-4	none	The preventive fire safety requirements from EN 45545-4 for the mechanical design of the car body mainly refer to the interior of the vehicle and the evacuation possibilities from the vehicle to the outside when there is a fire on board the train. The existence of an alternative propulsion system does not influence these requirements.	Medium	None	No Modification
19	C2	Thermal impact / over temperature	EC 79/2009	Annex IV to VI	EC 79/2009 applies for hydrogen road vehicles only. In combination with its implementing directive EU 406/2010, it is one of the most comprehensive regulations for hydrogen components in mobile application and provides - in combination with existing railway standards - an acceptable level of safety for railways. EC 79 requires numerous tests for hydrogen tanks and components in annexes IV and V and provides additional design rules in annex VI. There are generic material and type test requirements to prove tightness and integrity of the tanks within the given boundaries (temperature, pressure, cycles, etc.). The detailed requirements are described in EU 406/2010.	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Adopting either one of them requires an assessment of the gaps with the boundary conditions of railway application and closing of these gaps with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-2.	Other RCS
20	C2	Thermal impact / over temperature	EU 406/2010	Annex IV, Parts 1 to 3	EU 406/2010 is the implementing directive of the hydrogen road vehicles directive EC 79/2009. It is one of the most comprehensive regulations for hydrogen components in mobile application and provides - in combination with existing railway standards - an acceptable level of safety for railways. Design rules, tests, thresholds and pass fail criteria of gaseous compressed hydrogen tanks and components can be found in Annex IV, parts 1 to 3. Requirements for materials of hydrogen tanks, such as liner softening temperature, resin glass transition temperature are defined in chapter 3.5 of Annex IV, part 2. The upper temperature limit for all Tanks is set at 85 °C. The softening temperature for Type 4 tank liners is set at 100 °C. The extreme temperature cycling type test (+85 °C to -40 °C) is defined in chapter 4.2.9 of Annex IV, part 2. These tests directly serve to ensure the tanks integrity and tightness within the given boundaries (temperature, pressure, cycles, etc.). The components, such as safety valves, TPRDs and fittings, must undergo similar tests to prove integrity and tightness under all operating temperatures (see Annex IV, part 3) Type 3 tanks are less sensitive on over temperature but still require TPRDs acc. to EC 79. The TPRD triggering temperature is not defined but is generally, set at 110 °C with a tolerance of +/- 5 % acc. to chapter 4.2.2.2.5 of Annex IV, part 3.	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Adopting either one of them requires an assessment of the gaps with the boundary conditions from railway application and closing of these gaps with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-2. Type 4 tanks are more sensitive to over temperatures (max. 85°C gas, max. 100°C liner), while both, Type 3 and Type 4 tanks maximum temperatures are limited by the given triggering temperature of the TPRDs. The adoption of TPRDs shall be discussed for railways in the ongoing standardisation processes. With regards to operating temperatures, components with EC 79-approval can undergo a conformity assessment to EN 50155.	Other RCS
21	C2	Thermal impact / over temperature	UN ECE R 134	Clauses 5 to 7 and Annex 3 to 4	UN ECE R 134 will substitute EC 79/2009 and EU 406/2010 in the near future. However, the scope of R 134 is limited to the hydrogen tank and the directly attached safety components, such as solenoid valve, check valve and TPRD, while EC 79 has a wider scope an also includes pipework, fittings and components up to the filling receptacle. The requirements defined by R 134 for the tanks are similar to EU 406/2010 but testing is mostly done in sequences where the test sample must undergo several different stresses to reflect a characteristic conservative load profile in road application, which serve to reduce or avoid leakage of hydrogen and remain burst pressure over the tanks live. Transfering these test sequences to railways requires a more detailed analysis and comparison of load profiles. It is expected though that the safety level of tanks with an R 134 type approval provide at least the same level of safety compared to EC 79. The upper temperature limit for all Tanks is set at 85 °C. There is no threshold for the liner temperature. The high temperature static pressure and extreme temperature pressure cycling type tests (+85 °C to -40 °C) are part of the verification tests for performance durability, which are defined in chapter 5.2. These tests directly serve to ensure the tanks integrity and tightness within the given boundaries (temperature, pressure, cycles, etc.). The components, such as safety valves, TPRDs and fittings, must undergo similar tests to prove integrity and tightness under all operating temperatures (see Annex 4, chapter 2.3). R 134 does not differentiate between Type 3 and Type 4 tanks. TPRDs shall protect the tank from overpressure when overheating and are mandatory without definition of a triggering temperature. They shall activate within 2 minuntes after application of a defined heat source (Annex 4, chapter 1.9). The location of TPRDs, TPRD vents and their triggering temperature require additional analysis when adopted in railway application.	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Adopting either one of them requires an assessment of the gaps with the boundary conditions railway application and closing of these gaps with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-2. With regards to operating temperatures, components with R 134-approval can undergo a conformity assessment to EN 50155. Adopting TPRDs from automotive regulations requires assessment of the residual risks posed by their application, such as probability of unintended activation, breakage of life ports, activation by heat but without a flame, etc. This topic shall be discussed in the ongoing standardisation processes.	Other RCS
22	C2	Thermal impact / over temperature	SAE J2601-1	all	SAE J2601-1 defines refuelling protocols for road vehicles with tank sizes between 49.7 and 248.6 litres for 350 bar systems and a maximum flow rate of 60 g/s. A typical hydrogen train tank has a volume of over 250 to 350 litres per single cylinder of which it has at least a dozen connected to a hydrogen storage system. A flow rate of 60 g/s would not be compatible with Diesel refuelling times. In addition, SAE J2601-1 foresees refuelling of precooled hydrogen at -20 to -40 °C to allow fast refuelling and safely avoid any overheating due to gas dynamics and Joule-Thomson-Effect. For heavy-duty applications the needed energy to cool down the required amounts of hydrogen would not make the technology economically attractive. For this reason the current development aims for ambient temperature refuelling, which requires more accurate temperature and pressure control and a validated process to safely avoid overheating and overpressure. Appendix A describes the fueling protocol rationale and development process. That may be informative for the development of a fueling protocol for rail applications.	Low	SAE J2601-1 limits the maximum tank size to 248.6 litres, the maximum flow rate to 60 g/s and defines refuelling of precooled hydrogen at -20 to -40 °C. It is not applicable for refuelling of railway application hydrogen storage systems due to their volume and the intention to refuel at ambient temperature.	Other RCS
23	C2	Thermal impact / over temperature	SAE J2601-2	all	SAE J2601-2 provides general rules for refuelling of heavy-duty road vehicles with a nominal working pressure of 350 bar and a maximum flow rate of 120 g/s. The standard is not prescriptive and does not define any validated fast refuelling protocols which savely avoid overheating and over pressure. The current development aims for ambient temperature refuelling, which requires more accurate temperature and pressure control and a validated process to safely avoid overheating and overpressure.	Low	SAE J2601-2 would apply for railway vehicles but the standard does not yet provide validated protocols for ambient temperature refuelling of heavy-duty and railway hydrogen storage systems.	Other RCS
24	C2	Thermal impact / over temperature	2006/42/EC	Annex 1, clause 1.5.5.	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1, especially 1.5 must be considered. Clause 1.5.5. generally, refers to extreme temperature hazards from the machine itself that shall be avoided, without being prescriptive.	Low	None	Other RCS
25	C2	Thermal impact / over temperature	ISO/TR 15916	5.2.2.3	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.). It does mention the Joule-Thomson-Effect, but does not further elaborate on the hazards related to critical heat generation during refuelling processes. The topic of refuelling and especially fast refuelling of hydrogen tanks in the mobile application is not dealt with in thie technical report.	Low	ISO/TR 15916 should be ammendet to cover also the aspects of heat generation during fast refuelling of hydrogen tanks.	Other RCS
26	C2	Thermal impact / over temperature	EN 50155	4, 11, 13	Component malfunction may be caused by operational conditions. EN 50155 is a comprehensive standard covering all aspects of technical compatibility with the railway operational environment, such as climatic, environmental, mechanical and electrical aspects. It applies mainly to electric and electronic components and defines the minimum and maximum operating temperatures depending on the defined temperature class given in chapter 4.3.2. The worst case temperature class, OT6, corresponds with the temperature range of the international hydrogen standards and directives, such as EC 79/2009 and UN ECE R 134. Temperature tests are defined in chapters 13.4.4 to 13.4.7 and 13.4.14.	High	The scope of EN 50155 is limited to electric and electronic components and there is currently no equivalent standard requiring these tests for hydrogen systems and components. Either the scope of EN 50155 is extended to non-electrical component testing or other still to be developed standards, such as IEC 63341-1 and IEC 63341-2 adopt the international hydrogen standards and directives and define additional requirements.	Modification
27	C2	Thermal impact / over temperature	EN IEC 62928	12.2, 14.2.2.2 and 14.4.1.3	IEC 62928, especially with reference to IEC 62619, provides a comprehensive set of safety requirements for lithium-ion battery systems. Conformity to those requirements is considered as a basic safety evidence, provided that functional safety of the battery management system (for non-inherent safe batteries) is proven. Requirements for temperature management are defined in chapters 12.2, 14.2.2.2 and 14.4.1.3. However, the standard does not raise any requirements to protect the battery case from sun radiation or excessive waste heat from any adjacent component.	High	IEC 62928 does not define requirements to protect the battery from excessive heat caused by sun radiation of waste heat from adjacent components. This also applies for future standards IEC 63341-1 and IEC 63341-2 with regards to fuel cells and hydrogen storage systems. Especially hydrogen tanks with darf carbon fiber corpusses quickly heat up from sun radiation.	Modification
28	C2	Thermal impact / over temperature	EU 1302/2014	4.2.6.1.1.	TSI LOC&PAS generally, refers to EN 50125-1, temperature classes T1 to T3 and requires that these ambient temperatures are considered by component design. This covers the weather conditions but not any operating temperatures and heat release from other components. There is no reference to EN 50155 and the operating temperature classes defined therin.	Medium	TSI LOC&PAS needs to be revised e.g., by adding new requirements for alternative propulsion with traction batteries and or hydrogen and define a minimum set of safety requirements e.g., by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2, which require compliance with EN 50155.	Modification
29	C2	Thermal impact / over temperature	EN 50125-1	4.3, 4.9, 4.10	EN 50125-1 provides values for environmental conditions and limits the area of operation by classifying climate zones. Climatic conditions and influences, such as temperature, sun radiation and lightning strike may exceed temperature limits of sensitive components, such as Lithium-Ion-Batteries, Hydrogen tanks or electronic components under worst case climatic conditions, which are defined by EN 50125-1 (see also operating temperature classes of EN 50155, chapter 4.3.2) and must be considered in the technical design. (EN 50125-1 is referenced by EN 50155 and TSI LOC&PAS)	High	None	No Modification
30	C3	Cold impact / under temperature	EC 79/2009	Annex IV to VI	EC 79/2009 applies for hydrogen road vehicles only. In combination with its implementing directive EU 406/2010, it is one of the most comprehensive regulations for hydrogen components in mobile application and provides - in combination with existing railway standards - an acceptable level of safety for railways. EC 79 requires numerous tests for hydrogen tanks and components in annexes IV and V and provides additional design rules in annex VI. There are generic material and type test requirements to prove tightness and integrity of the tanks within the given boundaries (temperature, pressure, cycles, etc.). The detailed requirements are described in EU 406/2010.	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Adopting either one of them requires an assessment of the gaps with the boundary conditions of railway application and closing of these gaps with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-2.	Other RCS
31	C3	Cold impact / under temperature	EU 406/2010	Annex IV, Parts 1 to 3	EU 406/2010 is the implementing directive of the hydrogen road vehicles directive EC 79/2009. It is one of the most comprehensive regulations for hydrogen components in mobile application and provides - in combination with existing railway standards - an acceptable level of safety for railways. Design rules, tests, thresholds and pass fail criteria of gaseous compressed hydrogen tanks and components can be found in Annex IV, parts 1 to 3. The minimum operating temperature is set at -40 °C in order to be compatible with SAE J2601 and ISO 19880-1, which foresee refuelling with precooled hydrogen up to -40 °C. The extreme temperature cycling type test (+85 °C to -40 °C) is defined in chapter 4.2.9 of Annex IV, part 2. This test directly serves to ensure the tanks integrity and tightness within the given boundaries (temperature, pressure, cycles, etc.). The components, such as safety valves, TPRDs and fittings, must undergo similar tests to prove integrity and tightness under all operating temperatures (see Annex IV, part 3)	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Adopting either one of them requires an assessment of the gaps with the boundary conditions from railway application and closing of these gaps with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-2. With regards to operating temperatures, components with EC 79-approval can undergo a conformity assessment to EN 50155.	Other RCS
32	C3	Cold impact / under temperature	UN ECE R 134	Clauses 5 to 7 and Annex 3 to 4	UN ECE R 134 will substitute EC 79/2009 and EU 406/2010 in the near future. However, the scope of R 134 is limited to the hydrogen tank and the directly attached safety components, such as solenoid valve, check valve and TPRD, while EC 79 has a wider scope an also includes pipework, fittings and components up to the filling receptacle. The requirements defined by R 134 for the tanks are similar to EU 406/2010 but testing is mostly done in sequences where the test sample must undergo several different stresses to reflect a characteristic conservative load profile in road application, which serve to reduce or avoid leakage of hydrogen and remain burst pressure over the tanks live. Transfering these test sequences to railways requires a more detailed analysis and comparison of load profiles. It is expected though that the safety level of tanks with an R 134 type approval provide at least the same level of safety compared to EC 79. The lower temperature limit for all Tanks is set at -40 °C in order to be compatible with SAE J2601 and ISO 19880-1, which foresee refuelling with precooled hydrogen up to -40 °C. The extreme temperature pressure cycling type test (+85 °C to -40 °C) is part of the verification tests for performance durability, which are defined in chapter 5.2. These tests directly serve to ensure the tanks integrity and tightness within the given boundaries (temperature, pressure, cycles, etc.). The components, such as safety valves, TPRDs and fittings, must undergo similar tests to prove integrity and tightness under all operating temperatures (see Annex 4, chapter 2.3).	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Adopting either one of them requires an assessment of the gaps with the boundary conditions railway application and closing of these gaps with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-2. With regards to operating temperatures, components with R 134-approval can undergo a conformity assessment to EN 50155.	Other RCS

			Mitigation				Evaluation	
No.	**ID**	**Trigger / Cause**	**Applicable RCS**	**Applicable clauses**	**Assessment of suitability**	**Suitability for mitigation**	**Identified gap**	**Result**
33	C3	Cold impact / under temperature	2006/42/EC	Annex 1, clause 1.5.5.	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1, especially 1.5 must be considered. Clause 1.5.5. generally, refers to extreme temperature hazards from the machine itself that shall be avoided, without being prescriptive.	Low	None	Other RCS
34	C3	Cold impact / under temperature	EN 50155	4, 11, 13	Component malfunction may be caused by operational conditions. EN 50155 is a comprehensive standard covering all aspects of technical compatibility with the railway operational environment, such as climatic, environmental, mechanical and electrical aspects. It applies mainly to electric and electronic components and defines the minimum and maximum operating temperatures depending on the defined temperature class given in chapter 4.3.2. The worst case temperature class, OT6, corresponds with the temperature range of the international hydrogen standards and directives, such as EC 79/2009 and UN ECE R 134. Temperature tests are defined in chapters 13.4.4 to 13.4.7 and 13.4.14.	High	The scope of EN 50155 is limited to electric and electronic components and there is currently no equivalent standard requiring these tests for hydrogen systems and components. Either the scope of EN 50155 is extended to non-electrical component testing or other still to be developed standards, such as IEC 63341-1 and IEC 63341-2 adopt the international hydrogen standards and directives and define additional requirements.	Modification
35	C3	Cold impact / under temperature	EN IEC 62928	6.3.2	IEC 62928, especially with reference to IEC 62619, provides a comprehensive set of safety requirements for lithium-ion battery systems. Conformity to those requirements is considered as a basic safety evidence, provided that functional safety of the battery management system (for non-inherent safe batteries) is proven. The minimum operating temperature is defined at -25 °C acc. to T1 of IEC 62498-1 (EN 50125-1 respectively). Possible damages of lithium cells when operated at very low temperatures will be detected by the required supervising functions (over temperature, voltage, etc.).	High	None	No Modification
36	C3	Cold impact / under temperature	EU 1302/2014	4.2.6.1.1. and 4.2.6.1.2.	TSI LOC&PAS generally, refers to EN 50125-1, temperature classes T1 to T3 and requires that these ambient temperatures are considered by component design. This covers the weather conditions but not any operating temperatures, e.g., when systems are refuelled with pre-cooled hydrogen at -40 °C.	Medium	TSI LOC&PAS needs to be revised e.g., by adding new requirements for alternative propulsion with traction batteries and or hydrogen and define a minimum set of safety requirements e.g., by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2. The boundary conditions of the refuelling process must be defined as well, e.g., min. and max. temperatures of the refuelled gas.	Modification
37	C3	Cold impact / under temperature	EN 50125-1	4.3, 4.9, 4.10	EN 50125-1 provides values for environmental conditions and limits the area of operation by classifying climate zones. Climatic conditions and influences, such as temperature, sun radiation and lightning strike may exceed temperature limits of sensitive components, such as Lithium-Ion-Batteries, Hydrogen tanks or electronic components under worst case climatic conditions, which are defined by EN 50125-1 (see also operating temperature classes of EN 50155, chapter 4.3.2) and must be considered in the technical design. (EN 50125-1 is referenced by EN 50155 and TSI LOC&PAS)	High	None	No Modification
38	C4	Operational shock / vibration	ISO 19453-6	all	Shock and vibration testing acc. to ISO 19453-6 is typically used in the automotive industry. It is possible to assess conformity to IEC 61373 based on the test profile. However, IEC 61373 is more conservative in shock impulse, which lasts for 30 ms instead of 6 ms. If ISO 19453-6 test is combined with shock impulses of 30 ms in the shock test, it fully covers IEC 61373.	High	If adopted for railway application, shock tests s acc. to table 17 must be ammended by 30 ms shock impulses.	Other RCS
39	C4	Operational shock / vibration	EC 79/2009	Annex IV, 2 j)	Except for the H2-tank, EC 79 and EU 406 respectively do not specify requirements for vibration. There are general statements to consider crash impact in the design inside a road vehicle, but without any prescription. Acc. to Annex IV, chapter 2 j) the H2-tank (type 3 and 4) must undergo a drop test.	Low	Adopting components with EC 79 type approval requires conducting of additional shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11.	Other RCS
40	C4	Operational shock / vibration	EU 406/2010	Annex IV, Part 2, clause 4.2.10.	Except for the H2-tank, EC 79 and EU 406 respectively do not specify requirements for vibration. Acc. to chapter 4.2.10. of Annex IV, Part 2, the H2-tank (type 3 and 4) must undergo a drop test without valves (optionally with).	Low	Adopting components with EC 79 type approval requires conducting of additional shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11.	Other RCS
41	C4	Operational shock / vibration	UN ECE R 134	Part 3, clause 7.2. Annex 3, clause 3.2, Annex 4, clauses 1.7 and 2.8	For the automotive application, R134 requires frontal and side crash tests with the assembled hydrogen fuel system acc. to UN ECE regulations R 12, R, 94, and R 95 and additional tightness and leakage tests acc. to Annex 5 of R 134. If a test in a specific vehicle is not foreseen, the test shall be done on a test bench, with the hydrogen system positioned acc. to Part 3, clause 7.2.4, and the accelerations (for heavy-duty vehicles M3/N3) acc. to clause 7.2. of 6.6 g in both x directions and 5 g in both y directions. As the design of the complete fuel system differs in railways, the results cannot be fully transferred. R 134 additionally defines dropt tests for tanks and vibration tests for the on tank valve and the TPRD. Acc. to Annex 3, clause 3.2, the tank (without valve) must undergo a four drop tests at different angle and at a height of 0,6 to 1,8 m, which is part of a test sequence. The vibration tests for tank valve and TPRD are defined in Annex 4, clauses 1.7 and 2.8, however, the test duration is much shorter compared to those required by IEC 61373 and ISO 19453-6 and there is no shock impulse tested. It is not possible to adopt these test results without additional tests for railway application.	Medium	Impact tests defined in Part 3, clause 7.2 for the complete fuel system with 6.6 and 5 g. Drop tests from 0.6 to 1.8 m height for the tank defined in Annex 3, clause 3.2 (as part of a test sequence). Vibration tests defined in Annex 4, chapters 1.7 and 2.8 apply to valves only. Neither test can be taken for conformity assessment acc. to IEC 61373 because of a shorter test duration for vibrations and different shock impulses. Adopting components with R 134 type approval requires conducting of additional shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11.	Other RCS
42	C4	Operational shock / vibration	2006/42/EC	Annex 1, clauses 1.3.2 and 1.5.9.	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1 must be considered. Clause 1.3.2. generally, refers to avoiding hazard from loss of mechanical integrity due to any degrading factors, such as vibration and clause 1.5.9. generally, refers to hazards from vibrations of the machine itself that shall be avoided, without being prescriptive.	Low	None	Other RCS
43	C4	Operational shock / vibration	EN 50155	4.3.5 and 13.4.11	Component malfunction may be caused by operational conditions. EN 50155 is a comprehensive standard covering all aspects of technical compatibility with the railway operational environment, such as climatic, environmental, mechanical and electrical aspects. EN 50155 requires components to be shock and vibration tested according to EN 61373. It specifies additional requirements in chapters 4.3.5 and 13.4.11., which includes functional tests during random vibration. However, the test procedure acc. to IEC 61373 does not include any pressure or leakage tests as well as functional tests of mechanical safety components (e.g., Check Valves, Safety Valves, Excess Flow Valves) before and after the test. The scope of EN 50155 is limited to electric and electronic components and there is currently no equivalent standard requiring these tests for hydrogen systems.	High	The shock and vibration test is needed to test the mechanical integrity of racks and housings, hydrogen components and fittings as well as the function of mechanical or electro-mechanical safety components of the hydrogen gas system. The function test is only required by EN 50155 (chapter 13.4.11.3 and 13.4.11.4), hence testing acc. to IEC 61373 only, would not cover this aspect. In order to prove enhanced tightness (no leakage under all expectable operational stress scenarios), the entire gas system must undergo a functional inspection and a pressure and tightness test before and after the shock and vibration test, which is not part of IEC 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt IEC 61373 and EN 50155 and define additional requirements.	Modification
44	C4	Operational shock / vibration	IEC 61373	all	A potential source of technical failures is loosening, braking or displacement of mechanical or electrical connections due to schock and vibration. Improper electrical connections may lead to high contact resistance or arcing, improper mechanical connections may lead to leakage of flammable gases or malfunction of valves and components. Therefore, it is necessary to have all safety related components tested acc. to IEC 61373 and test their function acc. to chapters 6.3.2 and 8. However, the test procedure does not include any pressure or leakage tests as well as functional tests of mechanical safety components (e.g., Safety Valves, Excess Flow Valves) before and after the test. (EN 61373 is required by EN 50155)	High	The shock and vibration test is needed to test the mechanical integrity of racks and housings, hydrogen components and fittings as well as the function of mechanical or electro-mechanical safety components of the hydrogen gas system. The function test is only required by EN 50155 (chapter 13.4.11.3 and 13.4.11.4), hence testing acc. to IEC 61373 only, would not cover this aspect. In order to prove enhanced tightness (no leakage under all expectable operational stress scenarios), the entire gas system must undergo a functional inspection and a pressure and tightness test before and after the shock and vibration test, which is not part of IEC 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt IEC 61373 and EN 50155 and define additional requirements.	Modification
45	C4	Operational shock / vibration	EN IEC 62928	6.2 and 14.3.3	IEC 62928 requires shock and vibration test acc. to IEC 61373 for battery systems. However, it does not specify any functional requirements under random vibration conditions, as required by EN 50155. For any functional components of the battery system that carries a safety function, especially the battery management system, this test must be performed to demonstrate functional safety under operating conditions. IEC 60571, which is referenced by IEC 62928 for the electronics of the battery management system, does not specify any additional requirements for the IEC 61373 test.	Medium	IEC 62928 and there referenced standards IEC 61373 and IEC 60571 respectively do not foresee any functional tests during random vibration, as required by EN 50155, 13.4.11.	Modification
46	C4	Operational shock / vibration	EU 1302/2014	all	TSI LOC&PAS does not require any shock and vibration test for safety relevant components.	Low	TSI LOC&PAS needs to be revised e.g., by adding a generic requirement for shock and vibration testing of safety relevant components or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
47	C4	Operational shock / vibration	EN 12663-1	6.5.2, 6.6.4, 6.7.3	EN 12663-1 defines operational accelerations in x, y, z direction that component fasteners must sustain (chapter 6.5.2). In addition, the fatigue resistance of the component fasteners must be proven (chapter 6.6.4 and 6.7.3). This applies to all components that are attached to the car body, including racks and housings of hydrogen tanks and components, fuel cells and battery housings and proven by finite elements and modal analysis. If housings and fasteners have been tested according to IEC 61373 in the corresponding class, they automatically comply with the requirements of EN 12663-1, chapter 6.5.2, 6.6.4 and 6.7.3.	High	None	No Modification
48	C5	Electro magnetic emission / interference	EC 79/2009	---	EC 79 and EU 406 respectively do not specify any EMC requirements.	Low	Adopting components with EC 79 type approval requires conducting of additional EMC tests acc. to EN 50121-3-2.	Other RCS
49	C5	Electro magnetic emission / interference	EU 406/2010	---	EC 79 and EU 406 respectively do not specify any EMC requirements.	Low	Adopting components with EC 79 type approval requires conducting of additional EMC tests acc. to EN 50121-3-2.	Other RCS
50	C5	Electro magnetic emission / interference	UN ECE R 134	---	R 134 does not specify any EMC requirments.	Low	Adopting components with R 134 type approval requires conducting of additional EMC tests acc. to EN 50121-3-2.	Other RCS
51	C5	Electro magnetic emission / interference	UN ECE R 10	all	The ECE R 10 describes tests in order to proove the electromagnetic compatibility of vehicles and components used in vehicles. It is possible to assess fulfillment of the requirements from EN 50121-3-2 on component basis.	Medium	Adopting components with R 10 type approval requires assessment with the requirements from EN 50121-3-2.	Other RCS
52	C5	Electro magnetic emission / interference	2014/30/EU	all	2014/30/EU specifically describes principal requirements for electrical devices with regards to electro magnetic compatibility and is the basis for product certification in this field. Depending on the test and assessment basis of the related certification, it may be possible to assess fulfillment of the requirements from EN 50121-3-2 on component basis.	Medium	Adopting components with 2014/30/EU certification requires assessment with the requirements from EN 50121-3-2.	Other RCS
53	C5	Electro magnetic emission / interference	2006/42/EC	Annex 1, clause 1.5.10. and 1.5.11.	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1, especially 1.5 must be considered. Clause 1.5.10. and 1.5.11. generally, refer to limited emission of radiation from the machine and resistance to radiation of the machine, without being prescriptive.	Low	None	Other RCS
54	C5	Electro magnetic emission / interference	EN 50155	4.3.6, 5.2.3, 13.4.8	EN 50155 requires electric and electronic components to be EMC-tested acc. to EN 50121-3-2.	High	None	No Modification
55	C5	Electro magnetic emission / interference	EN IEC 62928	6.5, 14.4.2.6	IEC 62928 requires EMC test acc. to IEC 62236-3-2 (EN 50121-3-2 respectively) for battery systems.	High	None	No Modification
56	C5	Electro magnetic emission / interference	EU 1302/2014	4.2.3.3.1.1, 4.2.3.3.1.2	TSI LOC&PAS does not require any functional component tests acc. to EN 50121-3-2. It only refers to EMC requirements for compatibility with communication and train protection systems.	Low	TSI LOC&PAS needs to be revised e.g., by adding a generic requirement for EMC testing of safety relevant components or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
57	C5	Electro magnetic emission / interference	EN 50121-3-1	all	EN 50121-3-1 specifies test methods to measure the electromagnetic emissions of the fully assembled and functional vehicle. The electromagnetic fields emitted from high voltage and high-power electrical components, such as Traction Battery and Fuel Cell, shall not exceed specified limits in order to protect trackside and on board signalling systems but also any other safety function on the vehicle. The compatibility of vehicle components with electromagnetic fields is validated according to EN 50121-3-2. The limits of both standards are harmonized, meaning that if the emission values are below the thresholds, the resistance thresholds apply. The standard is referenced by EN 50343.	High	None	No Modification
58	C5	Electro magnetic emission / interference	EN 50121-3-2	all	EN 50121-3-2 specifies test methods to measure the eletromagnetic emissions and compatibility of components. Any electric or electronic component with a safety function must be compatible with the specified transient emissions and remain its technical function. Examples of relevant components of alternative propulsion systems are: battery management system, temperature sensors, pressure sensors, pressure switches, control units, relays and switches, related cabling and power supply. The standard is referenced by EN 50155 and EN 50343 and a mandatory requirement in functional safety assessments.	High	None	No Modification
59	C6	Hydrogen purity / particle ingress	ISO 14687	all	ISO 14687 defines purities and test methods for different use cases of hydrogen (for gasaeous hydrogen and PEM fuel cells in mobile application Type 1 D applies).	High	None	Other RCS
60	C6	Hydrogen purity / particle ingress	EN 17124	all	EN 17124 defines methods how to check the quality of the hydrogen especially used with PEM-fuel cells and delivers also some information about the effect of impurities. It serves for availability and reliability of the power generation function of the fuel cells rather than mitigating a safety hazard.	Low	None	Other RCS
61	C6	Hydrogen purity / particle ingress	ISO/TR 15916	7.2.7.3	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.). The use of filters is justified and recommended in chapter 7.2.7.3 and provides general guidance how to maintain them.	High	None	Other RCS
62	C6	Hydrogen purity / particle ingress	EU 1302/2014	---	TSI LOC&PAS does not define any requirements for hydrogen purity or application of filters.	Low	TSI LOC&PAS needs to be revised e.g., by adding a generic requirements for hydrogen purity and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification

			Mitigation				Evaluation	
No.	ID	Trigger / Cause	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
63	C7	Hydrogen incompatibility	EC 79/2009	Annex III	EC 79 generally, requires that hydrogen compatibility shall be proven. Details are outlined in EU 406.	High	None	Other RCS
64	C7	Hydrogen incompatibility	EU 406/2010	Annex IV, Part 2, clause 3.5 and Part 3, clause 4.1	EU 406 requires tanks or different types and materials (see Annex IV, Part 2, clause 3.5) as well as components of the hydrogen system (see Annex IV, Part 3, clause 4.1) to be compatible with hydrogen by refering to several international and north american standards.	High	None	Other RCS
65	C7	Hydrogen incompatibility	UN ECE R 134	---	R 134 does not specify any requirements for hydrogen compatibility.	High	Adopting components with R 134 type approval requires additional proves for hydrogen compatibility.	Other RCS
66	C7	Hydrogen incompatibility	EU 2021/535	Annex XIV, Part 2, Section F	EU 2021/535 regulates the type approval for road vehicles and does not apply for railway vehicles. It requires materials of the hydrogen storage system to be compatible with hydrogen by refering to several international and north american standards. For metallic materials it refers to test according ISO 11114-4. It closes the gap from R134 after withdrawal of EC79, since R134 does not specify requirements for hydrogen compatibility.	High	None	Other RCS
67	C7	Hydrogen incompatibility	2006/42/EC	Annex 1, clause 1.3.2.	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1 must be considered. Clause 1.3.2. generally, refers to avoiding hazard from loss of mechanical integrity due to any degrading factors, such as material incompatibility, without being prescriptive.	Low	None	Other RCS
68	C7	Hydrogen incompatibility	ISO/TR 15916	7.2.2	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.). It provides general guidance in chapter 7.2.2 regarding low temperature design, hydrogen attack, hydrogen embrittlement and non-metallic materials.	Medium	None	Other RCS
69	C7	Hydrogen incompatibility	EU 1302/2014	---	TSI LOC&PAS does not define any requirements for hydrogen compatibility of materials.	Low	TSI LOC&PAS needs to be revised e.g., by adding a generic requirements for hydrogen compatibility and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
70	C7	Hydrogen incompatibility	ISO 11114-1	all	ISO 11114-1 applies to the compatibility of metal tanks and valves in contact with gases. It provides a list of gases and metals for tanks and valves, which are compatible with each other or require additional measures. The application of this standard provides basic material integrity with regards to hydrogen compatibility, especially with regards to pipes, fittings and valves, which are in contact with hydrogen.	High	None	Other RCS
71	C7	Hydrogen incompatibility	ISO 11114-2	all	ISO 11114-2 applies to the compatibility of non-metallic materials, such as gaskets, in contact with gases. It provides a list of gases and plastics and elastomers, which are compatible with each other or require additional measures. The application of this standard provides basic material integrity with regards to hydrogen compatibility, especially with regards to gaskets inside any fittings, valves or flexible tubes, which are in contact with hydrogen.	High	None	Other RCS
72	C7	Hydrogen incompatibility	ISO 11114-4	all	ISO 11114-4 provides test methods for steels that resist hydrogen embrittlement. The application of this standard provides basic material integrity with regards to hydrogen compatibility, especially with regards to pipes fittings and valves, which are in contact with hydrogen.	High	None	Other RCS
73	C7	Hydrogen incompatibility	ISO 11114-5	all	ISO 11114-5 provides test methods for testing the integrity of plastic liners inside hydrogen tanks (Type 4). This new standard will become a mandatory validation method for liners of any type 4 tank and will serve to mitigate the probability of leakages.	High	None	Other RCS
74	C8	Corrosion (dusts, aerosols, humidity, chemicals)	IEC 60529	all	EN 60529 provides test methods and classifications for tightness degree of component housings and enclosures. It may be applicable to electrical components, such as batteries or control units but is rather unlikely for hydrogen components due to the need to active and passive ventilation.	High	None	Other RCS
75	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN 60068-2-11	all	EN 60068-2-11 provides a test method for salt spray testing of components. This test can be applied on specific sensitive components and materials, which may corrode due to salty air (e.g., operation close to sea).	High	None	Other RCS
76	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EC 79/2009	Annex IV	EC 79 generally, requires that hydrogen tanks to sustain chemical exposure. Details are outlined in EU 406.	High	None	Other RCS
77	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EU 406/2010	Annex IV, Part 2, clauses 4.1.5.2, 4.2.6, and Part 3, clauses 4.1.3 and 4.2.1	EU 406 requires tanks to be exposed with specific chemicals after their outer surface is damaged by a pendulum (clause 4.2.6). The chemicals include sulphuric acid - 19 per cent by volume in water; sodium hydroxide - 25 % by weight in water; methanol/petrol - mixture in the ratio 5/95 %; ammonium nitrate - 28% by weight in water; windscreen washer fluid (solution of 50 per cent by volume each of methyl alcohol and water). The protective covers of tanks shall be additionally tested acc. to ASTM D1308 for chemical resistance and ASTM B117 for salt spray resistance (clause 4.1.5.2). Components other than tanks (Part 3) shall be tested for ozone resistance acc. to ISO 1431-1 (chapter 4.1.3) and salt spray resistance acc. to ISO 9227 (4.2.1). For components made from copper alloys, the resistance to ammonia shall be tested acc. to ISO 6957.	High	None	Other RCS
78	C8	Corrosion (dusts, aerosols, humidity, chemicals)	UN ECE R 134	Annex 3, clause 3.3, Annex 4, clauses 2.5 and 2.6	R 134 requires tanks to be exposed with specific chemicals as part of the performance durability tests sequence. The tank outer surface is damaged by a pendulum (Annex 3, clause 3.3). The chemicals include sulphuric acid - 19 per cent by volume in water; sodium hydroxide - 25 % by weight in water; methanol/petrol - mixture in the ratio 5/95 %; ammonium nitrate - 28% by weight in water; windscreen washer fluid (solution of 50 per cent by volume each of methyl alcohol and water). Check valves and On-Tank-Valves must be tested for the same chemical substances, except for methano/petrol (Annex 4, clause 2.5). In addition, they must sustain an Oxygen and Ozone exposure acc. to standard test methods ASTM D572 and ISO 1431-1, ASTM D1149 or equivalent (Annex 4, clause 2.6).	High	None	Other RCS
79	C8	Corrosion (dusts, aerosols, humidity, chemicals)	2006/42/EC	Annex 1, clause 1.3.2.	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1 must be considered. Clause 1.3.2. generally, refer to avoiding hazard from loss of mechanical integrity due to any degrading factors, such as corrosion, without being prescriptive.	Low	None	Other RCS
80	C8	Corrosion (dusts, aerosols, humidity, chemicals)	ISO/TR 15916	7.2.5	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.). It provides general guidance in chapter 7.2.5 regarding the possibility for galvanic corrosion at piping, joints and connections, which is a thread for tightness and integrity.	Medium	None	Other RCS
81	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN 50155	4.4.2, F.2.1	EN 50155 generally, requires that pollutants shall be specified by the customer. In the informative annex F some concentrations for chemical substances, fluids, biological substances, dusts as well as stones acc. to EN 60721-3-5 are outlined. The scope of EN 50155 is limited to electric and electronic components.	High	Either the scope of EN 50155 is extended to non-electrical component testing or other still to be developed standards, such as IEC 63341-1 and IEC 63341-2 adopt IEC EN 50155 and define additional requirements for this test.	Modification
82	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EU 1302/2014	4.2.6.1	TSI LOC&PAS makes generic reference to environmental conditions and includes chemical and biological conditions in the definition of those. There are no specific material properties or tests defined for safety relevant materials and components.	Medium	TSI LOC&PAS needs to be revised e.g., by adding a generic requirements for corrosion protection of safety relevant materials and components and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
83	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN 50125-1	4.7	EN 50125-1 provides values for environmental conditions and limits the area of operation by classifying climate zones. It defines values of air polution (chemical substances, biological substances, dust, sand, salt aerosol, etc.) in chapter 4.7, which are mainly adopted from EN 60721-3-5. These pollutants shall not cause any corrosion or damage to metallic or non-metallic materials, which may cause a component to leak or loose its integrity. (EN 50125-1 is referenced by EN 50155)	High	None	No Modification
84	C9	Human error (manufacturing, operation, maintenance)	1999/92/EG	Annex I and II	ATEX directive 1999/92/EG excludes vehicles for transportation. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage. Furthermore, it is, together with its harmonized standards, the most comprehensive rule to assess potential formation of explosive atmospheres. If it can be demonstrated that the probability of a signficant release of hydrogen is low, the on board hydrogen system is not classified as an explosive zone acc. to Annex I. Generic requirements for organizational and workers safety measures are provided in Annex II. Further details are provided in IEC 60079-10-1.	Low	None	Other RCS
85	C9	Human error (manufacturing, operation, maintenance)	2014/34/EU	Annex I and II	ATEX product directive 2014/34/EU itself does not apply for railway vehicles. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage. Furthermore, it is, together with its harmonized standards, the most comprehensive rule to assess explosive protection safety systems and devices suitable to work inside explosive atmospheres or outside with a safety related control function. If it can be demonstrated that the probability of a signficant release of hydrogen is low, the on board hydrogen system is not classified as an explosive zone, which would not require any components of the vehicle to fulfil ATEX product directive. The details for the assessment are provided in EN 1127-1. The requirements for components - if necessary - are defined in the IEC 60079-series.	Low	None	Other RCS
86	C9	Human error (manufacturing, operation, maintenance)	EN IEC 62928	7.3, 8.2 and 8.3	IEC 62928 provides requirements for labeling of components, warning signs inside and outside the battery and refers to the manufacturer to align safe handling with the intergrator and provide safety instructions with the operating manual. There are currently no requirements defined to protect the battery from false operation or mishandling. Additionally there are no requirements to support incident management when a thermal runaway has occurred. There are no requirements to provide basic information about location, handling, fire fighting and salvage of traction batteries to fire brigades. (see also "C1 Fire or Ignition Source (internal / external)")	Medium	IEC 62928 does not define requirements to protect the battery from false operation or mishandling. There are no requirements to support incident management, e.g., by informing fire brigades about the installed technology and provide means for an immediate and effective fire attack.	Modification
87	C9	Human error (manufacturing, operation, maintenance)	2006/42/EC	Annex 1, clause 1.	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1 must be considered. It provides several requirements to avoid hazards from poor ergonomics and handling, false operation, false mounting, false maintenance or limited information, without being prescriptive. The standards which are harmonized with 2006/42/EG provide more details. They are not further considered in this analysis.	Low	None	Other RCS
88	C9	Human error (manufacturing, operation, maintenance)	ISO/TR 15916	6.8, 7.1.2, 7.5, 7.6 and 7.7	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis. It provides general guidance in chapters 6.8, 7.1.2 and 7.5 to 7.7 regarding the education and training needed for the safe use of hydrogen, lessons learned from past experience, considerations for facilities, considerations for operation and recommended practices for organizations.	High	None	Other RCS
89	C9	Human error (manufacturing, operation, maintenance)	EU 1302/2014	---	TSI LOC&PAS does not specify any requirements to limit the capabilities for staff to critically influence the hydrogen storage system and energy storage system during operation.	Low	TSI LOC&PAS needs to be revised e.g., by adding generic requirements for to limit possibilities for human error and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
90	C9	Human error (manufacturing, operation, maintenance)	EN 1779	all	EN 1779 provides a number of leak testing methods and their criteria for correctly choosing the right method. It serves to choose and conduct the correct leak testing methods after assembly, maintenance or during regular inspection in order to avoid leaks in operation.	High	None	Other RCS
91	C9	Human error (manufacturing, operation, maintenance)	ISO 20485	4 to 7 and 9 to 10	ISO 20485 provides rules and instructions for several leak testing methods, such as the sniffer method in clause 9.6. It serves to apply proper leak testing methods after assembly, maintenance or during regular inspection in order to avoid leaks in operation.	High	None	Other RCS
92	C10	Improper mechanical design	2014/68/EU	all	Pressure Equipment Directive (PED) regulates in particular stationary installations as well as installations for industrial trucks under internal pressure >0,5 bar. It excludes road vehicles and their components, but does not explicitly exlude railways in its scope of application. PED defines essential requirements for the design and manufacturing process of pressure vessels, components and assemblies as well as equipment with safety function. Besides many generic non-prescriptive requirements, PED defines a test pressure ratio of 1.43 of the maximum possible operating pressure (PS) for end-of-line testing, which means for a nominal working pressure (NWP) at 15 °C of 350 bar a test pressure of 438 bar (at 85°C) x 1.43 = 626 bar. There is currently no standard, which is harmonized with PED, that applies to Type 3 and Type 4 hydrogen pressure vessels at NWPs of 350 or 700 bar, which complicates a CE-marking acc. PED for these vessels. Furthermore, as assembly certification acc. to PED requires all components to be compliant with PED. A type approval of a vessel according to EC 79 or R 134 does not mean that there is conformity according to PED. The conformity assessment must be restarted together with the notified body.	High	There is currently no standard, which is harmonized with PED, that applies to Type 3 and Type 4 hydrogen pressure vessels at NWPs of 350 or 700 bar, which complicates a CE-marking acc. PED for these vessels. Furthermore, as assembly certification acc. to PED requires all components to be compliant with PED. If the vessel follows automotive regulations, such as EC 79 or R 134, it is formally not possible for the Notified Body PED to certify the assembly.	Other RCS
93	C10	Improper mechanical design	EC 79/2009	Article 12 (2) a, Annex IV, clause 2, Annex V, clauses 1, to 6, Annex VI, clauses 1, 5, 6, 7, 8, 9	The general safety target is to achieve enhanced tightness of the hydrogen system under all operating conditions (pressure, cycles, temperature, corrosion) and crash szenarios as far as possible. The tests are required for Type 4 cylinders (Annex IV, clause 2) and for all components (Annex V, clauses 1 to 6). There are general statements to consider crash and impact in the design (e.g., automatic closure of valves upon crash), but without being prescriptive (Article 12 (2) a and Annex VI, clauses 1, 5, 6, 7, 8, 9). Acc. to Annex IV, chapter 2 j) the H2-tank (type 3 and 4) must undergo a drop test, which is the only test defined for impact scenarios. All required tests are prescribed in EU 406.	High	Tightness of tanks and components and their media compatibility under the given operating conditions is sufficiently proven by EC 79 type approval. Adopting components with EC 79 type approval requires conducting of additional shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11. It also requires an assessment of mechanical stress due to thermal expansion, especially with regards to longer pieces of pipes, in order to avoid mechanical stress on pipes, fittings and components.	Other RCS

			Mitigation				Evaluation	
No.	ID	Trigger / Cause	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
94	C10	Improper mechanical design	EU 406/2010	Annex IV, Part 2, clauses 3 and 4, Part 3, clauses 3 and 4	The general safety target is to achieve enhanced tightness of the hydrogen system under all operating conditions (pressure, cycles, temperature, corrosion) and crash szenarios as far as possible. The tests for tanks are defined in Annex IV, Part 2, clauses 3 and 4 and for all components (Annex IV, Part 3, clauses 3 and 4). Acc. to chapter 4.2.10. of Annex IV, Part 2, the H2-tank (type 3 and 4) must undergo a drop test without valves (only optionally with). Tightness and mechanical integrity are the main focus of all tests.	High	Tightness of tanks and components and their media compatibility under the given operating conditions is sufficiently proven by EC 79 type approval. Adopting components with EC 79 type approval requires conducting of additional shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11. It also requires an assessment of mechanical stress due to thermal expansion, especially with regards to longer pieces of pipes, in order to avoid mechanical stress on pipes, fittings and components.	Other RCS
95	C10	Improper mechanical design	UN ECE R 134	Part 3, clause 7.2, Annex III, clause 3.2, Annex IV, clause 1.7	For the automotive application, R134 requires frontal and side crash tests with the assembled hydrogen fuel system acc. to UN ECE regulations R 12, R, 94, and R 95 and additional tightness and leakage tests acc. to Annex 5 of R 134. If a test in a specific vehicle is not foreseen, the test shall be done on a test bench, with the hydrogen system positioned acc. to Part 3, clause 7.2.4, and the accelerations (for heavy-duty vehicles M3/N3) acc. to clause 7.2. of 6.6 g in both x directions and 5 g in both y directions. R 134 additionally defines drop tests for tanks and vibration tests for the on tank valve and the TPRD. Acc. to Annex 3, clause 3.2, the tank (without valve) must undergo four drop tests at different angle and at a height of 0,6 to 1,8 m, which is part of a test sequence. The vibration tests for tank valve and TPRD are defined in Annex 4, clauses 1.7 and 2.8, however, the test duration is much shorter compared to those required by IEC 61373 and ISO 19453-6 and there is no shock impulse tested. It can be concluded that the applied tests provide a basic proof for the robustness of the hydrogen fuel system (especially the tank, tank valve and TPRD). However, as the design of the complete fuel system differs in railways, the results cannot be fully transferred.	High	Impact tests defined in Part 3, clause 7.2 for the complete fuel system with 6.6 and 5 g. Drop tests from 0.6 to 1.8 m height for the tank defined in Annex 3, clause 3.2 (as part of a test sequence). Vibration tests defined in Annex 4, chapters 1.7 and 2.8 apply to valves only. Neither test can be taken for conformity assessment acc. to IEC 61373 because of a shorter test duration for vibrations and different shock impulses. It also requires as assessment of mechanical stress due to thermal expansion, especially with regards to longer pieces of pipes, in order to avoid mechanical stress on pipes, fittings and components.	Other RCS
96	C10	Improper mechanical design	1999/92/EG	Annex I and II	ATEX directive 1999/92/EG excludes vehicles for transportation. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage (depending on a dedicated hazard analysis). Furthermore, it is, together with its harmonized standards, the most comprehensive rule to assess potential formation of explosive atmospheres. If it can be demonstrated that the probability of a signficant release of hydrogen is low, the on board hydrogen system is not classified as an explosive zone acc. to Annex I. Generic requirements for organizational and workers safety measures are provided in Annex II. Further details are provided in IEC 60079-10-1.	Medium	None	Other RCS
97	C10	Improper mechanical design	2014/34/EU	Annex I and II	ATEX product directive 2014/34/EU itself does not apply for railway vehicles. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage (depending on a dedicated hazard analysis). Furthermore, it is, together with its harmonized standards, the most comprehensive rule to assess explosive protection safety systems and devices suitable to work inside explosive atmospheres or outside with a safety related control function. If it can be demonstrated that the probability of a signficant release of hydrogen is low, the on board hydrogen system is not classified as an explosive zone, which would not require any components of the vehicle to fulfil ATEX product directive. The details for the assessment are provided in EN 1127-1. The requirements for components - if necessary - are defined in the IEC 60079-series.	Medium	None	Other RCS
98	C10	Improper mechanical design	2006/42/EC	Annex 1, clause 1.5.6.	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1 must be considered. Clause 1.5.7. generally, refers to explosion from the machine itself that shall be avoided, without being prescriptive. Details are outlined in the harmonized standard EN 1127-1.	Low	None	Other RCS
99	C10	Improper mechanical design	EN 1127-1	Clauses 3.2, 4, 6.1, 6.2.1.2, Annex B	EN 1127-1 defines the term "enhanced tightness" in clause 3.2 and Annex B, meaning that an installation does not permeate or leak sufficient amounts of medium to create an explosion zone under all operating conditions, which is the basic design goal of any hydrogen installation. Clause 4 defines principles of risk assessment of explosion risks, clauses 6.1 and 6.2 provide further guidance how to limit the risk and the concentration of a combustible medium to avoid an explosive athmosphere. The standard is not prescriptive with regards to design principles, but it supports the risk assessment and mitigation and clearly defines the design goal.	High	None	Other RCS
100	C10	Improper mechanical design	IEC 60079-10-1	all	IEC 60079-10-1 comprehensively provides rules for definition of zones with explosive atmospheres, assess releases, assess dillution and ventilation and define the topological limits of a zone. It contains additional information for the assessment of hydrogen in an informative Annex H, which also makes reference to ISO/TR 15916.	High	None	Other RCS
101	C10	Improper mechanical design	EN IEC 62928	6.2, 11	IEC 62928 provides only little requirements for mechanical properties of the traction battery system. It mainly refers to shock and vibration test acc. to IEC 61373 (see also "C4 Operational shock / vibration" and IP-protection of housing acc. IEC 60529.	High	None	Other RCS
102	C10	Improper mechanical design	ISO/TR 15916	7.2, 7.3, 7.4	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.). It provides general guidance in chapters 7.2, 7.3 and 7.4 on mitigation of design hazards, prevention of fire and explosion hazards as well as detection considerations. However, the list of proposed mitigations is neither complete nor binding as the individual application requires an individual hazard analysis which may lead to different mitigations - especially for railway application, which was not considered by the authors of this technical report.	High	None	Other RCS
103	C10	Improper mechanical design	EN 50155	4.3.5 and 13.4.11	EN 50155 requires shock & vibration test acc. to IEC 61373 with additional functional tests, see "C4 Operational shock & vibration". It provides further mechanical design and installation requirements for electronics, see "C11 Improper electrical design".	High	See "C4 Operational shock & vibration"	No Modification
104	C10	Improper mechanical design	IEC 61373	all	A potential source of technical failures is loosening, braking or displacement of mechanical or electrical connections due to schock and vibration. Improper electrical connections may lead to high contact resistance or arcing, improper mechanical connections may lead to leakage of flammable gases or malfunction of valves and components. Therefore, it is necessary to have all safety related components tested acc. to IEC 61373 and test their function acc. to chapters 6.3.2 and 8. However, the test procedure does not include any pressure or leakage tests as well as functional tests of mechanical safety components (e.g., Safety Valves, Excess Flow Valves) before and after the test. (EN 61373 is required by EN 50155)	High	The shock and vibration test is needed to test the mechanical integrity of racks and housings, hydrogen components and fittings as well as the function of mechanical or electro-mechanical safety components of the hydrogen gas system. The function test is only required by EN 50155 (chapter 13.4.11.3 and 13.4.11.4), hence testing acc. to IEC 61373 only, would not cover this aspect. In order to prove enhanced tightness (no leakage under all expectable operational stress scenarios), the entire gas system must undergo a functional inspection and a pressure and tightness test before and after the shock and vibration test, which is not part of IEC 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt IEC 61373 and EN 50155 and define additional requirements.	Modification
105	C10	Improper mechanical design	EU 1302/2014	4.2.2.7.	Except for the component fixation (clause 4.2.2.7. with referene to EN 12663-1, 6.5.2), TSI LOC&PAS does not specify any requirements for proper mechanical design, proper material choice, leak tightness or avoidance of explosive atmospheres for hydrogen (or other gas) storage systems and energy storage systems.	Medium	TSI LOC&PAS needs to be revised e.g., by adding generic requirements for proper mechanical design, proper material choice, leak tightness or avoidance of explosive atmospheres and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
106	C10	Improper mechanical design	EN 12663-1	6.5.2, 6.6.4, 6.7.3	EN 12663-1 defines operational accelerations in x, y, z direction that component fasteners must sustain (chapter 6.5.2). In addition, the fatigue resistance of the component fasteners must be proven (chapter 6.6.4 and 6.7.3). This applies to all components that are attached to the car body, including racks and housings of hydrogen tanks and components, fuel cells and battery housings and proven by finite elements and modal analysis. If housings and fasteners have been tested according to IEC 61373 in the corresponding class, they automatically comply with the requirements of EN 12663-1, chapter 6.5.2, 6.6.4 and 6.7.3.	High	None	No Modification
107	C10	Improper mechanical design	EN 15085-1	all	If racks, housings and brackets are welded, it must be done in accordance with EN 15085 and the applicable parts. This standard does not apply for welding of hydrogen piping.	High	None	No Modification
108	C11	Improper electrical design (including functional safety of E/E/PE systems)	EC 79/2009	---	EC 79 and EU 406 respectively provide basic electrical requirements for the integration into road vehicles, but do not specify any electrical requirements on component level, which can be adopted for railway application, except for the temperature range of components.	Low	Adopting components with EC 79 type approval requires conducting of additional tests for safety relevant components, as defined by EN 50155.	Other RCS
109	C11	Improper electrical design (including functional safety of E/E/PE systems)	EU 406/2010	---	EC 79 and EU 406 respectively provide basic electrical requirements for the integration into road vehicles, but do not specify any electrical requirements on component level, which can be adopted for railway application, except for the temperature range of components.	Low	Adopting components with EC 79 type approval requires conducting of additional tests for safety relevant components, as defined by EN 50155.	Other RCS
110	C11	Improper electrical design (including functional safety of E/E/PE systems)	UN ECE R 134	Annex 4, clause 2.7	R 134 specifies a few electrical tests for solenoid on-tank-valves in Annex 4, clause 2.7. This covers overvoltage (up to 1,5 times nominal voltage for one hour and 2 times nominal voltage for one minute), the minimum opening voltage (18 V for 24 V system) and insulation resistance at 1000 V DC for 2 seconds between cable and housing (the minimum resistance shall be 240 kohm). The values are below the requirements of EN 50155, chapter 13.4.9.	Medium	Adopting components with R 134 type approval requires additional tests for safety relevant components, as defined by EN 50155. Conformity asssessment for some electrical tests is not possible.	Other RCS
111	C11	Improper electrical design (including functional safety of E/E/PE systems)	2014/34/EU	Annex I and II, especially clauses 1.3.1., 1.3.2. and 1.3.3., 1.4, 1.5 and 1.6	ATEX product directive 2014/34/EU itself does not apply for railway vehicles. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage (depending on a dedicated hazard analysis). Furthermore, it is, together with its harmonized standards, the most comprehensive rule to assess explosive protection safety systems and devices suitable to work inside explosive atmospheres or outside with a safety related control function. In case ATEX product directive applies, there are specific requirements for an explosion proof electrical design as well as functional safety. The requirements for components - if necessary - are defined in the IEC 60079-series.	Medium	None	Other RCS
112	C11	Improper electrical design (including functional safety of E/E/PE systems)	2006/42/EC	Annex 1, clauses 1.5.1., 1.5.2.	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1 must be considered. Clause 1.5.1. and 1.5.2. provide general requirements for protection against electrical hazards for people. These requirements are already sufficiently covered by the existing electrical railway standards, such an EN 50153.	Low	None	Other RCS
113	C11	Improper electrical design (including functional safety of E/E/PE systems)	ISO/TR 15916	7.5.9	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.). It provides general guidance in chapter 7.5.9 regarding the arrangement and choice of electrical components in the vicinity of potential leaks or vents and requires proper electrical grounding and avoidance of any static charges and sparks.	Low	None	Other RCS
114	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN 50155	all, especially 11 and 13	Component malfunction may be caused by operational conditions. EN 50155 is a comprehensive standard covering all aspects of technical compatibility with the railway operational environment, such as climatic, environmental, mechanical and electrical aspects. It is specifically made for electrical components and a basic requirement to succeed in any functional safety assessment, especially with regards to the safety requirements in chapter 11 and the test requirements in chapter 13. Regarding hydrogen applications, there are some aspects, such as climatic tests for solenoid valves, transducers or sensors, which may be already covered by automotive type approval regulations and can be adopted by conformity assessment. However, the major scope of requirements, especially regarding shock and vibration and EMC is an essential amendment for railway application. Further tests, such as salt spray or IP-protection may be required as a result of the individual risk analysis (see also "C8 Corrosion (dusts, aerosols, humidity, chemicals")	High	None	No Modification
115	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN 45545-5	all	A proper electrical design is the basis to mitigate the majority of technical fire hazards. The topic of Fire Protection is seprately assessed under "C1 Fire or Ignition Sources (internal, external)".	Medium	None	No Modification
116	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN IEC 62928	6.3, 6.4, 6.5, 6.6, 8., 10 , 14.2	IEC 62928 provides a comprehensive set of electrical safety requirements to prevent electrical hazards, safe handling during installation and maintenance as well as prevention of thermal runaway caused by short circuit or exceedance any electrical boundaries of the battery cells. These requirements are defined in chapters 6.3 to 6.6, 8, 10 and 14.2.	High	None	No Modification
117	C11	Improper electrical design (including functional safety of E/E/PE systems)	EU 1302/2014	4.2.8.4.	Except for the protection against electrical hazards (clause 4.2.8.4. with referene to EN 50153), TSI LOC&PAS does not specify any requirements for proper electrical design, such as electromagnetic compatibility and function under operational voltage fluctuation of any safety relevant component. However, all requirements under clause 4.2.8.2. apply to vehicles with overhead wires in the systems defined by TSI ENE. Hence, vehicles with on board energy supply are not covered.	Medium	TSI LOC&PAS needs to be revised e.g., by adding electrical safety requirements for vehicles that are independent from catenary and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
118	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN 50153	all	EN 50153 deals with electrical safety and provides a comprehensive set of requirements for protection of passengers, staff and service personnel from electrical hazards, primarily electrocution e.g., caused by improper electrical installation, failure of electrical components or electrical arcing from outside. It indirectly protects from electrical ignition sources and loss of functional integrity under the existence of false electrical currents. The standard applies for any electrical component and electrically conductive structure installed on a railway vehicle, regardless of its function. Hence, it applies for any component of the hydrogen and battery system as it does for any other vehicle component. EN 50153 is referenced by EN 50155, EN 50343, EN 45545-5 as well as TSI LOC&PAS.	High	None	No Modification

			Mitigation				Evaluation	
No.	ID	Trigger / Cause	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
119	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN 50124-1	all	EN 50124-1 deals with insulation coordinates in railways and provides a comprehensive set of requirements for safe electrical design to avoid arcing and electrical ignition sources and ensure functional integrity of electrical installations. The standard applies for any high voltage electrical component installed on a railway vehicle, regardless of its function. Hence, it applies for any component of the hydrogen and battery system (if within the voltages defined by EN 50163) as it does for any other vehicle component. EN 50124-1 is referenced by EN 50153, EN 50155, EN 50343 and EN 45545-5.	High	None	No Modification
120	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN 50121-3-1	all	The electro magnetetic compatibility (EMC) belongs to a proper electrical design for safety functions. The topic of EMC is separately assessed under "C4 electromagnetic emission / intererence".	High	None	No Modification
121	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN 50121-3-2	all	The electro magnetetic compatibility (EMC) belongs to a proper electrical design for safety functions. The topic of EMC is separately assessed under "C4 electromagnetic emission / intererence".	High	None	No Modification
122	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN 50125-1	all	EN 50125-1 provides values for environmental conditions and classifies climate zones, which limits the area of operation. Climatic conditions and influences, such as temperature, sun radiation, lightning strike, moisture, pollution, etc. may cause electric or electronic components to fail if not protected accordingly. Electrical components with a safety function must be protected against any expectable environmental influence, which is not any different for components of a hydrogen or battery system. (EN 50125-1 is referenced by EN 50155 and EN 50343)	High	None	No Modification
123	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN 50343	all	EN 50343 provides rules for installation of electrical wires and cables. This is mainly applicable for the vehicle side cabling, but also applies for internal cabling of cabinets and components with different voltage levels, such as fuel cells and traction batteries. The fulfilment of these requirements indirectly provides protection against short circuit caused by improper or damaged cable insulation or connection. The standard includes numerous normative references, that are not further evaluated in depth.	High	None	No Modification
124	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN 50128	all	EN 50128 defines the process for development and assessment of software functions for railway applications that takes over a safety responsibility with a certain safety integrity beyond "basic integrity" (Safety Integrity Level SIL>0). The requirement for a specific SIL is derived from a risk analysis and depends on the actual safety responsibility of the software function, meaning the potential severity of an incident caused by its failure.	High	None	No Modification
125	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN 50129	all	EN 50128 defines the process for development and assessment of electric and electronic functions for railway applications that takes over a safety responsibility with a certain safety integrity beyond "basic integrity" (Safety Integrity Level SIL>0). The requirement for a specific SIL is derived from a risk analysis and depends on the actual safety responsibility of the electric and electronic function, meaning the potential severity of an incident caused by its failure.	High	None	No Modification
126	C11	Improper electrical design (including functional safety of E/E/PE systems)	EN 50215	all	EN 50215 provides a comprehensive set of rules and test criteria for vehicle type and routine testing as well as commissioning after production. It adresses nearly all components and functions of a typical railway vehicles. The basic principles and boundary conditions of testing are also relevant for vehicles with hydrogen and high voltages batteries. This specially applies for the general eletrical tests in clauses 8.7 and 8.7. However, the specific test methods and criteria for hydrogen tanks, fuel cells and high voltage batteries when being integrated on a railway vehicle are not covered by this standard.	Medium	EN 50215 adresses testing of thermal combustion engines, but not for hydrogen fuel cells, hydrogen storage systems and high voltages batteries. The standard should be updated to cover state of the art railway propulsion technology.	Modification
127	C12	Crash / Derailment / mechanical impact	EN 45545-7	5.1	The requirements for flammable gas installations from EN 45545-7 is currently only partially applicable to hydrogen gas installations, since this standard was intended to address gasoline, petroleum, oil and natural gas installations and the corresponding tanks at much lower working pressures, e.g., for combustion engines, heating or cooking. It requires an extensive update or a reference to future standards, such as IEC 63341-1 and 2. However, it already requires in chapter 5.1 that flammable gas installations shall not be integrated in crash zones. This requirement also applies for hydrogen installations.	High	None	No Modification
128	C12	Crash / Derailment / mechanical impact	EC 79/2009	Article 12 (2) a, Annex IV, clause 2, Annex V, clauses 1, to 6, Annex VI, clauses 1, 5, 6, 7, 8, 9	The general safety target is to achieve enhanced tightness of the hydrogen system under all operating conditions (pressure, cycles, temperature, corrosion) and crash szenarios as far as possible. The tests are required for Type 4 cylinders (Annex IV, clause 2) and for all components (Annex V, clauses 1 to 6). There are general statements to consider crash and impact in the design (e.g., automatic closure of valves upon crash), but without being prescriptive (Article 12 (2) a and Annex VI, clauses 1, 5, 6, 7, 8, 9). Acc. to Annex IV, chapter 2 j) the H_2-tank (type 3 and 4) must undergo a drop test, which is the only test defined for impact scenarios. All required tests are prescribed in EU 406.	Medium	Tightness of tanks and components and their media compatibility under the given operating conditions is sufficiently proven by EC 79 type approval. When adopting components with EC 79 type approval future standards, such as IEC 63341-1 and IEC 63341-2, should require additional shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11, validated fixations acc. to EN 12663-1, 6.5.2 and a consideration of the deformation zones acc. to EN 15227, where components must not be arranged.	Other RCS
129	C12	Crash / Derailment / mechanical impact	EU 406/2010	Annex IV, Part 2, clauses 3 and 4, Part 3, clauses 3 and 4	The general safety target is to achieve enhanced tightness of the hydrogen system under all operating conditions (pressure, cycles, temperature, corrosion) and crash szenarios as far as possible. The tests for tanks are defined in Annex IV, Part 2, clauses 3 and 4 and for all components (Annex IV, Part 3, clauses 3 and 4). Acc. to chapter 4.2.10. of Annex IV, Part 2, the H_2-tank (type 3 and 4) must undergo a drop test without valves (only optionally with). Tightness and mechanical integrity are the main focus of all tests.	Medium	Tightness of tanks and components and their media compatibility under the given operating conditions is sufficiently proven by EC 79 type approval. When adopting components with EC 79 type approval future standards, such as IEC 63341-1 and IEC 63341-2, should require additional shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11, validated fixations acc. to EN 12663-1, 6.5.2 and a considation of the deformation zones acc. to EN 15227, where components must not be arranged.	Other RCS
130	C12	Crash / Derailment / mechanical impact	UN ECE R 134	Part 3, clause 7.2, Annex III, clause 3.2, Annex IV, clause 1.7	For the automotive application, R134 requires frontal and side crash tests with the assembled hydrogen fuel system acc. to UN ECE regulations R 12, R, 94, and R 95 and additional tightness and leakage tests acc. to Annex 5 of R 134. If a test in a specific vehicle is not foreseen, the test shall be done on a test bench, with the hydrogen system positioned acc. to Part 3, clause 7.2.4, and the accelerations (for heavy-duty vehicles M3/N3) acc. to clause 7.2. of 6.6 g in both x directions and 5 g in both y directions. R 134 additionally defines drop tests for tanks and vibration tests for the on tank valve and the TPRD. Acc. to Annex 3, clause 3.2, the tank (without valve) must undergo four drop tests at different angle and at a height of 0,6 to 1,8 m, which is part of a test sequence. The vibration tests for tank valve and TPRD are defined in Annex 4, clauses 1.7 and 2.8, however, the test duration is much shorter compared to those required by IEC 61373 and ISO 19453-6 and there is no shock impulse tested. It can be concluded that the applied tests provide a basic proof for the robustness of the hydrogen fuel system (especially the tank, tank valve and TPRD). However, as the design of the complete fuel system differs in railways, the results cannot be fully transferred.	High	The defined crash and impact tests provide a basic evidence of robustness, but do not allow complete conformity assessment for railway application, because the fuel system of hydrogen trains is much larger. When adopting components with R 134 type approval future standards, such as IEC 63341-1 and IEC 63341-2, should require additional shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11, validated fixations acc. to EN 12663-1, 6.5.2 and a considation of the deformation zones acc. to EN 15227, where components must not be arranged.	Other RCS
131	C12	Crash / Derailment / mechanical impact	IEC 61373	all	The shock and vibration test acc. to IEC 61373 does not cover the impulse of a crash szenario acc. to EN 15227 or worse. However, it provides an evidence of basic integrity of the component housing, rack or frame in impulse szenarios of 30 to 50 m/s^2 for 30 ms (see "C4 Operational shock & vibration").	High	See "C4 Operational shock & vibration"	No Modification
132	C12	Crash / Derailment / mechanical impact	EN 15227	all	EN 15227 comprehensively defines the requirements for assessment and testing of crashworthiness of rail vehicles with the main goal to reduce the consequence of a collision for passengers and staff as far as possible. It complements the existing requirements to avoid collisions and shall further reduce the residual risk. The crashworthiness of course also leads to a reduction of deceleration forces on any equipment that is attached to the car body. As hydrogen storage systems and lithium-ion-batteries have the potential to aggravate the outcome of a crash szenario, it is worth assessing their position and fixations accordingly. An arrangement of components in the deformation zones of the car body must be avoided in any case.	High	EN 15227 does not refer to the component arrangement in deformation zones of the car body. As this is not in the sense of this standard, the existing and future standards for hydrogen and traction battery systems, such as IEC 62928, IEC 63341-1 and IEC 63341-2, shall prohibit the arrangement of any hydrogen or battery components in the deformation zones of the car body.	Modification
133	C12	Crash / Derailment / mechanical impact	EN IEC 62928	14.3.3 and 14.4.1.2	IEC 62928 requires shock and vibration test of the complete battery case in clause 14.3.3 with reference to IEC 61373 and several mechanical abuse tests on cell and module level, such as impact test, drop test, etc. (not leading to any fire or explosion) in clause 14.4.1.2. with reference to EN 62619 (similar tests are defined by UN 38.3, which can be transferred by conformity assessment). These tests provide basic evidence that the battery would sustain the impulse and deceleration of a crash szenario, provided that the battery case remains fixed to the car body and is not mechanically deformed or crushed. As a consequence, a battery case must not be placed in the deformation zone of the car body.	High	IEC 62928 should prohibit integration of battery cases in the primary and secondary crash deformation zones of the car body. This also applies for future standards IEC 63341-1 and IEC 63341-2 with regards to fuel cells and hydrogen storage systems.	Modification
134	C12	Crash / Derailment / mechanical impact	EN 50155	4.3.5 and 13.4.11	EN 50155 requires shock & vibration test acc. to IEC 61373. This does not cover the impulse of a crash szenario acc. to EN 15227 or worse. However, it provides an evidence of basic integrity of the component housing, rack or frame in impulse szenarios of 30 to 50 m/s^2 for 30 ms (see "C4 Operational shock & vibration").	High	See "C4 Operational shock & vibration"	No Modification
135	C12	Crash / Derailment / mechanical impact	EU 1302/2014	4.2.2.5. and 4.2.2.7.	TSI LOC&PAS requires all vehicles to fulfil passive safety requirements with reference to crashworthiness standard EN 15227, except for OTMs and all units / locomotives operated on 1520 mm / 1524 mm systems, for which is requirement applies voluntarily. In addition, all fixations must in compliance with EN 12663-1, 6.5.2. There is no requirement that prevents arrangements of tanks, storage systems or batteries in crash deformation zones of the car body.	Medium	TSI LOC&PAS needs to be revised e.g., by adding generic requirements for the arrangement of hydrogen storage and traction battery systems outside of crash deformation zones and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
136	C12	Crash / Derailment / mechanical impact	EN 12663-1	6.5.2	EN 12663-1 defines operational accelerations in x, y, z direction that component fastenings must sustain (chapter 6.5.2). This applies to all components that are attached to the car body, including racks and housings of hydrogen tanks and components, fuel cells and battery housings and proven by finite analysis. If housings and fasteners have been tested according to IEC 61373 in the corresponding class, they automatically comply with the requirements of EN 12663-1, chapter 6.5.2.	High	None	No Modification
137	C13	External short circuit / arcing	EC 79/2009	---	EC 79 and EU 406 respectively provide basic electrical requirements for the integration into road vehicles, but do not specify any electrical requirements on component level, which can be adopted for railway application, except for the temperature range of components.	Low	Adopting components with EC 79 type approval requires conducting of additional tests for safety relevant components, as defined by EN 50155.	Other RCS
138	C13	External short circuit / arcing	EU 406/2010	---	EC 79 and EU 406 respectively provide basic electrical requirements for the integration into road vehicles, but do not specify any electrical requirements on component level, which can be adopted for railway application, except for the temperature range of components.	Low	Adopting components with EC 79 type approval requires conducting of additional tests for safety relevant components, as defined by EN 50155.	Other RCS
139	C13	External short circuit / arcing	UN ECE R 134	Annex 4, clause 2.7	R 134 specifies a few electrical tests for solenoid on-tank-valves in Annex 4, clause 2.7. This covers overvoltage (up to 1,5 times nominal voltage for one hour and 2 times nominal voltage for one minute), the minimum opening voltage (18 V for 24 V system) and insulation resistance at 1000 V DC for 2 seconds between cable and housing (the minimum resistance shall be 240 kohm). The values are below the requirements of EN 50155, chapter 13.4.9.	Medium	Adopting components with R 134 type approval requires additional tests for safety relevant components, as defined by EN 50155. Conformity asssessment for some electrical tests is not possible.	Other RCS
140	C13	External short circuit / arcing	1999/92/EG	Annex I and II, especially clause 2.3	ATEX directive 1999/92/EG excludes vehicles for transportation. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage (depending on a dedicated hazard analysis). Furthermore, it is, together with its harmonized standards, the most comprehensive rule to assess potential formation of explosive atmospheres. If it can be demonstrated that the probability of a signficant release of hydrogen is low, the on board hydrogen system is not classified as an explosive zone acc. to Annex I. Generic requirements for organizational and workers safety measures are provided in Annex II. Clause 2.3 refers to avoidance of electrostatic discharge. Further details are provided in IEC 60079-10-1.	Low	None	Other RCS
141	C13	External short circuit / arcing	2014/34/EU	Annex I and II, especially clauses 1.3.1., 1.3.2. and 1.3.3.	ATEX product directive 2014/34/EU itself does not apply for railway vehicles. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage (depending on a dedicated hazard analysis). Furthermore, it is, together with its harmonized standards, the most comprehensive rule to assess explosive protection safety systems and devices suitable to work inside explosive atmospheres or outside with a safety related control function. In case ATEX product directive applies, there are specific requirements for an explosion proof electrical design as well as functional safety. The requirements for components - if necessary - are defined in the IEC 60079-series.	Low	None	Other RCS
142	C13	External short circuit / arcing	ISO/TR 15916	7.5.9	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.). It provides general guidance in chapter 7.5.9 regarding the arrangement and choice of electrical components in the vicinity of potential leaks or vents and requires proper electrical grounding and avoidance of any static charges and sparks.	Low	None	Other RCS
143	C13	External short circuit / arcing	EN 50155	all, especially 11 and 13	Component malfunction may be caused by operational conditions. EN 50155 is a comprehensive standard covering all aspects of technical compatibility with the railway operational environment, such as climatic, environmental, mechanical and electrical aspects. It is specifically made for electrical components and a basic requirement to succeed in any functional safety assessment, especially with regards to the safety requirements in chapter 11 and the test requirements in chapter 13. Especially test requirements in 13.4.3 and 13.4.9 serve to withstand voltage (insulation test) and peaks in the voltage supply. EN 50155 also requires components to be equipped with earthing acc. to EN 50153.	High	None	No Modification
144	C13	External short circuit / arcing	EN IEC 62928	6.4, 8., 10 , 14.2	IEC 62928 provides a comprehensive set of electrical safety requirements to prevent thermal runaway caused by short circuit or exceedance any electrical boundaries of the battery cells. These requirements are defined in chapters 6.4, 8, 10 and 14.2. This includes the external short circuit test acc. to EN 62619, chapter 7.2.1 (similar tests are defined by UN 38.3, which can be transferred by conformity assessment).	High	None	No Modification
145	C13	External short circuit / arcing	EN 45545-5	all	Protection against short circuit and arcing mitigates technical fire hazards. The topic of Fire Protection is sepratelv assessed under "C1 Fire or Ignition Sources (internal, external)".	Medium	None	No Modification

			Mitigation				Evaluation	
No.	ID	Trigger / Cause	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
146	C13	External short circuit / arcing	EU 1302/2014	4.2.8.4, 4.2.8.2.10	Except for the protection against electrical hazards (clause 4.2.8.4. with referene to EN 50153), TSI LOC&PAS generally, requires that the vehicle shall be protected against internal short circuits (clause 4.2.8.2.10). However, all requirements under clause 4.2.8.2. apply to vehicles with overhead wires in the systems defined by TSI ENE. Hence, vehicles with on board energy supply are not covered.	Medium	TSI LOC&PAS needs to be revised e.g., by adding electrical safety requirements for vehicles that are independent from catenary and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
147	C13	External short circuit / arcing	EN 50125-1	all	EN 50125-1 provides values for environmental conditions and classifies climate zones, which limits the area of operation. It defines lightning strike (which includes arcing from catenary) as an environmental condition to be considered and refers to EN 50124-2. If the vehicle does not properly arrest the electrical energy, this can lead to hot spots, punctured component or car body parts and fires. Especially roof mounted equipment of an alternative propulsion system, such as hydrogen storages or traction batteries shall be protected or the impact of arcing further investigated.	High	None	No Modification
148	C13	External short circuit / arcing	EN 50124-1	all	EN 50124-1 deals with insulation coordinates in railways and provides a comprehensive set of requirements for safe electrical design to avoid arcing and electrical ignition sources and ensure functional integrity of electrical installations. The standard applies for any high voltage electrical component installed on a railway vehicle, regardless of its function. Hence, it applies for any component of the hydrogen and battery system (if within the voltages defined by EN 50163) as it does for any other vehicle component. EN 50124-1 is referenced by EN 50153, EN 50155 and EN 45545-5.	High	None	No Modification
149	C13	External short circuit / arcing	EN 50124-2	all	EN 50124-2 provides simulation and validation methods for over voltage protection measures. It applies for equipment that is protected by metal oxide arresters.	High	None	No Modification
150	C13	External short circuit / arcing	EN 50153	all	EN 50153 deals with electrical safety and provides a comprehensive set of requirements for protection of passengers, staff and service personnel from electrical hazards, primarily electrocution e.g., caused by improper electrical installation, failure of electrical components or electrical arcing from outside. It indirectly protects from electrical ignition sources and loss of functional integrity under the existence of false electrical currents. The standard applies for any electrical component and electrically conductive structure installed on a railway vehicle, regardless of its function. Hence, it applies for any component of the hydrogen and battery system as it does for any other vehicle component. EN 50153 is referenced by EN 50155, EN 45545-5 as well as TSI LOC&PAS.	High	None	No Modification
151	C13	External short circuit / arcing	EN 50343	all	EN 50343 provides rules for installation of electrical wires and cables. This is mainly applicable for the vehicle side cabling, but also applies for internal cabling of cabinets and components with different voltage levels, such as fuel cells and traction batteries. The fulfilment of these requirements indirectly provides protection against short circuit caused by improper or damaged cable insulation or connection. The standard includes numerous normative references, that are not further evaluated in depth.	High	None	No Modification
152	C13	External short circuit / arcing	EN 50122-1	all	EN 50122-1 is dedicated to grounding of fixed electrical installations. It standard provides input with regards to the grounding between vehicle, rail and refuelling station. Considering the hazard of a broken catenary falling down on the vehicle, the standard may additionally provide useful countermeasures also for the vehicle, in addition to EN 50153.	Low	None	No Modification
153	C14	Input over voltage / over current	EC 79/2009	---	EC 79 and EU 406 respectively provide basic electrical requirements for the integration into road vehicles, but do not specify any electrical requirements on component level, which can be adopted for railway application, except for the temperature range of components.	Low	Adopting components with EC 79 type approval requires conducting of additional tests for safety relevant components, as defined by EN 50155.	Other RCS
154	C14	Input over voltage / over current	EU 406/2010	---	EC 79 and EU 406 respectively provide basic electrical requirements for the integration into road vehicles, but do not specify any electrical requirements on component level, which can be adopted for railway application, except for the temperature range of components.	Low	Adopting components with EC 79 type approval requires conducting of additional tests for safety relevant components, as defined by EN 50155.	Other RCS
155	C14	Input over voltage / over current	UN ECE R 134	Annex 4, clause 2.7	R 134 specifies a few electrical tests for solenoid on-tank-valves in Annex 4, clause 2.7. This covers overvoltage (up to 1,5 times nominal voltage for one hour and 2 times nominal voltage for one minute), the minimum opening voltage (18 V for 24 V system) and insulation resistance at 1000 V DC for 2 seconds between cable and housing (the minimum resistance shall be 240 kohm). The values are below the requirements of EN 50155, chapter 13.4.9.	Medium	Adopting components with R 134 type approval requires additional tests for safety relevant components, as defined by EN 50155. Conformity asssessment for some electrical tests is not possible.	Other RCS
156	C14	Input over voltage / over current	2014/34/EU	Annex I and II, especially clauses 1.4., 1.5. and 1.6.	ATEX product directive 2014/34/EU itself does not apply for railway vehicles. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage (depending on a dedicated hazard analysis). Furthermore, it is, together with its harmonized standards, the most comprehensive rule to assess explosion protection safety systems and devices suitable to work inside explosive atmospheres or outside with a safety related control function. In case ATEX product directive applies, there are specific requirements for functional safety. The requirements for components - if necessary - are defined in the IEC 60079-series.	Low	None	Other RCS
157	C14	Input over voltage / over current	EN 50155	all, especially 11 and 13	Component malfunction may be caused by operational conditions. EN 50155 is a comprehensive standard covering all aspects of technical compatibility with the railway operational environment, such as climatic, environmental, mechanical and electrical aspects. It is specifically made for electrical components and a basic requirement to succeed in any functional safety assessment, especially with regards to the safety requirements in chapter 11 and the test requirements in chapter 13. Especially test requirements in 13.4.3 and 13.4.9 serve to withstand voltage (insulation test) and peaks in the voltage supply. EN 50155 also requires components to be equipped with earthing acc. to EN 50153.	High	None	No Modification
158	C14	Input over voltage / over current	EN IEC 62928	6.4, 10 , 14.2	IEC 62928 provides a comprehensive set of electrical safety requirements to prevent thermal runaway caused by short circuit or exceedance any electrical boundaries of the battery cells. These requirements are defined in chapters 6.4, 10 and 14.2. This includes the external short circuit test acc. to EN 62619, chapter 7.2.1 (similar tests are defined by UN 38.3, which can be transferred by conformity assessment).	High	None	No Modification
159	C14	Input over voltage / over current	EU 1302/2014	---	TSI LOC&PAS defines requirements for overhead supply voltages, with reference to EN 50388, but it does not deal with on board supply, especiall for vehicles that are independent from catenary.	Low	TSI LOC&PAS needs to be revised e.g., by adding electrical safety requirements for vehicles that are independent from catenary and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
160	C15	Clogging / aerodynamic effects (of natural or forced ventilation)	1999/92/EG	Annex I and II, especially clause 2.5	ATEX directive 1999/92/EG excludes vehicles for transportation. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage (depending on a dedicated hazard analysis). Furthermore, it is, together with its harmonized standards, the most comprehensive rule to assess potential formation of explosive atmospheres. If it can be demonstrated that the probability of a signficant release of hydrogen is low, the on board hydrogen system is not classified as an explosive zone acc. to Annex I. Generic requirements for organizational and workers safety measures are provided in Annex II. Clause 2.5 generically refers to proper maintenance of the facilities with explosion protection measures. Further details are provided in IEC 60079-10-1.	Low	None	Other RCS
161	C15	Clogging / aerodynamic effects (of natural or forced ventilation)	IEC 60079-10-1	7	IEC 60079-10-1 comprehensively provides rules for definition of zones with explosive atmospheres, assess releases, assess dillution and ventilation and define the topological limits of a zone. It contains additional information for the assessment of hydrogen in an informative Annex H, which also makes reference to ISO/TR 15916. The requirements for the design and assessment of natural and forced ventilation are provided in chapter 7. It refers to worst case assupmtions in the estimation of flow rates and consideration of aerodynamic or environmental effects that may stop or invert the flow.	Medium	None	Other RCS
162	C15	Clogging / aerodynamic effects (of natural or forced ventilation)	ISO/TR 15916	7.5.8	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.). It provides general guidance in chapter 7.5.8 regarding the design and performance of ventilation systems.	Low	None	Other RCS
163	C15	Clogging / aerodynamic effects (of natural or forced ventilation)	EU 1302/2014	---	TSI LOC&PAS defines generic requirements for the documentation of safety relevant maintenance intervals. It does not define any ventilation requirements for areas with potential for explosive hazards.	Low	TSI LOC&PAS needs to be revised e.g., by adding maintenance requirements also for hydrogen and traction battery systems and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
164	C16	Over filling / charging	EC 79/2009	Annex IV to VI	EC 79/2009 applies for hydrogen road vehicles only. In combination with its implementing directive EU 406/2010, it is one of the most comprehensive regulations for hydrogen components in mobile application and provides - in combination with existing railway standards - an acceptable level of safety for railways. EC 79 requires numerous tests for hydrogen tanks and components in annexes IV and V and provides additional design rules in annex VI. The tests required to achieve type approval foresee burst, pressure / temperature cycling and leakage tests, which prove the tanks integrity also under extreme conditions. The detailed requirements are described in EU 406/2010.	High	None	Other RCS
165	C16	Over filling / charging	EU 406/2010	Annex IV, Parts 1 to 3	EU 406/2010 is the implementing directive of the hydrogen road vehicle directive EC 79/2009. It is one of the most comprehensive regulations for hydrogen components in mobile application and provides - in combination with existing railway standards - an acceptable level of safety for railways. Design rules, tests, thresholds and pass fail criteria of gaseous compressed hydrogen tanks and components can be found in Annex IV, parts 1 to 3. The minimum burst pressure ratios are defined in part 2, clause 3.6.. For carbon fiber reinforced tanks (Type 4) a burst pressure ratio of 2.25 times nominal working pressure (NWP) applies. With an NWP of 350 bar, the tank must sustain at least 787,5 bar. Acc. to clause 3.9, this burst test in combination with an ambient temperature cycle test (9 times duty cycles of 5.000 = 45.000 cycles) is repeated in a batch test every 200 tank (batch size can be extended after successful tests). Acc. to clause 3.10., every single manufactured tank must undergo specific production tests, such as hydraulic pressure test with a ratio of 1.5 times NWP. With an NWP of 350 bar, every tank is end-of-line-tested at 525 bar. The operating temperature of the tank is -40 °C to +85 °C. These measures provides a certain safety margin to the hazards caused by over filling, which however does not mean that EC 79 tanks are capable of being regularly over filled. The vehicle and or the filling station must protect the tanks from being over filled.	High	None	Other RCS
166	C16	Over filling / charging	UN ECE R 134	Clauses 5 to 7 and Annex 3 to 4	UN ECE R 134 will substitute EC 79/2009 and EU 406/2010 in the near future. However, the scope of R 134 is limited to the hydrogen tank and the directly attached safety components, such as solenoid valve, check valve and TPRD, while EC 79 has a wider scope an also includes pipework, fittings and components up to the filling receptacle. The requirements defined by R 134 for the tanks are similar to EU 406/2010 but testing is mostly done in sequences where the test sample must undergo several different stresses to reflect a characteristic conservative load profile in road application, which serve to reduce or avoid leakage of hydrogen and remain burst pressure over the tanks live. Transfering these test sequences to railways requires a more detailed analysis and comparison of load profiles. It is expected though that the safety level of tanks with an R 134 type approval provide at least the same level of safety compared to EC 79. The specification for the tank system can be found in clause 5. For carbon fiber reinforced tanks (Type 4) a burst ratio of 2.25 times nominal working pressure (NWP) applies. With an NWP of 350 bar, the tank must sustain at least 787,5 bar. Acc. to clause 9.3.2, this burst test in combination with an ambient temperature cycle test (2 times duty cycles of 11.000 = 22.000 cycles) is repeated in a batch test (besides several other batch tests) every 200 tank (batch size can be extended after successful tests). Acc. to clause 9.3.1., every single manufactured tank must undergo hydraulic pressure test with a ratio of 1.5 times NWP. With an NWP of 350 bar, every tank is end-of-line-tested at 525 bar. The operating temperature of the tank is -40 °C t +85 °C. These measures provides a certain safety margin to the hazards caused by over filling, which however does not mean that R 134 tanks are capable of being regularly over filled. The vehicle and or the filling station must protect the tanks from being over filled.	High	None	Other RCS
167	C16	Over filling / charging	EN 17127	5.3	EN 17127 defines requirements for hydrogen refuelling of road vehicles at pressures of 350 bar and 700 bar, for vehicles with EC 79 or R 134 type approved tanks and a maximum mass flow of 120 g/s. For the refuelling protocol the standard refers to SAE J2601-1, for the communication protocol to SAE J2799 and for the dispenser to ISO 17268. This communication protocol includes safety related stop signals in case of any criticality, such as over pressure or over temperature. The fuel station determines the residual pressure inside the vehicle with pressure pulse at start up of the refuelling process. The refuelling station has an additional pressure protection to avoid over filling. The gas temperature and pressure at the end of the refuelling process is crucial for the final state of charge and depends on the sensors of vehicle, refuelling station and the SAE protocols.	Medium	The refuelling protocols acc. to SAE J2601-1 do not apply for the size of hydrogen storage systems typically applied on railway vehicles. Functional safety aspects of the communication protocol and plausibility of sensing functions do not fulfil railway standards.	Other RCS
168	C16	Over filling / charging	ISO 19880-1	8.2	ISO 19880-1 defines requirements for hydrogen refuelling of road vehicles at pressures of 350 bar and 700 bar. For the refuelling protocol the standard refers to SAE J2601-1 and SAE J2601-2, for the communication protocol to SAE J2799 and for the dispenser to ISO 17268. This communication protocol includes safety related stop signals in case of any criticality, such as over pressure or over temperature. The fuel station determines the residual pressure inside the vehicle with pressure pulse at start up of the refuelling process. The refuelling station has an additional over pressure protection. This however does not avoid over filling. The gas temperature and pressure at the end of the refuelling process is crucial for the final state of charge and depends on the sensors of vehicle, refuelling station and the SAE protocols.	Medium	The refuelling protocols acc. to SAE J2601-2, which apply for railway vehicles, are not presciptive. Validated refuelling protocols for heavy-duty systems and at ambient temperatures are still to be developed. Functional safety aspects of the communication protocol and plausibility of sensing functions do not fulfil railway standards.	Other RCS
169	C16	Over filling / charging	SAE J2601-1	all	SAE J2601-1 defines refuelling protocols for road vehicles with tank sizes between 49.7 and 248.6 litres for 350 bar systems and a maximum flow rate of 60 g/s. A typical hydrogen train tank has a volume of over 250 to 350 litres per single cylinder of which it has at least a dozen connected to a hydrogen storage system. A flow rate of 60 g/s would not be compatible with Diesel refuelling times. In addition, SAE J2601-1 foresees refuelling of precooled hydrogen at -20 to -40 °C to allow fast refuelling and safely avoid any overheating due to gas dynamics and Joule-Thomson-Effect. For heavy-duty applications the needed energy to cool down the required amounts of hydrogen would not make the technology economically attractive. Hence the current development aims for ambient temperature refuelling, which requires more accurate temperature and pressure control and a validated process to safely avoid overheating and overpressure.	Low	SAE J2601-1 limits the maximum tank size to 248.6 litres and defines refuelling of precooled hydrogen at -20 to -40 °C. It is not applicable for refuelling of railway application hydrogen storage systems due to their volume and the intention to refuel at ambient temperature.	Other RCS

			Mitigation				Evaluation	
No.	ID	Trigger / Cause	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
170	C16	Over filling / charging	SAE J2601-2	all	SAE J2601-2 provides general rules for refuelling of heavy-duty road vehicles with a nominal working pressure of 350 bar and a maximum flow rate of 120 g/s. The standard is not prescriptive and does not define any validated fast refuelling protocols which savely avoid overheating and over pressure. The current development aims for ambient temperature refuelling, which requires more accurate temperature and pressure control and a validated process to safely avoid overheating and overpressure.	Low	SAE J2601-2 would apply for railway vehicles but the standard does not yet provide validated protocols for ambient temperature refuelling of heavy-duty and railway hydrogen storage systems.	Other RCS
171	C16	Over filling / charging	SAE J2799	all	SAE J2799 defines the communication interface between road vehicle and filling station with hydrogen couplings acc. to SAE J2600. It foresees infrared (IR) transmitter on both sides. The communication is also used to transmit safety related information and signals.	Low	The communication via IR emitters has not been validated with regards to functional safety and security according to railway standards. State of the art technologies for sensing gas temperatures inside heavy-duty hydrogen tanks do not deliver reliable values during the refuelling process, which currently puts the transmittance of safety related stopping signals at question.	Other RCS
172	C16	Over filling / charging	EU 1302/2014	---	TSI LOC&PAS does not specify any requirements for hydrogen storage or traction battery systems from getting over filled or overcharged. The interfaces between the infrastructure and the vehicles, such as electrants and hydrogen filling stations, needs to be defined and aligned with other subsystems of the railway system.	Low	TSI LOC&PAS needs to be revised e.g., by adding generic requirements for refuelling and charging and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2. The interfaces between the infrastructure and the vehicles, such as electrants and hydrogen filling stations, needs to be defined and aligned with other subsystems of the railway system.	Modification
173	C16	Over filling / charging	EN IEC 62928	12.2, 14.2.2.2, 14.4.1.2 and 14.4.1.3	IEC 62928, especially with reference to IEC 62619, provides a comprehensive set of safety requirements for lithium-ion battery systems. Conformity to those requirements is considered as a basic safety evidence, provided that functional safety of the battery management system (for non-inherent safe batteries) is proven. The main functions of the Battery Management System (BMS) are defined in chapter 4.3. These include supervision of e.g., temperature, voltage, state of charge. Requirements for voltage and temperature management are defined in chapters 12.2, 14.2.2.2, 14.4.1.2 and 14.4.1.3. They sufficiently protect the battery from overheating, when fulfiled.	High	None	No Modification
174	C17	Excessive mass flow	EN 17127	5.3	EN 17127 defines requirements for hydrogen refuelling of road vehicles at pressures of 350 bar and 700 bar, for vehicles with EC 79 or R 134 type approved tanks and a maximum mass flow of 120 g/s. For the refuelling protocol the standard refers to SAE J2601-1, for the communication protocol to SAE J2799 and for the dispenser to ISO 17268. The mass flow is typically regulated by the refuelling station and depends on the applied refuelling protocol. If the protocol is chosen based on incorrect assumptions or sensor signals, the mass flow may be too high and cause the tank system to heat up more quickly. This is typically compensated by pre cooling the hydrogen. A mass flow of 120 g/s at ambient gas temperature (e.g., 20 to 30 °C) is likely to cause overheating of the tank if continuously refuelled at the same rate. Vehicle side temperature measurements and communication protocols have not been validated with regards to functional safety for railway application.	Low	The refuelling protocols acc. to SAE J2601-1 do not apply for the size of hydrogen storage systems typically applied on railway vehicles. The maximum flow rate is limited to 120 g/s, which may cause overheating of the tanks when refuelling with ambient gas temperatures. Functional safety aspects of the communication protocol and plausibility of sensing functions do not fulfil railway standards.	Other RCS
175	C17	Excessive mass flow	ISO 17268	all	ISO 17268 is a comprehensive standard to for a safe and reliable design of refuelling connection devices. It defines different connectors for different pressure levels of which the H35HF hydrogen receptacle (high flow for commercial vehicle applications) is the one, which would fit the best for rolling stock. The flow rates are defined by the refuelling protocols and related standards, EN 17127 and SAE J2601-1 / 2. The current state of the art foresees different connectors, which are not in the scope of ISO 17268, that foresee a larger bore than the H35HF to allow higher flow rates for fast refuelling.	Low	ISO 17268 provides a comprehensive set of requirements for safe and reliable design of refuelling connectors. The current state of the art in railway application foresees different connectors, which are not in the scope of ISO 17268, that foresee a larger bore than the H35HF to allow higher flow rates for fast refuelling. These connectors are not compatible with EN 17127 and SAE J2601-1 / 2.	Other RCS
176	C17	Excessive mass flow	ISO 19880-1	8.2	ISO 19880-1 defines requirements for hydrogen refuelling of road vehicles at pressures of 350 bar and 700 bar. For the refuelling protocol the standard refers to SAE J2601-1 and SAE J2601-2, for the communication protocol to SAE J2799 and for the dispenser to ISO 17268. The mass flow is not limited by ISO 19880-1. It is limited by the applied protocol, e.g., SAE J2601-2, which sets the maximum flow at 120 g/s for heavy-duty 350 bar systems. As the refuelling station is likely to be capable of higher flows, the limitation of this rate is a safety function. Vehicle side temperature measurements and communication protocols have not been validated with regards to functional safety for railway application.	Low	The refuelling protocols acc. to SAE J2601-2, which apply for railway vehicles, are not presciptive. Validated refuelling protocols for heavy-duty systems and at ambient temperatures are still to be developed. Functional safety aspects of the communication protocol and plausibility of sensing functions, which have an influence on the flow rate, do not fulfil railway standards.	Other RCS
177	C17	Excessive mass flow	SAE J2601-1	all	SAE J2601-1 defines refuelling protocols for road vehicles with tank sizes between 49.7 and 248.6 litres for 350 bar systems and a maximum flow rate of 60 g/s. A typical hydrogen train tank has a volume of over 250 to 350 litres per single cylinder of which it has at least a dozen connected to a hydrogen storage system. A flow rate of 60 g/s would not be compatible with Diesel refuelling times. In addition, SAE J2601-1 foresees refuelling of precooled hydrogen at -20 to -40 °C to allow fast refuelling and safely avoid any overheating due to gas dynamics and Joule-Thomson-Effect. For heavy-duty applications the needed energy to cool down the required amounts of hydrogen would not make the technology economically attractive. Hence the current development aims for ambient temperature refuelling, which requires more accurate temperature and pressure control and a validated process to safely avoid overheating and overpressure.	Low	SAE J2601-1 limits the maximum tank size to 248.6 litres and defines refuelling of precooled hydrogen at -20 to -40 °C. It is not applicable for refuelling of railway application hydrogen storage systems due to their volume and the intention to refuel at ambient temperature.	Other RCS
178	C17	Excessive mass flow	SAE J2601-2	all	SAE J2601-2 provides general rules for refuelling of heavy-duty road vehicles with a nominal working pressure of 350 bar and a maximum flow rate of 120 g/s. The standard is not prescriptive and does not define any validated fast refuelling protocols which savely avoid overheating and over pressure. The current development aims for ambient temperature refuelling, which requires more accurate temperature and pressure control and a validated process to safely avoid overheating and overpressure.	Low	SAE J2601-2 would apply for railway vehicles but the standard does not yet provide validated protocols for ambient temperature refuelling of heavy-duty and railway hydrogen storage systems.	Other RCS
179	C17	Excessive mass flow	SAE J2799	all	SAE J2799 defines the communication interface between road vehicle and filling station with hydrogen couplings acc. to SAE J2600. It foresees infrared (IR) transmitter on both sides. The communication is also used to transmit safety related information and signals.	Low	The communication via IR emitters has not been validated with regards to functional safety and security according to railway standards. State of the art technologies for sensing gas temperatures inside heavy-duty hydrogen tanks do not deliver reliable values during the refuelling process, which currently puts the transmittance of safety related stopping signals at question.	Other RCS
180	C17	Excessive mass flow	EU 1302/2014	---	TSI LOC&PAS does not specify any requirements for hydrogen storage systems from getting refuelled with excessive mass flow.	Low	TSI LOC&PAS needs to be revised e.g., by adding generic requirements for refuelling of hydrogen systems and/or by referencing to existing and future standards, such as IEC 63341-2.	Modification
181	C18	Deep discharge	EU 406/2010	Annex IV, Parts 1 to 3	Type 4 tanks have the characteristic that the plastic liner inside the carbon fiber corpus requires a residual pressure in order to not loosen from the corpus due to its small wall thickness, especially with large tanks. This may lead to damages when quickly refuelling the tank again, which may lead to leakage. EU 406 defines a minimum residual pressure of 2 bar inside the tank. However, the cycle tests require a minimum pressure of at max. 20 bar, optionally less. The manufacturer specifies the minimum allowable pressure of the tank, which is typically set at around 10 bar. Type 1 to 3 tanks are not affected.	Low	The minimum allowable residual pressure of large heavy-duty Type 4 tanks is defined with 2 bar, which is too low. The integrator needs to be aware of this characteristic and provide vehicle side protection measures to avoid deep discharge. Type 1 to 3 tanks are not affected.	Other RCS
182	C18	Deep discharge	UN ECE R 134	Clauses 5 to 7 and Annex 3 to 4	Type 4 tanks have the characteristic that the plastic liner inside the carbon fiber corpus requires a residual pressure in order to not loosen from the corpus due to its small wall thickness, especially with large tanks. This may lead to damages when quickly refuelling the tank again, which may lead to leakage. R 134 does not define a residual pressure inside the tank. However, the cycle tests require a minimum pressure of at 20 bar. The manufacturer specifies the minimum allowable pressure of the tank, which is typically set at around 10 bar. Type 1 to 3 tanks are not affected.	Low	The minimum allowable residual pressure of large heavy-duty Type 4 tanks is not clearly defined. The integrator needs to be aware of this characteristic and provide vehicle side protection measures to avoid deep discharge. Type 1 to 3 tanks are not affected from this.	Other RCS
183	C18	Deep discharge	SAE J2601-1	6.4.1 and 8.3.1	SAE J2601-1 refuelling protocols foresee a lower limit of 5 bar initial pressure inside the tank. If the pressure in the tank is below 5 bar, the refueling process is aborted or not started (chapter 6.4.1 and 8.3.1). This is mainly to avoid overheating as the heat impact on the tank becomes worse, the lower the residual pressure is. For road vehicle application with tank sizes that fall under SAE J2601-1 (up to 248.6 litres), the characteristic of the liner at very low pressures is not as critical as it is with large heavy-duty tanks. Type 1 to 3 tanks are not affected.	Low	SAE J2601-1 is not applicable for heavy-duty refuelling. The minimum initial pressure is set lower than what most tank manufacturers specify as allowable residual pressure. Type 1 to 3 tanks are not affected.	Other RCS
184	C18	Deep discharge	SAE J2601-2	5.1	SAE J2601-2 specifies a lower SOC limit / minimum pressure of 5 bar initial pressure inside the tank. This is mainly to avoid overheating as the heat impact on the tank becomes worse, the lower the residual pressure is. However, it does not foresee the characteristics large heave duty Type 4 tanks, which typically have an allowable minimum pressure of around 10 bar. Type 1 to 3 tanks are not affected.	Low	SAE J2601-2 specifies a minimum initial pressure of 5 bar for refuelling. The minimum allowable residual pressure of large heavy-duty Type 4 tanks typically higher than that. The integrator needs to be aware of this characteristic and provide vehicle side protection measures to avoid deep discharge. Type 1 to 3 tanks are not affected.	Other RCS
185	C18	Deep discharge	EU 1302/2014	---	TSI LOC&PAS does not specify any requirements for hydrogen storage systems or traction battery systems to prevent deep discharge.	Low	TSI LOC&PAS needs to be revised e.g., by adding generic requirements to prevent deep discharge of hydrogen storage and traction battery systems and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
186	C18	Deep discharge	EN IEC 62928	14.4.1.2	EN IEC 62928 does not define specific measures to avoid deep discharge of batteries. Lithium-Ion cells typically react with degrading capacity of voltage as well as temperature development when being recharged after deep discharge. These values are typically supervised by the battery management system (BMS). The standard defines a deep discharge test acc. to EN 62619, chapter 7.2.6. However this test does not consider the behaviour of the cell when being recharged after deep discharge. It proves that the cell will not burn or explode when being discharged. Any measures to prevent deep discharge primarily improve availability and reliability of the battery.	High	None	No Modification
187	C19	Falling Objects	EU 1302/2014	---	TSI LOC&PAS does not specify any requirements for hydrogen storage systems or traction battery systems to protect them from falling objects.	Low	TSI LOC&PAS needs to be revised e.g., by adding generic requirements for falling objects on sensitive components.	Modification
188	C19	Falling Objects	EN IEC 62928	14.3.3 and 14.4.1.2	IEC 62928 requires several mechanical abuse tests on cell and module level, such as impact test, drop test, etc. (not leading to any fire or explosion) in clause 14.4.1.2. with reference to EN 62619 (similar tests are defined by UN 38.3, which can be transferred by conformity assessment). These tests provide basic evidence that the battery would sustain the impulse of an impact. However, a plastic deformation or puncturing of the battery will most likely lead to an immediate thermal reaction of the battery.	Medium	IEC 62928 should define requirements for mechanical protection of the battery case, especially when arranged on the car body roof or under floor.	Modification
189	C20	Vandalism / Terrorism	EN 45545-1	all	The EN 45545-series defines preventive measures for technical and vandalist ignition sources. The ignition models 1 to 3 and 5 as defined in annex A of EN 45545-1 mainly cover vandalist fires. The fulfilment of standard series including EN 50553 is considered an adequate measure to prevent vandalist fires to become so large to pose a thread to hydrogen or traction battery systems, expecting these systems to be placed outside of the car body or separated by fire barriers. For further details, see "C1 Fire and Ignition Sources (internal / external)".	High	None	No Modification
190	C20	Vandalism / Terrorism	EN 50553	all	EN 50553 defines a main sources of a critical fire source (Type 2) in nearly all passenger areas to be a luggage fire equivalent to ignition model 5 of EN 45545-1. As any part of the propulsion system can be generically considered a sensitive system function, the standard fulfilment already provide sufficient protection against the impact from a vandalist fire.	High	None	No Modification
191	C20	Vandalism / Terrorism	EU 1302/2014	---	TSI LOC&PAS does not specify any requirements for security of sensitive equipment, where vandalism or terrorism could have a catastrophic consequence.	Low	TSI LOC&PAS needs to be revised e.g., by adding generic requirements for security of sensitive equipment, especially hydrogen systems and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification
192	C21	Residual voltage	2006/42/EC	Annex 1, clause 1.5.2.	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1 must be considered. Clause 1.5.2. provides general requirements for protection static electrical charges. This is already sufficiently covered by the existing electrical railway standards, such an EN 50153.	Low	None	Other RCS
193	C21	Residual voltage	1999/92/EG	Annex I and II, especially clause 2.3	ATEX directive 1999/92/EG excludes vehicles for transportation. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage (depending on a dedicated hazard analysis). Furthermore, it is, together with its harmonized standards, the most comprehensive rule to assess potential formation of explosive atmospheres. If it can be demonstrated that the probability of a signficant release of hydrogen is low, the on board hydrogen system is not classified as an explosive zone acc. to Annex I. Generic requirements for organizational and workers safety measures are provided in Annex II. Clause 2.3 refers to avoidance of electrostatic discharge. Further details are provided in IEC 60079-10-1.	Low	None	Other RCS
194	C21	Residual voltage	ISO/TR 15916	7.5.9	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.). It provides general guidance in chapter 7.5.9 regarding the arrangement and choice of electrical components in the vicinity of potential leaks or vents and requires proper electrical grounding and avoidance of any static charges and sparks.	Low	None	Other RCS
195	C21	Residual voltage	EN 50155	all, especially 11 and 13	EN 50155 also requires components to be equipped with earthing acc. to EN 50153.	High	None	No Modification
196	C21	Residual voltage	EN IEC 62928	6.4, 8.3, 10.6 , 14.2.5, 14.4.2.4	IEC 62928 provides a comprehensive set of electrical safety requirements to prevent electrical hazards, safe handling during installation and maintenance. These requirements are defined in chapters 6.4, 8.3, 10.6, 14.2.5 and 14.4.2.4.	High	None	No Modification
197	C21	Residual voltage	EU 1302/2014	4.2.8.4	TSI LOC&PAS requires protection against electrical hazards (clause 4.2.8.4. with referene to EN 50153). However, all requirements under clause 4.2.8.2. apply to vehicles with overhead wires in the systems defined by TSI ENE. Hence, vehicles with on board energy supply are not covered.	Low	TSI LOC&PAS needs to be revised e.g., by adding electrical requirements for vehicles that are independent from catenary and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification

			Mitigation				Evaluation	
No.	**ID**	**Trigger / Cause**	**Applicable RCS**	**Applicable clauses**	**Assessment of suitability**	**Suitability for mitigation**	**Identified gap**	**Result**
198	C21	Residual voltage	EN 50153	all	EN 50153 deals with electrical safety and provides a comprehensive set of requirements for protection of passengers, staff and service personnel from electrical hazards, primarily electrocution e.g., caused by improper electrical installation, failure of electrical components or electrical arcing from outside. The standard applies for any electrical component and electrically conductive structure installed on a railway vehicle, regardless of its function. Hence, it applies for any component of the hydrogen and battery system as it does for any other vehicle component. EN 50153 is referenced by EN 50155, EN 45545-5 as well as TSI LOC&PAS.	High	None	No Modification
199	C22	Wear, poor / improper maintenance	1999/92/EG	Annex I and II, especially clause 2.5	ATEX directive 1999/92/EG excludes vehicles for transportation. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage (depending on a dedicated hazard analysis). Furthermore, it is, together with its harmonized standards, the most comprehensive rule to assess potential formation of explosive atmospheres. If it can be demonstrated that the probability of a signficant release of hydrogen is low, the on board hydrogen system is not classified as an explosive zone acc. to Annex I. Generic requirements for organizational and workers safety measures are provided in Annex II. Clause 2.5 generically refers to proper maintenance of the facilities with explosion protection measures. Further details are provided in IEC 60079-10-1.	Low	None	Other RCS
200	C22	Wear, poor / improper maintenance	EU 1302/2014	---	TSI LOC&PAS defines generic requirements for the documentation of safety relevant maintenance intervals. It does not define any ventilation requirements for areas with potential for explosive hazards.	Low	TSI LOC&PAS needs to be revised e.g., by adding maintenance requirements also for hydrogen and traction battery systems and/or by referencing to existing and future standards, such as IEC 62928, IEC 63341-1 and IEC 63341-2.	Modification

IV List of Railway RCS without need for modification

No.	Applicable RCS	Title	Applicable to mitigate following Causes	Suitablity for mitigation
1	EN 12663-1	Railway applications - Structural requirements of railway vehicle bodies - Part 1: Locomotives and passenger rolling stock	C4 Operational shock / vibration C10 Improper mechanical design C12 Crash / Derailment / mechanical impact	High
2	EN 15085-X	Railway applications - Welding of railway vehicles and components - series	C10 Improper mechanical design	High
3	EN 45545-4	Railway applications – Fire protection on railway vehicles – Part 4: Fire safety requirements for rolling stock design;	C1 Fire or Ignition Source (internal, external)	Medium
4	EN 50121-3-1	Railway applications - Electromagnetic compatibility - Part 3-1: Rolling stock - Train and complete vehicle	C5 Electro magnetic emission / interference C11 Improper electrical design	High
5	EN 50121-3-2	Railway applications - Electromagnetic compatibility - Part 3-2: Rolling stock - Apparatus (analogue to IEC 62236-3-2)	C5 Electro magnetic emission / interference C11 Improper electrical design	High
6	EN 50122-1	Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 1: Protective provisions against electric shock	C13 External short circuit / arcing	Low
7	EN 50124-1	Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment	C11 Improper electrical design C13 External short circuit / arcing	High
8	EN 50124-2	Railway applications – Insulation coordination – Part 2: Overvoltages and related protection	C13 External short circuit / arcing	High
9	EN 50125-1	Railway applications - Environmental conditions for equipment - Part 1: Rolling stock and on-board equipment	C1 Fire or Ignition Source (internal, external) C2 Thermal impact / over temperature C3 Cold impact / under temperature C8 Corrosion (dusts, aerosols, humidity, chemicals) C11 Improper electrical design C13 External short circuit / arcing	High
10	EN 50128	Railway applications - Communication, signalling and processing systems - Software for railway control and protection systems	C11 Improper electrical design	High
11	EN 50129	Railway applications - Communication, signalling and processing systems - Safety related electronic systems for signalling	C11 Improper electrical design	High
12	EN 50153	Railway applications - Rolling stock - Protective provisions relating to electrical hazards	C11 Improper electrical design C13 External short circuit / arcing C21 Residual voltage	High
13	EN 50343	Railway applications - Rolling stock - Rules for installation of cabling	C11 Improper electrical design C13 External short circuit / arcing	High

V List of Railway Application RCS with need for modification

No.	Applicable RCS	Title	Causes where gaps have been identified	Suitability for mitigation	Gaps / deficits	Priority
1	EN 15227	Railway applications - Crashworthiness requirements for rail vehicles	C12 Crash / Derailment / mechanical impact	High	EN 15227 does not refer to the component arrangement in deformation zones of the car body. As this is not in the sense of this standard, the existing and future standards for hydrogen and traction battery systems, such as IEC 62928, IEC 63341-1 and IEC 63341-2, shall prohibit the arrangement of any hydrogen or battery components in the deformation zones of the car body.	Low
2	EN 45545-1	Railway applications - Fire protection on railway vehicles - Part 1: General	C1 Fire or Ignition Source (internal, external) C20 Vandalism / Terrorism	High	Running capability requirements in 5.2.3, Table 1 (harmonized with TSI LOC&PAS) currently do not reflect the time beyond evacuation of passengers and the catastrophic impact of a further developing fire on Traction Batteries and/or Hydrogen Storage Systems.	Medium
3	EN 45545-2	Railway applications - Fire protection on railway vehicles - Part 2: Requirements for fire behaviour of materials and components	C1 Fire or Ignition Source (internal, external)	High	No specific requirement set for typical combustible materials of an alternative propulsion system, such as CRP of Type 3 or Type 4 hydrogen tanks (currently fulfiling R9, acc. to clause 4.2 l), because samples for flame spread test cannot be produced from the cylindric tanks).	Low
4	EN 45545-3	Railway applications - Fire protection on railway vehicles - Part 3: Fire resistance requirements for fire barriers	C1 Fire or Ignition Source (internal, external)	High	No specific requirement for hydrogen tank systems and its piping to protect it from onboard fires (optionally external fires), protect the structure (e.g., car body roof) from collapsing after extended heat impact, causing further critical damage on hydrogen tanks. No specific requirement for protection of passenger and staff areas from fires starting in the hydrogen tank system and its piping.	High
5	EN 45545-5	Railway applications - Fire protection on railway vehicles - Part 5: Fire safety requirements for electrical equipment including that of trolley buses, track guided buses and magnetic leviation vehicles	C1 Fire or Ignition Source (internal, external) C11 Improper electrical design C13 External short circuit / arcing	Medium	No consideration of Lithium-Ion-Batteries, Fuel Cells and Hydrogen Storage Systems as well as the corresponding railway application standards, which already exist. It does not require electrical components to comply with shock and vibration requirements acc. to EN 61373 or alternatively fulfil railway suitability requirements of EN 50155.	Medium
6	EN 45545-6	Railway applications – Fire protection on railway vehicles – Part 6: Fire control and management systems	C1 Fire or Ignition Source (internal, external)	High	There is no consideration of Lithium-Ion-Batteries, Fuel Cells and Hydrogen Storage Systems with regards to fire detection and functional reaction upon fire detection.	Medium
7	EN 45545-7	Railway applications – Fire protection on railway vehicles – Part 7: Fire safety requirements for flammable liquid and flammable gas installations	C1 Fire or Ignition Source (internal, external)	Low	The standard was not intended for hydrogen gas installations and requires a comprehensive update and normative references to future standards, such as IEC 63341-1 and 2.	High
8	EN 50155	Railway applications - Rolling stock - Electronic equipment	C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock / vibration C8 Corrosion (dusts, aerosols, humidity, chemicals) C10 Improper mechanical design C12 Crash / Derailment / mechanical impact	High	The scope of EN 50155 is limited to electric and electronic components and there is currently no equivalent standard requiring these tests for hydrogen systems and components. Either the scope of EN 50155 is extended to non-electrical component testing or other still to be developed standards, such as IEC 63341-1 and IEC 63341-2 adopt the international hydrogen standards and directives and define additional requirements. The shock and vibration test is needed to test the mechanical integrity of racks and housings, hydrogen components and fittings as well as the function of mechanical or electro-mechanical safety components of the hydrogen gas system. The function test is only required by EN 50155 (chapter 13.4.11.3 and 13.4.11.4), hence testing acc. to IEC 61373 only, would not cover this aspect. In order to prove enhanced tightness (no leakage under all expectable operational stress scenarios), the entire gas system must undergo a functional inspection and a pressure and tightness test before and after the shock and vibration test, which is not part of IEC 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt IEC 61373 and EN 50155 and define additional requirements.	Medium
9	EN 50215	Railway applications - Rolling stock - Testing of rolling stock on completion of construction and before entry into service	C11 Improper electrical design	Medium	EN 50215 adresses testing of thermal combustion engines, but not for hydrogen fuel cells, hydrogen storage systems and high voltages batteries. The standard should be updated to cover state of the art railway propulsion technology.	Low
10	EN 50553	Railway applications – Requirements for running capability in case of fire on board of rolling stock	C1 Fire or Ignition Source (internal, external)	High	Running capability requirements (defined by EN 45545-1 and TSI LOC&PAS) currently do not reflect the time beyond evacuation of passengers and the catastrophic impact of a further developing fire on Traction Batteries (TB) and/or Hydrogen Storage Systems (HSS). The definition of Type 2 and Type 3 fires (chapter 5.2) requires an update to cover new hazards from TB and HSS as well as Fuel Cells or Hydrogen Combustion Engines. The requirements to achieve conformity in the decision boxes (chapter 6) must be updated to cover the new technologies and define new functional requirements.	High
11	IEC 61373	Railway applications - Rolling stock equipment - Shock and vibration tests	C1 Fire or Ignition Source (internal, external) C4 Operational shock / vibration C10 Improper mechanical design C12 Crash / Derailment / mechanical impact	High	The shock and vibration test is needed to test the mechanical integrity of racks and housings, hydrogen components and fittings as well as the function of mechanical or electro-mechanical safety components of the hydrogen gas system. The function test is only required by EN 50155 (chapter 13.4.11.3 and 13.4.11.4), hence testing acc. to IEC 61373 only, would not cover this aspect. In order to prove enhanced tightness (no leakage under all expectable operational stress scenarios), the entire gas system must undergo a functional inspection and a pressure and tightness test before and after the shock and vibration test, which is not part of IEC 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt IEC 61373 and EN 50155 and define additional requirements.	High

No.	Applicable RCS	Title	Causes where gaps have been identified	Suitability for mitigation	Gaps / deficits	Priority
12	EN IEC 62928	Railway applications - Rolling stock - Onboard lithium-ion traction batteries	C1 Fire or Ignition Source (internal, external) C2 Thermal impact / over temperature C4 Operational shock / vibration C9 Human error (manufacturing, operation, maintenance) C12 Crash / Derailment / mechanical impact C19 Falling Objects	High	Neither the measurement of the toxicity and flammability of released gases during thermal runaway, nor a limitation of such is defined in IEC 62928 or IEC 62619 respectively. There are no functional requirement to minimize propagation (e.g., by continuous on board cooling). There are no requirements to support incident management, e.g., by informing fire brigades about the installed technology and provide means for an immediate and effective fire attack. IEC 62928 does not define requirements to protect the battery from excessive heat caused by sun radiation of waste heat from adjacent components. This also applies for future standards IEC 63341-1 and IEC 63341-2 with regards to fuel cells and hydrogen storage systems. Especially hydrogen tanks with darf carbon fiber corpusses quickly heat up from sun radiation. IEC 62928 and there referenced standards IEC 61373 and IEC 60571 (IEC pendant to EN 50155) respectively do not define any functional tests during random vibration, as required by EN 50155, 13.4.11. IEC 62928 does not define requirements to protect the battery from false operation or mishandling. There are no requirements to support incident management, e.g., by informing fire brigades about the installed technology and provide means for an immediate and effective fire attack. IEC 62928 should prohibit integration of battery cases in the primary and secondary crash deformation zones of the car body. This also applies for future standards IEC 63341-1 and IEC 63341-2 with regards to fuel cells and hydrogen storage systems. IEC 62928 should define requirements for mechanical protection of the battery case, especially when arranged on the car body roof or under floor.	Medium
13	EU 1302/2014	COMMISSION REGULATION (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the ‘rolling stock — locomotives and passenger rolling stock’ subsystem of the rail system in the European Union	C1 Fire or Ignition Source (internal, external) C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock / vibration C5 Electro magnetic emission / interference C6 Hydrogen purity / particle ingress C7 Hydrogen incompatibility C8 Corrosion (dusts, aerosols, humidity, chemicals) C9 Human error (manufacturing, operation, maintenance) C10 Improper mechanical design C11 Improper electrical design C12 Crash / Derailment / mechanical impact C13 External short circuit / arcing C14 Input over voltage / over current C15 Clogging / aerodynamic effects C20 Vandalism / Terrorism C21 Residual voltage C22 Wear, poor / improper maintenance	Low	TSI LOC&PAS needs to be revised e.g., by adding generic requirements for alternative propulsion with traction batteries and/or hydrogen and define a minimum set of safety requirements, such as - consideration of potential fire sources from new technologies in 4.2.10.3.4. (3), to be harmonized with EN 45545-3 - consideration of additional running time for vehicles with hydrogen or lithium-batteries in 4.2.10.4.4., to be harmonized with EN 50553 - new fire risk areas from new technologies in 6.2.3.23., to be harmonized with EN 45545-6 - new shock and vibration testing of safety relevant components, - new EMC testing of safety relevant components, - new requirements for hydrogen compatibility, - new corrosion protection of safety relevant materials and components, - new requirements to limit human error, - new requirements for enhanced tightness of hydrogen installations, - new electrical safety requirements for vehicles that are independent from catenary (by extending the scope of clause 4.2.8.4.), - new requirements for arrangement of hydrogen storage and traction battery systems outside of crash deformation zones (e.g., in clause 4.2.2.5.), - new requirements to prevent deep discharge of Type 4 hydrogen storage and traction battery systems, - new requirements for protection from falling objects on sensitive components, - new security measures of sensitive equipment, - new maintenance requirements e.g., by referencing to existing and future standards, such as IEC 62928, IEC 63341-1, IEC 63341-2, etc. In addition the interfaces between the infrastructure and the vehicles, such as electrants and hydrogen filling stations, needs to be defined and aligned with other subsystems of the railway system. This includes the hydrogen purity, gas temperature, filling rate, nozzle, etc.	

VI List of applicable RCS from other industries

No.	Applicable RCS	Title	Applicable to mitigate following Causes	Suitability for mitigation	Remarks
1	1999/92/EG	DIRECTIVE 1999/92/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 1999 on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres	C9 Human error (manufacturing, operation, maintenance) C10 Improper mechanical design C13 External short circuit / arcing C15 Clogging / aerodynamic effects C21 Residual voltage C22 Wear, poor / improper maintenance	Low	ATEX directive 1999/92/EG excludes vehicles for transportation. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage (depending on a dedicated hazard analysis). Furthermore, it is, together with its harmonized standards, a comprehensive rule to assess potential formation of explosive atmospheres. If it can be demonstrated that the probability of a significant release of hydrogen is low, the on-board hydrogen system is not classified as an explosive zone acc. to Annex I. Generic requirements for organizational and workers safety measures are provided in Annex II.
2	2006/42/EC	DIRECTIVE 2006/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006 on machinery, and amending Directive 95/16/EC	C1 Fire or Ignition Source (internal, external) C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock / vibration C5 Electro magnetic emission / interference C7 Hydrogen incompatibility C8 Corrosion (dusts, aerosols, humidity, chemicals) C9 Human error (manufacturing, operation, maintenance) C10 Improper mechanical design C11 Improper electrical design C21 Residual voltage	Low	2006/42/EG does also not apply for railway vehicles but applies for machines installed on railway vehicles. As a hydrogen and battery system can be considered a machine attached to a railway vehicle, at least the general safety requirements acc. to Annex 1, clause 1 must be considered.
3	2014/30/EU	DIRECTIVE 2014/30/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility (recast)	C5 Electro magnetic emission / interference	Medium	2014/30/EU specifically describes principal requirements for electrical devices with regards to electro magnetic compatibility and is the basis for product certification in this field. Depending on the test and assessment basis of the related certification, it may be possible to assess fulfillment of the requirements from EN 50121-3-2 on component basis. Adopting components with 2014/30/EU certification requires assessment with the requirements from EN 50121-3-2.
4	2014/34/EU	DIRECTIVE 2014/34/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres	C9 Human error (manufacturing, operation, maintenance) C10 Improper mechanical design C11 Improper electrical design C13 External short circuit / arcing C14 Input over voltage / over current	Medium	ATEX product directive 2014/34/EU itself does not apply for railway vehicles. However, it may apply for workers safety whenever a hydrogen vehicle is refuelled or parked or operated inside a workshop or depot with a pressurized storage. Furthermore, it is, together with its harmonized standards, a comprehensive rule to assess explosive protection safety systems and devices suitable to work inside explosive atmospheres or outside with a safety related control function. If it can be demonstrated that the probability of a significant release of hydrogen is low, the on-board hydrogen system is not classified as an explosive zone, which would not require any components of the vehicle to fulfil ATEX product directive.
5	2014/68/EU	DIRECTIVE 2014/68/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 May 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment	C10 Improper mechanical design	High	Pressure Equipment Directive (PED) regulates in particular stationary installations as well as installations for industrial trucks under internal pressure >0,5 bar. It excludes road vehicles and their components, but does not explicitly exclude railways in its scope of application. PED defines essential requirements for the design and manufacturing process of pressure vessels, components and assemblies as well as equipment with safety function. Besides many generic non-prescriptive requirements, PED defines a test pressure ratio of 1.43 of the maximum possible operating pressure (PS) for end-of-line testing, which means for a nominal working pressure (NWP) at 15 °C of 350 bar a test pressure of 438 bar (at 85°C) x 1.43 = 626 bar. There is currently no standard, which is harmonized with PED, that applies to Type 3 and Type 4 hydrogen pressure vessels at NWPs of 350 or 700 bar, which complicates a CE-marking acc. PED for these vessels. Furthermore, an assembly certification acc. to PED requires all components to be compliant with PED. If the vessel follows automotive regulations, such as EC 79 or R 134, it is formally not possible for the Notified Body PED to certify the assembly.
6	EC 79/2009	REGULATION (EC) No 79/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 January 2009 on type-approval of hydrogen-powered motor vehicles, and amending Directive 2007/46/EC	C1 Fire or Ignition Source (internal, external) C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock / vibration C7 Hydrogen incompatibility C8 Corrosion (dusts, aerosols, humidity, chemicals) C10 Improper mechanical design C12 Crash / Derailment / mechanical impact C16 Over filling / charging	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Tightness of tanks and components and their media compatibility under the given operating conditions is sufficiently proven by EC 79 type approval. Adopting components with EC 79 type approval requires a comparison with the boundary conditions of railway application and closure of these gaps with additional tests and design rules from existing and still to be developed railway standards, such as IEC 63341-2: - shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11. - validation of fixations acc. to EN 12663-1, 6.5.2 - consideration of the deformation zones acc. to EN 15227, where components must not be arranged. - EMC tests acc. to EN 50121-3-2. It also requires an assessment of mechanical stress due to thermal expansion, especially with regards to longer pieces of pipes, in order to avoid mechanical stress on pipes, fittings and components. The minimum allowable residual pressure of large heavy-duty tanks is defined with 2 bar acc. to EU 406, which is too low for Type 4 tanks and may lead to damages of the liner. The integrator needs to be aware of this characteristic and provide vehicle side protection measures to avoid deep discharge. Type 1 to 3 tanks are not affected.

No.	Applicable RCS	Title	Applicable to mitigate following Causes	Suitability for mitigation	Remarks
7	EU 406/2010	COMMISSION REGULATION (EU) No 406/2010 of 26 April 2010 implementing Regulation (EC) No 79/2009 of the European Parliament and of the Council on type-approval of hydrogen-powered motor vehicles	C1 Fire or Ignition Source (internal, external) C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock / vibration C7 Hydrogen incompatibility C8 Corrosion (dusts, aerosols, humidity, chemicals) C10 Improper mechanical design C12 Crash / Derailment / mechanical impact C16 Over filling / charging	High	EC 79/2009 and EU 406/2010 respectively will be withdrawn and replaced by UN ECE R134. Both regulations are made for road vehicles only. Tightness of tanks and components and their media compatibility under the given operating conditions is sufficiently proven by EC 79 type approval. Adopting components with EC 79 type approval requires a comparison with the boundary conditions of railway application and closure of these gaps with additional tests and design rules from existing and still to be developed railway standards, such as IEC 63341-2: - shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11. - validation of fixations acc. to EN 12663-1, 6.5.2 - consideration of the deformation zones acc. to EN 15227, where components must not be arranged. - EMC tests acc. to EN 50121-3-2. It also requires an assessment of mechanical stress due to thermal expansion, especially with regards to longer pieces of pipes, in order to avoid mechanical stress on pipes, fittings and components. The minimum allowable residual pressure of large heavy-duty tanks is defined with 2 bar acc. to EU 406, which is too low for Type 4 tanks and may lead to damages of the liner. The integrator needs to be aware of this characteristic and provide vehicle side protection measures to avoid deep discharge. Type 1 to 3 tanks are not affected.
8	EU 2021/535	COMMISSION IMPLEMENTING REGULATION (EU) 2021/535 of 31 March 2021 laying down rules for the application of Regulation (EU) 2019/2144 of the European Parliament and of the Council as regards uniform procedures and technical specifications for the type-approval of vehicles, and of systems, components and separate technical units intended for such vehicles, as regards their general construction characteristics and safety	C7 Hydrogen incompatibility	High	EU 2021/535 regulates the type approval for road vehicles and does not apply for railway vehicles. It requires materials of the hydrogen storage system to be compatible with hydrogen by refering to several international and north american standards. For metallic materials it refers to test according ISO 11114-4. It closes the gap from R134 after withdrawal of EC79, since R134 does not specify requirements for hydrogen compatibility.
9	EN 1127-1	Explosive atmospheres - Explosive prevention and protection - Part 1: Basic concepts and methodology	C10 Improper mechanical design	High	EN 1127-1 defines the term "enhanced tightness" in clause 3.2 and Annex B, meaning that an installation does not permeate or leak sufficient amounts of medium to create an explosion zone under all operating conditions, which is the basic design goal of any hydrogen installation.
10	EN 1779	Non-destructive testing - Leak testing - Criteria for the method and technique selection	C9 Human error (manufacturing, operation, maintenance)	High	EN 1779 provides a number of leak testing methods and their criteria for correctly choosing the right method. It serves to choose and conduct the correct leak testing methods after assembly, maintenance or during regular inspection in order to avoid leaks in operation.
11	EN 17124	Hydrogen fuel - Product specification and quality assurance - Proton exchange membrane (PEM) fuel cell applications for road vehicles	C6 Hydrogen purity / particle ingress	Low	EN 17124 defines methods how to check the quality of the hydrogen especially used with PEM-fuel cells and delivers also some information about the effect of impurities. It serves for availability and reliability of the power generation function of the fuel cells rather than mitigating a safety hazard.
12	EN 17127	Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols	C16 Over filling / charging C17 Excessive mass flow	Medium	EN 17127 defines requirements for hydrogen refuelling of road vehicles at pressures of 350 bar and 700 bar, for vehicles with EC 79 or R 134 type approved tanks and a maximum mass flow of 120 g/s. For the refuelling protocol the standard refers to SAE J2601-1 (not applicable for railways), for the communication protocol to SAE J2799 and for the dispenser to ISO 17268. This communication protocol includes safety related stop signals in case of any criticality, such as over pressure or over temperature.
13	ISO 17268	Gaseous hydrogen land vehicle refuelling connection devices	C17 Excessive mass flow	Low	ISO 17268 provides a comprehensive set of requirements for safe and reliable design of refuelling connectors. The current state of the art in railway application foresees different connectors, which are not in the scope of ISO 17268, that foresee a larger bore than the H35HF to allow higher flow rates for fast refuelling. These connectors are not compatible with EN 17127 and SAE J2601-1 / 2.
14	EN 60068-2-11	Environmental testing - Part 2: Tests; test Ka: Salt mist	C8 Corrosion (dusts, aerosols, humidity, c	High	EN 60068-2-11 provides a test method for salt spray testing of components. This test can be applied on specific sensitive components and materials, which may corrode due to salty air (e.g. operation close to sea)
15	IEC 60079-10-1	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres - Edition 3.0	C10 Improper mechanical design C15 Clogging / aerodynamic effects	High	IEC 60079-10-1 comprehensively provides rules for definition of zones with explosive atmospheres, assess releases, assess dilution and ventilation and define the topological limits of a zone. It contains additional information for the assessment of hydrogen in an informative Annex H, which makes reference to ISO/TR 15916.
16	IEC 60529	Degrees of protection provided by enclosures (IP Code)	C8 Corrosion (dusts, aerosols, humidity, c	High	EN 60529 provides test methods and classifications for tightness degree of component housings and enclosures. It may be applicable to electrical components, such as batteries or control units but is rather unlikely for hydrogen components due to the need to active and passive ventilation.
17	ISO 11114-1	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 1: Metallic materials	C7 Hydrogen incompatibility	High	ISO 11114-1 applies to the compatibility of metal tanks and valves in contact with gases. It provides a list of gases and metals for tanks and valves, which are compatible with each other or require additional measures. The application of this standard provides basic material integrity with regards to hydrogen compatibility, especially with regards to pipes, fittings and valves, which are in contact with hydrogen.
18	ISO 11114-2	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 2: Non-metallic materials	C7 Hydrogen incompatibility	High	ISO 11114-2 applies to the compatibility of non-metallic materials, such as gaskets, in contact with gases. It provides a list of gases and plastics and elastomers, which are compatible with each other or require additional measures. The application of this standard provides basic material integrity with regards to hydrogen compatibility, especially with regards to gaskets inside any fittings, valves or flexible tubes, which are in contact with hydrogen.
19	ISO 11114-4	Transportable gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 4: Test methods for selecting steels resistant to hydrogen embrittlement	C7 Hydrogen incompatibility	High	ISO 11114-4 provides test methods for steels that resist hydrogen embrittlement. The application of this standard provides basic material integrity with regards to hydrogen compatibility, especially with regards to pipes fittings and valves, which are in contact with hydrogen.
20	ISO 11114-5	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 5: Test methods for evaluating plastic liners	C7 Hydrogen incompatibility	High	ISO 11114-5 provides test methods for testing the integrity of plastic liners inside hydrogen tanks (Type 4). This new standard will become a mandatory validation method for liners of any type 4 tank and will serve to mitigate the probability of leakages.
21	ISO 14687	Hydrogen fuel quality - Product specification	C6 Hydrogen purity / particle ingress	High	ISO 14687 defines purities and test methods for different use cases of hydrogen (for gaseous hydrogen and PEM fuel cells in mobile application Type 1 D applies).
22	ISO 19453-6	Road vehicles - Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles - Part 6: Traction battery packs and systems	C4 Operational shock / vibration	High	Shock and vibration testing acc. to ISO 19453-6 is typically used in the automotive industry. It is possible to assess conformity to IEC 61373 based on the test profile. However, IEC 61373 is more conservative in shock impulse, which lasts for 30 ms instead of 6 ms. If ISO 19453-6 test is combined with shock impulses of 30 ms in the shock test, it fully covers IEC 61373.

No.	Applicable RCS	Title	Applicable to mitigate following Causes	Suitability for mitigation	Remarks
23	ISO 19880-1	Gaseous hydrogen - Fuelling stations - Part 1: General requirements	C16 Over filling / charging C17 Excessive mass flow	Medium	ISO 19880-1 defines requirements for hydrogen refuelling of road vehicles at pressures of 350 bar and 700 bar. For the refuelling protocol the standard refers to SAE J2601-1 (not applicable for railways) and SAE J2601-2 (not prescriptive), for the communication protocol to SAE J2799 and for the dispenser to ISO 17268. This communication protocol includes safety related stop signals in case of any criticality, such as over pressure or over temperature.
24	ISO 20485	Non-destructive testing - Leak testing - Tracer gas method	C9 Human error (manufacturing, operation, maintenance)	High	ISO 20485 provides rules and instructions for several leak testing methods, such as the sniffer method in clause 9.6. It serves to apply proper leak testing methods after assembly, maintenance or during regular inspection in order to avoid leaks in operation.
25	ISO/TR 15916	Basic considerations for the safety of hydrogen systems	C1 Fire or Ignition Source (internal, external) C2 Thermal impact / over temperature C6 Hydrogen purity / particle ingress C7 Hydrogen incompatibility C8 Corrosion (dusts, aerosols, humidity, chemicals) C9 Human error (manufacturing, operation, maintenance) C10 Improper mechanical design C11 Improper electrical design C13 External short circuit / arcing C15 Clogging / aerodynamic effects C21 Residual voltage	Medium	ISO/TR 15916 consolidates state of the art hydrogen knowledge and experience from the basic physical properties to safety considerations for gaseous and liquid hydrogen applications. The technical report is not binding but serves as literature and knowledge basis independently of the foreseen hydrogen application (stationary, mobile, etc.).
26	SAE J2601-1	Fueling Protocol for Gaseous Hydrogen Powered heavy-duty Vehicles	C2 Thermal impact / over temperature C16 Over filling / charging C17 Excessive mass flow C18 Deep discharge	Low	SAE J2601-1 defines refuelling protocols for road vehicles with tank sizes between 49.7 and 248.6 litres, refuelled at a maximum flow rate to 60 g/s um 350 or 700 bar and with precooled hydrogen at -20 to -40 °C. It is not applicable for refuelling of railway application hydrogen storage systems due to their volume and the intention to refuel at ambient gas temperatures.
27	SAE J2601-2	Fuelling Protocol for Gaseous Hydrogen Powered heavy-duty Vehicles	C2 Thermal impact / over temperature C16 Over filling / charging C17 Excessive mass flow C18 Deep discharge	Low	SAE J2601-2 provides general rules for refuelling of heavy-duty road vehicles with a nominal working pressure of 350 bar and a maximum flow rate of 120 g/s. It would apply for railway vehicles but the standard does not yet provide validated protocols for ambient temperature refuelling of heavy-duty and railway hydrogen storage systems. It specifies a minimum initial pressure of 5 bar for refuelling. The minimum allowable residual pressure of large heavy-duty Type 4 tanks typically higher (around 10 bar). The integrator needs to be aware of this characteristic and provide vehicle side protection measures to avoid deep discharge. Type 1 to 3 tanks are not affected.
28	SAE J2799	Hydrogen Surface Vehicle to Station Communications Hardware and Software	C16 Over filling / charging C17 Excessive mass flow	Low	SAE J2799 defines the communication interface between road vehicle and filling station with hydrogen couplings acc. to SAE J2600. It foresees infrared (IR) transmitter on both sides. The communication is also used to transmit safety related information and signals. The communication via IR emitters has not been validated with regards to functional safety and security according to railway standards. State of the art technologies for sensing gas temperatures inside heavy-duty hydrogen tanks do not deliver reliable values during the refuelling process, which currently puts the transmittance of safety related stopping signals at question.
29	UN ECE R 10	Regulation No 10 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility	C5 Electro magnetic emission / interference	Medium	The ECE R 10 describes tests in order to proove the electromagnetic compatibility of vehicles and components used in vehicles. It is possible to assess fulfillment of the requirements from EN 50121-3-2 on component basis. Adopting components with R 10 type approval requires assessment with the requirements from EN 50121-3-2.
30	UN ECE R 134	Regulation No 134 of the Economic Commission for Europe of the United Nations (UN/ECE) - Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fuelled vehicles (HFCV)	C1 Fire or Ignition Source (internal, external) C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock / vibration C5 Electro magnetic emission / interference C7 Hydrogen incompatibility C8 Corrosion (dusts, aerosols, humidity, chemicals) C10 Improper mechanical design C11 Improper electrical design C12 Crash / Derailment / mechanical impact C14 Input over voltage / over current C16 Over filling / charging C18 Deep discharge	High	UN ECE R 134 will substitute EC 79/2009 and EU 406/2010 in the near future. However, the scope of R 134 is limited to the hydrogen tank and the directly attached safety components, such as solenoid valve, check valve and TPRD, while EC 79 has a wider scope an also includes pipework, fittings and components up to the filling receptacle. The requirements defined by R 134 for the tanks are similar to EU 406/2010 but testing is mostly done in sequences where the test sample must undergo several different stresses to reflect a characteristic conservative load profile in road application, which serve to reduce or avoid leakage of hydrogen and remain burst pressure over the tanks live. Tightness of tanks and components under the given operating conditions is sufficiently proven by R 134 type approval. However, R 134 does not raise any requirements for hydrogen compatibility. Adopting components with R 134 type approval requires a comparison with the boundary conditions of railway application and closure of these gaps with additional tests and design rules from existing and still to be developed railway standards, such as IEC 63341-2: - shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11. - validation of fixations acc. to EN 12663-1, 6.5.2 - consideration of the deformation zones acc. to EN 15227, where components must not be arranged. - EMC tests acc. to EN 50121-3-2. It also requires an assessment of mechanical stress due to thermal expansion, especially with regards to longer pieces of pipes, in order to avoid mechanical stress on pipes, fittings and components. The minimum allowable residual pressure of large heavy-duty Type 4 tanks is not clearly defined. The integrator needs to be aware of this characteristic and provide vehicle side protection measures to avoid deep discharge. Type 1 to 3 tanks are not affected from this

VII List of Hazards where no applicable RCS exists

No.	Cause	related Faults	related Hazards	Description of technical issue
1	C1 Fire / Ignition source (internal, external)	F1 Leakage F2 Vent F3 Burst	H1 Fire hazards H2 Explosion hazards	There is no RCS that requires component and vehicle manufacturers to consider the possibilities for the fire brigades to effectively extinguish a fire, such as a battery fire. The physical integration typically does not allow any effective firefighting. There is also no requirement to consider the hazard for fire fighters in case of an emergency.
2	C2 Thermal impact / over temperature	F1 Leakage F2 Vent F3 Burst F4 Overpressure F5 Overtemperature	H1 Fire hazards H2 Explosion hazards H3 Pressure related hazards	There is no RCS that defines adequate measures to prevent hydrogen tanks from excessive sun radiation or heat dissipation.
3	C11 Improper electrical design (including functional safety of E/E/PE systems)	F1 Leakage F2 Vent F12 Spark generation F14 Insufficient Ventilation	H1 Fire hazards H2 Explosion hazards	There is no RCS that defines requirements how to validate the correct placement of H2-Sensors inside a confined space. It is unclear which boundary conditions shall be tested or simulated to cover all potential operational situations. This is an important aspect when H2 sensors have a certain safety relevance as a result from the risk analysis and require functional safety analysis.
4	C15 Clogging / aerodynamic effects	F14 Insufficient Ventilation	H2 Explosion hazards	There is no RCS that clearly defines measures to foresee inspection and cleaning of any ventilation system, especially when a tank system is placed inside a confined space.
5	C16 Over filling	F1 Leakage F2 Vent F3 Burst F4 Overpressure F5 Overtemperature	H1 Fire hazards H2 Explosion hazards H3 Pressure related hazards	There is no RCS that adequately prevents heavy-duty tank systems from over filling, especially when refuelling at ambient gas temperature is foreseen.
6	C17 Excessive mass flow	F1 Leakage F4 Overpressure F5 Overtemperature	H2 Explosion hazards	There is no RCS that adequately prevents heavy-duty tank systems from being refuelled with too high mass flows, which may lead to hot spots at the plastic liners of Type 4 tanks, especially when refuelling at ambient gas temperature is foreseen.
7	C18 Deep discharge	F1 Leakage F4 Overpressure F5 Overtemperature	H2 Explosion hazards	There is no RCS that adequately prevents fast refuelling of Type 4 tanks with an SOC of less than 10 to 20 %. This may lead to liner damage and consquently leakage if not detected. Additionally, there is a risk of higher temperatures during fast refuelling at ambient gas temperatures of heavy-duty tanks as the temperature development increases with low SOCs.
8	C19 Falling Objects	F1 Leakage F3 Burst F6 Component defect F9 Loss of electrical isolation F10 Loss of mechanical integrity F11 Loud noise	H1 Fire hazards H2 Explosion hazards H3 Pressure related hazards H4 Eletrical hazards H5 Health related hazards H6 Environmental damage	There is no RCS that adequately prevents or limits damage to the hydrogen system from falling objects (e.g., object thrown from a bridge, branch hanging from a tree), especially when mounted on the roof of under floor (e.g., objects being catapulted against components).
9	C20 Vandalism / Terrorism	F1 Leakage F2, Vent F3 Burst F6 Component defect F9 Loss of electrical isolation F10 Loss of mechanical integrity F11 Loud noise F14 Insufficient Ventilation	H1 Fire hazards H2 Explosion hazards H3 Pressure related hazards H4 Eletrical hazards H5 Health related hazards H6 Environmental damage	There is no RCS that adequately prevents vandalism or terrorism to hydrogen systems. It requires a security assessment due to potential catastrophic consequence.

ANNEX_B – CNH2 Report FCH2RAIL_LGA

Identification of Gaps in regulatory framework regarding the HRS

Work Package 7.1

NATIONAL CENTER OF EXPERIMENTATION OF HYDROGEN TECHNOLOGIES AND FUEL CELLS

www.cnh2.es

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	00	06/09/2022	FIRST EDITION ANALYSIS	EJRM	BNC	BNC
PROJECT						
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D7.1. ANNEX B						

Table of contents

1. Introduction

1.1. Abbreviations

Abbreviations	Description
LGA	Legislative Gap Analysis
HRS	Hydrogen Refuelling Station
RCS	Regulations, Codes and Standards
FCHPP	Fuel Cell Hybrid PowerPack
FCH2RAIL	European funding project Fuel Cell Hybrid Power Pack for Rail Applications
WP	Work Package
H_2	Hydrogen
FCS	Fuel Cell System
HSS	Hydrogen Storage System
TSI	Technical Specification for Interoperability
GA	Grant Agreement

1.2. Purpose

This document includes a LGA of the HRS regarding the European standards in the within the framework of the European funding project FCH_2RAIL where members of the consortium are developing and testing a hybrid demonstrator vehicle. The gap analysis of the HRS is part of WP7 of the project.

The aim of WP7 is the fundamental basis of a normative framework for the use of hydrogen technology in different kinds of railway applications across Europe.

The specific objectives of the WP are as follows:

- Task 7.1 - Identification of the gaps in the normative EN, TSI framework.
- Task 7.2 - Collection of proposal for modifications of the normative framework.
- Task 7.3 - Networking activities to transfer the proposals in the related standard committees to motivate them for the reworking of the existing standard or to create new once.

The goal of the gap analysis of the HRS corresponds to Task 7.1 and shall provide the necessary information's to define clearly the open items in the existing normative framework.

1.3. Scope

The scope of this analysis is based on the integration of an HRS in the railway sector, with the aim of supplying fuel to the powerpack that the train has integrated with pressurized gaseous hydrogen. Also, are considered the interfaces with the vehicle and its transit facility, as well as the maintenance and commissioning programs of the HRS.

The scope of the legislative gap analysis is centred on the following stages:

- Definition of the approach, methodology and design of the report. It includes the analysis of technical information in the design stage as well as the review of compliance with regulations adapted by manufacturers in the choice of supplied parts.
- General HRS requirements.
- Analysis and implementation of specific solutions for the adaptation of the HRS to the sites proposed for the testing and validation of the demonstrator train, considering the specific requirements of each one, and implementing measures of general application.

2. Objective

The general objective of the LGA, is the identification of the existing railway and non-railway regulations, codes and standards (RCS) that apply for the introduction of Hydrogen technology into the railway environment to analyse the gaps in the current applicable regulatory and voluntary framework (TSI and EN).

Specifically, the objective of this document is to identify the RCS that could apply to fuelling stations orientated to vehicles that use H_2 as fuel into the railway sector.

This shall be done by evaluation of the input documents with regards to all RCS referenced as a code of practice to mitigate hazards and assess the adequacy into this specific application field.

3. Methodology

The methodology implemented for the analysis of regulatory gaps is based on the following points described below:

- Compilation of the regulations, codes and standards (RCS) that apply to the design, testing, security measures and implementation of the necessary equipment for the development of the hydrogen, from a general point of view.
- Study of the requirements associated with the integration of H_2 in the train and railway systems.
- Technical and safety compatibility of current application codes from other industries, such as SAE.
- Applicability of the codes to the Project.
- Identify those codes that do not fully cover the specifications of the railway sector.
- Identification of verifications, validations, interfaces and additional codes.

As a result of the previous paragraph, the following points are reflected:

- Determination of the generic dangers, the related faults and the related causes, which are expected with the applied technology.
- Enumeration and categorization of regulations, codes and RCS standards applicable to the H2 sector, from a general point of view.
- Analysis of the RCS, where those that apply to the project itself are extracted.

- From the previous point, RCS are classified according to:

1. RCS that do not require modification
2. RCS that require modification

- List of hazards that are not covered by current regulations, where the failures that could result from not applying mitigating measures are associated with the hazard, as well as the causes that generate it.

4. Findings

4.1. Generic Hazards, Faults and Causes

The identified Hazards, Faults and Causes are listed below.

4.1.1. Hazards

- H1 Fire hazards (such as a hydrogen jet-flame or a HRS at fire)
- H2 Explosion hazards (such as detonation or deflagration)
- H3 Pressure related hazards (such as burst or flying away parts)
- H4 Electrical hazards (such as electrocution)
- H5 Health related hazard (such as intoxication, burn or hearing damage)

4.1.2. Faults

- F1 Leakage of hydrogen
- F2 Vent
- F3 Bursting (of pressure equipment)
- F4 Over-pressure
- F5 Over-temperature
- F6 Component malfunction
- F7 Output overvoltage/over current
- F8 Internal short circuit (electrical and electronics devices)
- F9 Loss of electrical isolation (of any electrical component)
- F10 Loss of mechanical integrity (of equipment racks or fixations)
- F11 Loud noise (caused by a leak of pressurized gas or explosion)
- F12 Spark generation (electrical, mechanical)
- F13 Insufficient Ventilation (in confined spaces with hydrogen equipment)

4.1.3. Causes

- C1 Fire / Ignition source
- C2 Thermal impact / over temperature (from sun radiation / operational heat)
- C3 Cold impact / under temperature (from cold weather or cold gas)
- C4 Vibration (produced by compressor)
- C5 Electromagnetic emission / interference
- C6 Hydrogen purity / particle ingress

- C7 Hydrogen incompatibility (leading to hydrogen embrittlement)
- C8 Corrosion (dusts, aerosols, humidity, chemicals)
- C9 Human error (manufacturing, operation, maintenance)
- C10 Improper mechanical design (includes also tightness, ventilation, etc.)
- C11 Improper electrical design (including functional safety)
- C12 Crash / mechanical impact
- C13 External short circuit / arcing (from a defective component or outside)
- C14 Input over voltage / over current (due to variations in the power supply)
- C15 Clogging / aerodynamic effects (of natural or forced ventilation)
- C16 Over filling (from supplier)
- C17 Excessive mass flow (from supplier)
- C18 Deep discharge (of hydrogen tanks)
- C19 Falling objects (such as stones or tree branches)
- C20 Vandalism / Terrorism (any kind of intentional damage)
- C21 Residual voltage (Capacitors or electrostatic charge)
- C22 Wear, poor/improper maintenance

4.2. Input RCS-List

Up to the current stage, a total of 82 RCS are listed. This list provides the code, the full title, the current release date, a brief orientation about the application field which it belongs, if the RCS has been analysed, and the category. This last parameter has been defined for four main types of RCS, which are:

- Test standard (Describing a test procedure or alternative validation method)
- Design standard (Providing requirements regarding technical characteristics, safety, etc)
- Process / Quality standard (Defining a process to follow or organizational structure to apply)
- Legislation (conditions to obey, mostly European directives or regulations)

LIST OF INPUT RCS						
Nº	**NORMATIVE**	**DATE**	**ANALYSED**	**CATEGORY**	**APPLICATION FIELD**	**TITLE**
1	ISO 19880-1	2020	YES	D	FUELLING STATIONS	Gaseous hydrogen — Fuelling stations — Part 1: General requirements
2	ISO 19880-2	2020	YES	D	FUELLING STATIONS	Gaseous hydrogen — Fuelling stations — Part 2: Dispensers
3	ISO 19880-3	2018	YES	T	FUELLING STATIONS	Gaseous hydrogen — Fuelling stations — Part 3: Valves
4	ISO 19880-5	2019	YES	D	FUELLING STATIONS	Gaseous hydrogen — Fuelling stations — Part 5: Dispenser hoses and hose assemblies
5	ISO 19880-8	2019	YES	P	FUELLING STATIONS	Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control
6	EN 17127	2020	YES	D	FUELLING STATIONS	Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols
7	SAE J2601-1	2020	YES	D	FUELLING STATIONS	Fuelling Protocol for Light Duty Gaseous Hydrogen Surface Vehicles

8	SAE J2601-2	2014	YES	D	FUELLING STATIONS	Fuelling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles
9	2014/34/EU	2014	YES	L	ATEX	Harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres
10	EN 60079-0	2021	YES	D	ATEX	Electrical apparatus for explosive atmospheres. General requirements
11	EN 60079-1	2015	YES	D	ATEX	Explosive atmospheres - Part 1: Equipment protection by flameproof enclosures "d"
12	EN 60079-7	2016	YES	D	ATEX	Explosive atmospheres - Part 7: Equipment protection by increased safety "e"
13	EN 60079-10	2016	YES	D	ATEX	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres
14	EN 60079-11	2013	YES	D	ATEX	Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i"
15	EN 60079-14	2016	YES	D	ATEX	Explosive atmospheres - Part 14: Electrical installations design, selection and erection
16	EN 60079-17	2014	YES	T	ATEX	Explosive atmospheres - Part 17: Electrical installations inspection and maintenance
17	EN 60079-29	2016	YES	D	ATEX	Explosive atmospheres -- Part 29-4: Gas detectors - Performance requirements of open path detectors for flammable gases
18	EN 80079-37	2018	YES	D	ATEX	Explosive atmospheres - Part 37: Non-electrical equipment for explosive atmospheres - Non-electrical type of protection constructional safety ''c'', control of ignition sources ''b'', liquid immersion ''k''
19	EN 60079-32	2018	YES	D	ATEX	Explosive atmospheres - Part 32-2: Electrostatics hazards.
20	EN 80079-36	2017	YES	D	ATEX	Part 36: Non-electrical equipment for explosive atmospheres - Basic method and requirements
21	EN 1127-1	2020	YES	D	ATEX	Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology
22	2014/30/EU	2014	YES	L	ATEX	Harmonisation of the laws of the Member States relating to electromagnetic compatibility
23	2014/35/EU	2014	YES	L	ATEX	Harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits
24	EN 61439-1	2012	YES	D	ATEX	Low-voltage switchgear and control gear assemblies - Part 1: General rules
25	1999/92/EC	1999	YES	L	ATEX	Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres
26	2014/68/EU	2014	YES	L	PRESSURE EQUIPMENT	Harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment
27	2010/35/EU	2010	YES	L	PRESSURE EQUIPMENT	Transportable pressure equipment
28	ADR	2021	YES	L	TRANSPORT	International Carriage of Dangerous Goods by Road
29	EN 13807	2017		D/T	PRESSURE EQUIPMENT	Transportable gas cylinders - Battery vehicles and multiple-element gas containers (MEGCs) - Design, manufacture, identification and testing

30	EN 13480-3	2017	YES	D	PIPING	Metallic industrial piping - Part 3: Design and calculation (includes Amendment A1:2021)
31	OIML R 139-1	2018		D	MEASUREMENT	International Recommendation for Compressed gaseous fuel measuring systems for vehicles. Part 1: Metrological and technical requirements
32	ISO 26142	2010	YES	D	SAFETY	Hydrogen detection apparatus — Stationary applications
33	ISO/TR 15916	2015	YES	P	SAFETY	Basic considerations for the safety of hydrogen systems
34	EN ISO 4126-7	2014	YES	D	SAFETY	Safety devices for protection against excessive pressure — Part 7: Common data
35	2006/42/CE	2006	YES	L	MACHINERY	Machinery Directive
36	EN ISO 12100	2012	YES	D	MACHINERY	Safety of machinery - General principles for design - Risk assessment and risk reduction
37	EN 13849-1	2016		D	MACHINERY	Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design
38	EN 60204-1	2007		D	MACHINERY	Safety of machinery - Electrical equipment of machines - Part 1: General requirements
39	EN 1012-3	2013	YES	D	MACHINERY	Compressors and vacuum pumps - Safety requirements - Part 3: Process compressors
40	ISO 14687	2019	YES	P	QUALITY FLOW	Hydrogen fuel quality — Product specification
41	ISO/TR 15916	2015	YES	P	QUALITY FLOW	Basic considerations for the safety of hydrogen systems
42	ISO 26142	2010	YES	D	DESIGN	Hydrogen detection apparatus — Stationary applications
43	ISO 19882	2018		D	SAFETY	Gaseous hydrogen — Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers
44	ISO 11114-5	2022		T	GAS CYLINDERS	Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 5: Test methods for evaluating plastic liners
45	ISO 11114-3	2010		D	GAS CYLINDERS	Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 3: Autogenous ignition test for non-metallic materials in oxygen atmosphere
46	ISO 13341	2015		D	GAS CYLINDERS	Gas cylinders — Fitting of valves to gas cylinders — Amendment 1
47	ISO 11114-2	2021		D	GAS CYLINDERS	Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 2: Non-metallic materials
48	ISO 11114-4	2017		T	GAS CYLINDERS	Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting steels resistant to hydrogen embrittlement
49	ISO 11114-1	2020		D	GAS CYLINDERS	Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 1: Metallic materials
50	ISO 13341	2010		D	GAS CYLINDERS	Gas cylinders — Fitting of valves to gas cylinders
51	ISO/TR 11364	2019		P	GAS CYLINDERS	Gas cylinders — Compilation of national and international valve stem/gas cylinder neck threads and their identification and marking system
52	J2719	2020	YES	P	QUALITY FLOW	Hydrogen Fuel Quality for Fuel Cell Vehicles

53	J2799	2019	YES	P	H/S COMMUNICATION	Hydrogen Surface Vehicle to Station Communications Hardware and Software
54	J3089	2018		D	SENSORS	Characterization of On-Board Vehicular Hydrogen Sensors
55	J2579	2019		D	FUEL	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles
56	J2907	2018		D	ELECTRICITY	Performance Characterization of Electrified Powertrain Motor-Drive Subsystem
57	J2908	2017		T	ELECTRICITY	Vehicle Power Test for Electrified Powertrains
58	J2990/1	2016		D	HAZARDS HV	Gaseous Hydrogen and Fuel Cell Vehicle First and Second Responder Recommended Practice
59	J2572	2014		D	CONSUMPTION	Recommended Practice for Measuring Fuel Consumption and Range of Fuel Cell and Hybrid Fuel Cell Vehicles Fuelled by Compressed Gaseous Hydrogen
60	J2578	2014		D	SAFETY	Recommended Practice for General Fuel Cell Vehicle Safety
61	J2615	2011		T	PERFORMANCE	Testing Performance of Fuel Cell Systems for Automotive Applications
62	J2600	2015		D	H/S COMMUNICATION	Compressed Hydrogen Surface Vehicle Fuelling Connection Devices
63	J2836-1	2019		D	H/S COMMUNICATION	Use Cases for Communication Between Plug-in Vehicles and the Utility Grid
64	J2836/2	2011		D	H/S COMMUNICATION	Use Cases for Communication between Plug-in Vehicles and the Supply Equipment (EVSE)
65	J2836/4	2021		D	H/S COMMUNICATION	Use Cases for Diagnostic Communication for Plug-in Vehicles
66	J2836/5	2021		D	H/S COMMUNICATION	Use Cases for Communication between Plug-in Vehicles and their customers
67	J2836/6	2021		D	H/S COMMUNICATION	Use Cases for Wireless Charging Communication between Plug-in Electric Vehicles and the Utility Grid
68	J2910	2014		D/T	SAFETY	Design and Test of Hybrid Electric Trucks and Buses for Electrical Safety
69	J2931/2	2021		D	H/S COMMUNICATION	In-band-Signalling Communication for Plug-in Electric Vehicles
70	J2931/3	2011		D	H/S COMMUNICATION	PLC Communication for Plug-in Electric Vehicles
71	J2931/4	2014		D	H/S COMMUNICATION	Broadband PLC Communication for Plug-in Electric Vehicles
72	J2931/6	2021		D	H/S COMMUNICATION	Digital Communication for Wireless Charging Plug-in Electric Vehicles
73	J2931/7	2018		D	H/S COMMUNICATION	Security for Plug in Electric Vehicle Communications
74	RD 656/ITC MIE APQ-5	2017	YES	L	SAFETY	Storage of Gases in Mobile Pressure Vessels
75	ASTM A269	2013		D	PIPELINE	Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service
76	ASTM A213	2021		D	PIPELINE	Tubing Standard Specification
77	RD 222/2001	2001	YES	T	INSPECTION	Periodic inspections of transportable pressure vessels
78	API RP 941	2016		D	PIPELINE	Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants
79	ASME B31.12	2019		D	PIPELINE	Hydrogen Piping and Pipeline Code Design Rules and Their Interaction With Pipeline Materials Concerns, Issues and Research
80	ASME B31.3	2018		P	PIPELINE	Process Pipeline
81	NFPA-2	2016		D	SAFETY	Hydrogen Technologies Code

82	IGC Doc 15/06/E	2006	YES	D	SAFETY	Gaseous Hydrogen Stations

4.3. Analysis

4.4. RCS without modifications

RCS THAT DO NOT NEED MODIFICATIONS				
Nº	**RCS**	**DATE**	**TITLE**	**REMARKS**
1	ISO 19880-2	2020	Gaseous hydrogen — Fuelling stations — Part 2: Gaseous Hydrogen Fuelling Station Dispensers. Safety aspects of dispenser equipment Hazardous atmospheres Safe fill of vehicle tank Type vs routine testing	
2	ISO 19880-3	2018	Gaseous hydrogen — Fuelling stations — Part 3: Valves This document provides the requirements and test methods for the safety performance of high pressure gas valves that are used in gaseous hydrogen stations of up to the H70 designation. This document covers the following gas valves: check valve; excess flow valve; flow control valve; hose breakaway device; manual valve; pressure safety valve; shut-off valve.	
3	ISO 19880-8	2019	Gaseous hydrogen — Fuelling stations — Part 8: Fuel quality control This International Standard specifies the protocol for ensuring the quality of the gaseous hydrogen quality at hydrogen distribution bases and hydrogen fuelling stations for proton exchange membrane (PEM) furl cells for road vehicles.	
4	EN 17127	2020	Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols. This document defines the minimum requirements to ensure the interoperability of hydrogen refuelling points, including refuelling protocols that dispense gaseous hydrogen to road vehicles (e.g. Fuel Cell Electric Vehicles) that comply with legislation applicable to such vehicles. The safety and performance requirements for the entire hydrogen fuelling station, addressed in accordance with existing relevant European and national legislation, are not included in this document.	
5	EN 60079-0	2021	Electrical apparatus for explosive atmospheres. General requirements NEN-EN-IEC 60079-0 specifies the general requirements for construction, testing and marking of Ex Equipment and Ex Components intended for use in explosive atmospheres. The standard atmospheric conditions (relating to the explosion characteristics of the atmosphere) under which it may be assumed that Ex Equipment can be operated are: - temperature - 20 °C to +60 °C; - pressure 80 kPa (0,8 bar) to 110 kPa (1,1 bar); and - air with normal oxygen content, typically 21 % v/v. This part of IEC 60079 and other standards supplementing this standard specify additional test requirements for Ex Equipment operating outside the standard temperature range, but further additional consideration and additional testing may be required for Ex Equipment operating outside the standard atmospheric pressure range and standard oxygen content. Such additional testing may be particularly relevant with respect to Types of Protection that depend on quenching of a flame such as 'flameproof enclosures "d"' (IEC 60079-1) or limitation of energy, 'intrinsic safety "i"' (IEC 60079-11)	
6	EN 60079-1	2015	Explosive atmospheres - Part 1: Equipment protection by flameproof enclosures "d" The Flameproof ATEX protection concept is providing a strong	

			and closely fitting enclosure to protect its contents. The enclosure must be capable of containing an potential explosion. Any electronic sparking equipment may be placed in a flameproof enclosure, however there are some restrictions for fluids and batteries and minimum requirements for internal free space. Flameproof protection lends itself to utilising off-the-shelf parts for the contents, for example electronic control boards or pcb's. The enclosures can either be custom designed or standard. Using a standard certified Flameproof enclosure removes any uncertainty about its integrity. For operator control, certified components such as pushbuttons can be fitted to an enclosure. Generally flameproof enclosures are made of cast iron or die cast aluminium, making them quite heavy. They are generally small to medium size because the casting process is more expensive as the size increases and the subsequent weight makes installation difficult. Plastic enclosures can be designed to meet ATEX flameproof construction and strength requirements. Usually plastic enclosures are quite small because they have to have thicker wall sections, compared to a metal counterpart, to withstand the explosion pressure. A metal enclosure is usually cheaper to manufacture.	
7	EN 60079-7	2016	Explosive atmospheres - Part 7: Equipment protection by increased safety "e" The most common equipment protected by Increased Safety are transformers, motors, luminaires, cells, batteries, terminals and wires. It is not appropriate for electronic components or sparking devices such as switches. Increased Safety relies upon a dust/water tight enclosure to avoid tracking across live circuits. A large number of manufacturers produce increased safety enclosures, terminals and junction boxes.	
8	EN 60079-10	2016	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres The ATEX standard EN 60079-10-1 is concerned with the classification of areas where flammable gas or vapour hazards may arise and may then be used as a basis to support the proper selection and installation of equipment for use in hazardous areas.	
9	EN 60079-11	2013	Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i" EN 60079-11 Intrinsic Safety relies upon the equipment supplies being of low voltage and power and is suited to electronic devices. The operating current of the circuitry should be low enough to not be affected by series resistance, which may be required to limit energy	
10	EN 60079-14	2016	Explosive atmospheres - Part 14: Specific requirements for the design, selection, erection and initial inspection of electrical installations in, or associated with, explosive atmospheres.	
11	EN 60079-17	2014	Explosive atmospheres - Part 17: Electrical installations inspection and maintenance NEN-EN-IEC 60079-17 applies to users and covers factors directly related to the inspection and maintenance of electrical installations within hazardous areas only, where the hazard may be caused by flammable gases, vapours, mists, dusts or fibres.	

12	EN 60079-29	2016	Explosive atmospheres -- Part 29-4: Gas detectors - Performance requirements of open path detectors for flammable gases This part of IEC 60079-29 specifies general requirements for construction, testing and performance, and describes the test methods that apply to portable, transportable and fixed equipment for the detection and measurement of flammable gas or vapour concentrations with air. The equipment, or parts thereof, is intended for use in explosive atmospheres and in mines susceptible to firedamp. This part of IEC 60079-29 is applicable to flammable gas detection equipment with a measuring range up to any volume fraction as declared by the manufacturer, and which is intended to provide an indication, alarm or other output function; the purpose of which is to indicate a potential explosion hazard and in some cases, to initiate automatic or manual protective action(s). For the purposes of this part of IEC 60079-29, the term "indicating up to a volume fraction of X % or X %LFL" includes equipment with an upper limit of the measuring range equal to or less than X % or X %LFL. This part of IEC 60079-29 is applicable to equipment, including the integral sampling systems of aspirated equipment, intended to be used for commercial, industrial and non-residential safety applications. This part of IEC 60079-29 does not apply to external sampling systems, or to equipment of laboratory or scientific type, or to equipment used only for process monitoring and/or control purposes. It also does not apply to open path (line of sight) detectors which are within the scope of IEC 60079-29-4. Only equipment with very short optical paths intended for use where the concentration is uniform over the optical path are within the scope of this standard For equipment used for sensing the presence of multiple gases, this part of IEC 60079-29 applies only to the detection of flammable gas or vapour. This part of IEC 60079-29 supplements and modifies the general requirements of IEC 60079-0. Where a requirement of this standard conflicts with a requirement of IEC 60079-0, the requirement of IEC 60079-29-1 takes precedence.	
13	EN ISO 80079-37	2018	Explosive atmospheres - Part 37: Non-electrical equipment for explosive atmospheres - Non-electrical type of protection constructional safety ''c'', control of ignition sources ''b'', liquid immersion ''k'' This part of ISO/IEC 80079 supplements and modifies the requirements in ISO 80079-36. Where a requirement of this standard conflicts with the requirement of ISO 80079-36 the requirement of this standard takes precedence. Types of Protection “c”, “k” and “b” are not applicable for Group I, EPL Ma without additional protective precautions. The types of ignition protection described in the standard can be used either on their own or in combination with each other to meet the requirements for equipment of Group I, Group II, and Group III depending on the ignition hazard assessment in ISO 80079-36.	
14	EN 60079-32	2018	Explosive atmospheres - Part 32-2: Electrostatics hazards. This standard BS EN 60079-32-2:2015 Explosive atmospheres is classified in these ICS categories: 29.260.20 Electrical apparatus for explosive atmospheres This part of IEC 60079 describes test methods concerning the equipment, product and process properties necessary to avoid ignition and electrostatic shock hazards arising from static electricity.	

15	EN ISO 80079-36	2017	Part 36: Non-electrical equipment for explosive atmospheres - Basic method and requirements ISO 80079-36:2016 specifies the basic method and requirements for design, construction, testing and marking of non-electrical Ex equipment, Ex Components, protective systems, devices and assemblies of these products that have their own potential ignition sources and are intended for use in explosive atmospheres. Hand tools and manually operated equipment without energy storage are excluded from the scope of this standard. This standard does not address the safety of static autonomous process equipment when it is not part of equipment referred to in this standard. This standard does not specify requirements for safety, other than those directly related to the risk of ignition which may then lead to an explosion. The standard atmospheric conditions (relating to the explosion characteristics of the atmosphere) under which it may be assumed that equipment can be operated are: - temperature -20 °C to 60 °C; - pressure 80 kPa (0,8 bar) to 110 kPa (1,1 bar); and - air with normal oxygen content, typically 21 % v/v. Such atmospheres can also exist inside the equipment. In addition, the external atmosphere can be drawn inside the equipment by natural breathing produced as a result of fluctuations in the equipment's internal operating pressure, and/or temperature. This part of ISO/IEC 80079 specifies the requirements for the design and construction of equipment, intended for explosive atmospheres in conformity with all Equipment Protection Levels (EPLs) of Group I, II and III. These standard supplements and modifies the general requirements of IEC 60079-0, as shown in Table 1 in the Scope of the document. Keywords: mechanical explosion protected equipment	
16	EN 1127-1	2020	Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology	
17	2014/30/EU	2014	Harmonisation of the laws of the Member States relating to electromagnetic compatibility. The EMC Directive (2014/30/EU) aims to ensure that any electrical and electronic equipment minimizes the emission of electromagnetic interference that may influence other equipment. The directive also requires equipment to be able to resist the disturbance of other equipment.	
18	2014/34/UE	2014	Harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast). DIRECTIVE 2014/34/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres	The document specifies in its scope, within chapter 1, article 1, paragraph 2, the fields of non-application of the directive. Specifically, it mentions that shall not apply to equipment and protective systems where the explosion hazard results exclusively from the presence of explosive substances or unstable chemical substances. Even though this point could delimit the scope of application of this directive to the HRS, to specify that there are integrated systems and/or subsystems susceptible to explosion hazards independent of the nature of the explosive substances within it.

19	2014/35/EU	2014	Harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits. The Directive 2014/35/EU shall apply to electrical equipment designed for use with a voltage rating of between 50 and 1000 volts for alternating current and between 75 and 1500 volts for direct current. These voltage ratings refer to the voltage of the electrical input or output, not to voltages that appear inside the equipment.	
20	EN 61439-1	2012	Low-voltage switchgear and control gear assemblies - Part 1: General rules This part of IEC 61439 lays down the general definitions and service conditions, construction requirements, technical characteristics and verification requirements for low-voltage switchgear and control gear assemblies. NOTE Throughout this document, the term assembly(s) (see 3.1.1) is used for a low-voltage switchgear and control gear assembly(s). For the purpose of determining assembly conformity, the requirements of the relevant part of the IEC 61439 series, Part 2 onwards, apply together with the cited requirements of this document. For assemblies not covered by Part 3 onward, Part 2 applies. This document applies to assemblies only when required by the relevant assembly standard as follows: - assemblies for which the rated voltage does not exceed 1 000 V AC or 1 500 V DC; - assemblies designed for a nominal frequency of the incoming supply or supplies not exceeding 1 000 Hz; - assemblies intended for indoor and outdoor applications; - stationary or movable assemblies with or without an enclosure; - assemblies intended for use in connection with the generation, transmission, distribution and conversion of electric energy, and for the control of electrical energy consuming equipment. This document does not apply to individual devices and self-contained components such as motor starters, fuse switches, power electronic converter systems and equipment (PECS), switch mode power supplies (SMPS), uninterruptable power supplies (UPS), basic drive modules (BDM), complete drive modules (CDM), adjustable speed power drives systems (PDS), and other electronic equipment which comply with their relevant product standards. This document describes the integration of devices and self-contained components into an assembly or into an empty enclosure forming an assembly. For some applications involving, for example, explosive atmospheres, functional safety, there can be a need to comply with the requirements of other standards or legislation in addition to those specified in the IEC 61439 series.	
21	1999/92/EC	1999	Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres	According to the scope defined in this directive, it will be excluded from its field of application according to the points defined in paragraph 2 of article 1 of section 1 of the document
22	2014/68/EU	2014	Harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment	The Pressure Equipment Directive (PED) defines the essential requirements for the design, manufacture and conformity assessment of pressure equipment and assemblies subjected to a maximum allowable pressure PS greater than 0.5 bar. The categorization of the equipment will depend on the type of process fluid, the pressure and the volume of the equipment, defined in

				annex II of the regulation. It contains the bases to obtain the CE certificate of conformity.
23	2010/35/EU	2010	Transportable pressure equipment. DIRECTIVE 2010/35/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 June 2010 on transportable pressure equipment and repealing Council Directives 76/767/EEC, 84/525/EEC, 84/526/EEC, 84/527/EEC and 1999/36/EC (Text with EEA relevance) THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,	
24	ADR	2021	Agreement of 30 September 1957 concerning the International Carriage of Dangerous Goods by Road, is a 1957 United Nations treaty that governs transnational transport of hazardous materials.	
25	ASTM A269	2013	Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service. This specification covers nominal-wall-thickness, seamless and welded austenitic steel tubing for general corrosion-resisting and low- or high-temperature service. All material shall be furnished in the heat-treated condition. The steel shall conform to the chemical composition requirements. Different mechanical test requirements that includes, flaring test, flange test, hardness test, and reverse flattening test are presented. Also, each tube shall be subjected to the non-destructive electric test or the hydrostatic test. Finally, the hardness requirements for different grades of tubes are highlighted.	Welded and Seamless Steel Tubing
26	ASTM A213	2021	Tubing Standard Specification ASTM A213 covers seamless ferritic and austenitic steel boiler, superheater, and heat-exchanger tubes, designated Grades T5, TP304,etc. Grades containing the letter, H, in their designation, have requirements different from those of similar grades not containing the letter H. These different requirements provide higher creep-rupture strength than normally achievable in similar grades without these different requirements. The tubing sizes and thicknesses usually furnished to this specification are 1⁄8 in. [3.2 mm] in inside diameter to 5 in. [127 mm] in outside diameter and 0.015 to 0.500 in. [0.4 to 12.7 mm], inclusive, in minimum wall thickness or, if specified in the order, average wall thickness. Tubing having other diameters may be furnished, provided such tubes comply with all other requirements of this specification General use A213/SA213 alloy tubing grades are T5, T9, T11, T12, T22, T91, stainless tubing is TP304/304L, TP316/316L.	Seamless Steel Tubing
27	EN 13480-3	2017	EN 13480-3:2017/A1:2021 (Amendment) Metallic industrial piping - Part 3: Design and calculation. SIST EN 13480-3:2018/kFprA1:2020. This Part of this European Standard specifies the design and calculation of industrial metallic piping systems, including supports, covered by EN 13480.	

28	ISO 26142	2010	Hydrogen detection apparatus — Stationary applications. This international standard defines the performance requirements and test methods of stationary hydrogen detection apparatus that is designed to measure and monitor hydrogen concentrations. The provisions in this standard cover the hydrogen detection apparatus used to achieve the single and/or multilevel safety operations such as nitrogen purging or ventilation and/or system shutoff corresponding to the hydrogen concentration. The requirements applicable to the control system as well as the installation requirements of such apparatus are excluded. This standard sets out only the requirements applicable to a product standard of hydrogen detection apparatus, such as precision, response time, stability, measuring range, selectivity and poisoning. This standard is intended to be used for certification purposes.	
29	ISO/TR 15916	2015	ISO/TR 15916:2015 provides guidelines for the use of hydrogen in its gaseous and liquid forms as well as its storage in either of these or other forms (hydrides). It identifies the basic safety concerns, hazards and risks, and describes the properties of hydrogen that are relevant to safety.	
30	EN ISO 4126-7	2014	Safety devices for protection against excessive pressure — Part 7: Common data. This part of ISO 4126 specifies requirements for safety valves. It contains information which is common to ISO 4126-1 to ISO 4126-6 to avoid unnecessary repetition. For flashing liquids or two-phase mixtures, see ISO 4126-10. The user is cautioned that it is not recommended to use the ideal gas formula presented in 6.3 when the relieving temperature is greater than 90 % of the thermodynamic critical temperature and the relieving pressure is greater than 50 % of the thermodynamic critical pressure. Additionally, condensation is not considered. If condensation occurs, the method presented in 6.3 should not be used.	
31	2006/42/CE	2006	Machinery Directive. This Directive aims at the free market circulation on machinery and at the protection of workers and consumers using such machinery. It defines essential health and safety requirements of general application, supplemented by a number of more specific requirements for certain categories of machinery.	The hazards referred to in Annex I of the Directive are wholly or partly covered more specifically by other Community Directives, this Directive shall not apply, or shall cease to apply, to that machinery in respect of such hazards from the date of implementation of those other directives.
32	EN ISO 12100	2012	Safety of machinery - General principles for design - Risk assessment and risk reduction. This International Standard specifies basic terminology, principles and a methodology for achieving safety in the design of machinery. It specifies principles of risk assessment and risk reduction to help designers in achieving this objective. These principles are based on knowledge and experience of the design, use, incidents, accidents and risks associated with machinery. Procedures are described for identifying hazards and estimating and evaluating risks during relevant phases of the machine life cycle, and for the elimination of hazards or the provision of sufficient risk reduction. Guidance is given on the documentation and verification of the risk assessment and risk reduction process.	
33	EN 1012-3	2013	Compressors and vacuum pumps - Safety requirements - Part 3: Process compressors. This European Standard is applicable to process gas compressors and process gas compressor units having an operating pressure greater than 0,5 bar (gauge), an input shaft power greater than 0,5 kW and designed to compress all gases other than air, nitrogen or inert gases which are covered in Part 1. This document deals with all significant hazards, hazardous situations and events relevant to the design, installation, operation, maintenance, dismantling and disposal of process gas	

			compressors and process gas compressor units, when they are used as intended and under conditions of misuse which are reasonably foreseeable by the manufacturer (see Clause 4). This part of EN 1012 includes under the general term compressor units those machines which comprise: - the compressor; - a drive system including the prime mover; - any component or device supplied which is necessary for operation. This part of EN 1012 is not applicable to compressors which are manufactured before the date of publication of this document by CEN. The requirements of this European Standard do not take into account the interaction between the compressor/compressor unit and other processes carried out on site. Excluded are: - refrigerant compressors used in refrigerating systems or heat pumps for which the safety requirements are given in EN 60335-2-34 or EN 12693; - the specification of performance levels and/or safety integrity levels for safety related parts of control systems. Performance levels and/or safety integrity levels are an important aspect of compressor design and should be determined by the manufacturer and the user based on a risk assessment (see Introduction). This European Standard does not cover those safety aspects of road transport dealt with by EC legislation for trailers.	
34	ISO 14687	2019	Hydrogen fuel quality — Product specification. This document specifies the minimum quality characteristics of hydrogen fuel as distributed for utilization in vehicular and stationary applications. It is applicable to hydrogen fuelling applications, which are listed in Table 1.	Complementary to ISO-19880-8
35	ISO/TR 15916	2015	Basic considerations for the safety of hydrogen systems. ISO/TR 15916:2015 provides guidelines for the use of hydrogen in its gaseous and liquid forms as well as its storage in either of these or other forms (hydrides). It identifies the basic safety concerns, hazards and risks, and describes the properties of hydrogen that are relevant to safety. Detailed safety requirements associated with specific hydrogen applications are treated in separate International Standards.	
36	J2719	2020	Hydrogen Fuel Quality for Fuel Cell Vehicles This standard provides background information and a hydrogen fuel quality standard for commercial proton exchange membrane (PEM) fuel cell vehicles. This report also provides background information on how this standard was developed by the Hydrogen Quality Task Force (HQTF) of the Interface Working Group (IWG) of the SAE Fuel Cell Standards Committee.	Complementary to ISO-19880-8
37	ISO 26142	2015	Hydrogen Detection Apparatus. Stationary applications This international standard defines the performance requirements and test methods of stationary hydrogen detection apparatus that is designed to measure and monitor hydrogen concentrations. The provisions in this standard cover the hydrogen detection apparatus used to achieve the single and/or multilevel safety operations such as nitrogen purging or ventilation and/or system shutoff corresponding to the hydrogen concentration. The requirements applicable to the control system as well as the installation requirements of such apparatus are excluded. This standard sets out only the requirements applicable to a product standard of hydrogen detection apparatus, such as precision, response time, stability, measuring range, selectivity and poisoning. This standard is intended to be used for certification purposes.	
38	RD 222/2001	2001	Periodic inspections of transportable pressure vessels	

4.5. RCS with need for modification

RCS THAT NEED MODIFICATIONS				
Nº	**RCS**	**DATE**	**DESCRIPTION**	**GAPS**
1	ISO 19880-1	2020	Gaseous hydrogen — Fuelling stations — Part 1: General requirements This document defines the minimum design, installation, commissioning, operation, inspection and maintenance requirements, for the safety, and, where appropriate, for the performance of public and non-public fuelling stations that dispense gaseous hydrogen to light duty road vehicles. This document is not applicable to the dispensing of cryogenic hydrogen, or hydrogen to metal hydride applications. Since this document is intended to provide minimum requirements for fuelling stations, manufacturers can take additional safety precautions as determined by a risk management methodology to address potential safety risks of specific designs and applications. While this document is targeted for the fuelling of light duty hydrogen road vehicles, requirements and guidance for fuelling medium and heavy duty road vehicles (e.g. buses, trucks) are also covered. Many of the generic requirements within this document are applicable to fuelling stations for other hydrogen applications, including but not limited to the following: - Fuelling stations for motorcycles, fork-lift trucks, trams, trains, fluvial and marine applications; - Fuelling stations with indoor dispensing; - Residential applications to fuel land vehicles; - Mobile fuelling stations; - Non-public demonstration fuelling stations. However, further specific requirements that can be necessary for the safe operation of such fuelling stations are not addressed in this document. This document provides requirements for and guidance on the following elements of a fuelling station: - H2 supply/production system - Compression - intermediate storage of gaseous hydrogen; - Pre-cooling device; - Gaseous hydrogen dispensers. - Hydrogen fuel, vehicle interface	This document should provide a more up-to-date guide than developed in ISO TS 20100 (repealed in favour of ISO 19880), in where the minimum safety distances of the systems are established, on the one hand for hydrogen storage, and on the other, for the systems of hydrogen processing, such as the compression stage and dispensing process. ISO 19880-1 annexes an update of the minimum safety distances based on examples of their implementation by countries, aligning them with current needs around the world. The objective is to serve as an example and help to understand and compare the rationality applied to reach an average of them. One of the future objectives of this ISO would be to create a common methodology for determining applicable safety distances based on local requirements and conventions. Nowadays, these are not established; this point constitutes the main gap. If the safety distances are too long, additional mitigation or prevention measures should be considered and the safety distances could be recalculated using a quantitative analysis. Other gaps are: -Determination of protection from impact: Guard posts or other approved means, bumpers, buffers, protection structure, etc.

2	ISO 19880-5	2019	Gaseous hydrogen — Fuelling stations — Part 5: Hoses This document specifies the requirements for wire or textile reinforced hoses and hose assemblies suitable for dispensing hydrogen up to 70 MPa nominal working pressure, in the operating temperature range of −40 °C to 65 °C. This document contains safety requirements for material, design, manufacture and testing of gaseous hydrogen hose and hose assemblies for hydrogen fuelling stations. Hoses and hose assemblies excluded from the scope of this document are the following: 1) those used as part of a vehicle high pressure on-board fuel storage system. 2) those used as part of a vehicle low pressure fuel delivery system. 3) flexible metal hoses.	In this document is possible to find the scope of operation of the dispensing hoses and their assemblies, limited to a nominal working pressure of up to 70 Mpa and an operating temperature range between -40 ºC to 65 ºC. Flexible metal hoses are excluded within the scope. The document contains a large number of reference regulations for rubber and plastic hoses and hose assemblies, among which are the standards related to hydrostatic testing, determination of gas permeability, flexibility, discoloration, etc. Specifically, the ISO 4671 standard establishes the methods of measuring the dimensions of the hoses and the lengths of the hose assemblies. However, it has been possible to find three gaps to clearly detail in the standard: - The standard does not contemplate the limitations of the length of the hose or the effect that pressure drops have on the dispensing process. Nor does it establish a guideline where the relationship between the nominal diameter of the hose and its length is reflected in order to minimize pressure losses. - The standard does not contemplate the intrinsic dangers related to the indistinct use of hoses of different lengths and sections. Manufacturers are currently limiting in many cases the length of the hose at 5 meters for pressures and temperatures included in the scope of this standard. - The typified defects of the lining are defined but not limited, although the standard establishes that the lining must have a uniform thickness and free from defects.

3	SAE J2601-1	2020	Fuelling Protocol for Light Duty Gaseous Hydrogen Surface Vehicles SAE J2601 establishes the protocol and process limits for hydrogen fuelling of vehicles with total volume capacities greater than or equal to 49.7 L. These process limits (including the fuel delivery temperature, the maximum fuel flow rate, the rate of pressure increase, and the ending pressure) are affected by factors such as ambient temperature, fuel delivery temperature, and initial pressure in the vehicle's compressed hydrogen storage system. SAE J2601 establishes standard fuelling protocols based on either a look-up table approach utilizing a fixed pressure ramp rate, or a formula-based approach utilizing a dynamic pressure ramp rate continuously calculated throughout the fill. Both protocols allow for fuelling with communications or without communications. The table-based protocol provides a fixed end-of-fill pressure target, whereas the formula-based protocol calculates the end-of-fill pressure target continuously. For fuelling with communications, this standard is to be used in conjunction with SAE J2799. An important factor in the performance of hydrogen fuelling is the station's dispensing equipment cooling capability and the resultant fuel delivery temperature. There are three fuel delivery temperature categories denoted by a "T" rating: T40, T30, and T20, where T40 is the coldest. Under reference conditions, SAE J2601 has a performance target of a fuelling time of 3 minutes and a state of charge (SOC) of 95 to 100% (with communications), which can be achieved with a T40-rated dispenser. However, with higher fuel delivery temperature dispenser ratings (T30 or T20) and/or at high ambient temperatures, fuelling times may be longer. Table 1 depicts the scope of SAE J2601 and potential work items for future revisions within this or other documents of the SAE J2601 series. SAE J2601 includes protocols which are applicable for two pressure classes (35 MPa and 70 MPa), three fuel delivery temperatures categories (-40 °C, -30 °C, -20 °C) and compressed hydrogen storage system sizes (total volume classification) from 49.7 to 248.6 L (35 MPa à H35, and 70 MPa à H70), and from 248.6 L and above (H70 only). Future versions of SAE J2601 work may incorporate warmer fuel delivery temperatures (-10 °C and ambient) and smaller total volume capacities for motorcycles and other applications. The fuelling protocols therein were developed based on a set of key assumptions described in Section 7 and Appendix A. These assumptions should be carefully considered in the development and implementation of an on-board compressed hydrogen storage system. In particular, hydrogen storage systems with properties which do not fall within the parameters in Table A3 should be further evaluated to confirm compatibility with the protocols therein.	This standard does not apply to refuelling railway vehicles. The document considers safety limits during refuelling process, such as over-pressure (limited 125% NWP), over-temperature (limited to 85 ºC) and overfill (determinated by SOC (State Of Charge)). Maximum pressure within the vehicle fuel system less than or equal to 125% NWP (Nominal Working Pressure) Three categories of fuel supply temperatures are established (-40 °C, -30 °C, -20 °C), not contemplating refuelling the gas at temperatures close to ambient temperature. It presents important limitations in the adaptation to the train refuelling process due to: - The mass of hydrogen transferred to the on-board storage of the train. - The setpoint temperature established in the refuelling process. - Maximum admissible flow during refuelling. - Characteristic curves for the refuelling process.
4	SAE J2601-2	2014	Fuelling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles The purpose of this document is to provide performance requirements for hydrogen dispensing systems used for fuelling 35 MPa heavy duty hydrogen transit buses and vehicles (other pressures are optional). This document establishes the boundary conditions for safe heavy duty hydrogen surface vehicle fuelling, such as safety limits and performance requirements for gaseous hydrogen fuel dispensers used to fuel hydrogen transit buses. For fuelling light-duty vehicles SAE J2601 should be used. SAE J2601-2 is a performance based protocol document that also provides guidance to fuelling system builders, manufacturers of gaseous hydrogen powered heavy duty transit buses, and operators of the hydrogen powered vehicle fleet(s). This fuelling protocol is suitable for heavy duty vehicles with a combined vehicle CHSS capacity larger than 10 kilograms aiming to support all practical capacities of transit buses. It is non-prescriptive in how to achieve a full fill or 100% state of charge (SOC) in the vehicle tank storage system. This document is an independent document from SAE J2601 "Fuelling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles" and should be used separately. The fuelling limits shown in this document are harmonized with the fuelling assumptions used for on-board fuel systems, as provided by gaseous hydrogen transit bus manufacturers.	This regulation constitutes an independent document from the SAE J2601-1 regulation, applied to heavy vehicles. Given the nature of the body responsible for drafting the document (SAE), it focuses on heavy land vehicles or similar. Although it focuses on hydrogen dispensing systems for nominal working pressures of 350 Bar, other pressures are optional, although they are not defined in the document. Limits the maximum flow rate to 120 g/s. Same limit conditions as those reflected in the SAE J2601-1 standard. A lower temperature limit of -40ºC is established for the process fluid.
5	J2799	2019	Hydrogen Surface Vehicle to Station Communications Hardware and Software This standard specifies the communications hardware and software requirements for fuelling Hydrogen Surface Vehicles (HSV), such as fuel cell vehicles, but may also be used where appropriate, with heavy duty vehicles (e.g., busses) and industrial trucks (e.g., forklifts) with compressed hydrogen storage.	"It could be extrapolated to communication with other vehicles not contemplated in the standard, such as trains, provided that the specific regulations of the sector are compatible."

6	RD 656/ITC MIE APQ-5	2017	"STORAGE OF GASES IN MOBILE PRESSURE VESSELS" Regulations for the storage of chemical products. Gases in mobile pressure vessels. The purpose of this technical instruction is to establish the technical requirements to storage and use of mobile pressure vessels containing compressed, liquefied and dissolved gases under pressure and their mixtures must comply.	This technical instruction establishes a guide to categorize the stores of mobile compressed gas pressure vessels, as well as the requirements of the site, where the minimum safety distances are specified based on the category of the store. The storage category is classified into five levels, depending on the characteristics of the gases (level of danger) and the quantity of gases stored. It contemplates complementary measures to reduce safety distances, such as the implementation of walls or the extension of mitigating measures against fires. Limitations: Hydrogen is not specifically characterized. The technical instruction does not contemplate storage pressure as a variable to categorize stores.
7	IGC Doc 15/06/E	2006	Gaseous Hydrogen Stations	This document introduces guidelines to be considered related to gaseous hydrogen stations. It contemplates and defines the parts and processes carried out in a hydrogen refuelling station, as well as the necessary premises for commissioning and maintenance, among other sections. It establishes general minimum safety distances for hydrogen stations, however, they are not aimed at railway facilities, and do not contemplate a minimum safety distance for trains.

4.6. List of Hazards where no applicable RCS exist

HAZARDS NO RCS EXIST			
Nº	**Cause**	**Related Faults**	**Description of technical issue**
1	C2 Thermal impact/over temperature	F1 Leakage F2 Vent F3 Burst F4 Over-pressure F5 Over-temperature F6 Component Malfunction	There is no a RCS that defines adequate measures to prevent hydrogen tanks from excessive sun radiation
2	C20 Vandalism/Terrorism	F1 Leakage F2 Vent F10 Loss of mechanical integrity F11 Loud noise	There is not a proper RCS that defines adequate measures to prevent terrorism actions or vandalism that could trigger catastrophic consequences for the facility and its surroundings
3	C15 Clogging	F14 insufficient Ventilation	There is not RCS that defines measures to avoid problems related to insufficient ventilation. This point should be integrated with the inspection and/or maintenance plan for the installation.

5. Conclusion

5.1. Summary of Findings

Starting from a total of 82 RCS in total, 45 RCS applicable to the project have been analyzed, from which it can be concluded that:

- 36 RCS do not need modification.
- 7 RCS need to be modified to adapt to Project requirements.
- 3 technical problems have been found where currently there is no RCS that specifies how to mitigate the effects that may generate a hazard.

If there is no RCS that can be adapted to some of the project requirements, it would be convenient to expand and/or modify an existing one, specifying the nature of the problem associated with the use of hydrogen in the railway sector.

ANNEX_C – STT Report FCH2RAIL_LGA

Co-funded by the European Union

/// STD3005REV00
Identification of Gaps in regulatory framework regarding the pantograph

Work Package 7.1

Project FCH2RAIL
Stemmann-Technik reference no. 566073

Document type : Analysis
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00	13/05/2022	First edition	---	WGH	MUN	MUN

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/// 1. Abbreviations

Table 1 – Abbreviations

Abbreviation	Definition
FCH2RAIL	European funding project Fuel Cell Hybrid Power Pack for Rail Applications
FCHPP	Fuel Cell Hybrid Power Pack
GA	Gap Analysis
H2	Hydrogen
HRP	Department Heavy Rail Pantographs (HRP) of the company Stemmann-Technik (A Wabtec Company)
IRIS	International Railway Industry Standard
RCS	Regulations, Codes and Standards
TSI	Technical Specification for Interoperability

/// 2. Introduction

2.1 Purpose

This document concerns a GA of the pantograph regarding the European standards in the within the framework of the European funding project, FCH2RAIL where members of the consortium are developing and testing a hybrid (H2 and electrically actuated by a pantograph) demonstrator vehicle. The new vehicle is a refurbishment of an existing electric multiple unit. The gap analysis of the pantograph is part of Work Package 7 (WP7) of the project.
The aim of WP7 is the fundamental basis of a normative framework for the use of hydrogen technology in different kinds of railway applications across Europe.
The specific objectives of the Work Package are as follows:

- Task 7.1 - Identification of the gaps in the normative EN, TSI framework.
- Task 7.2 - Collection of proposal for modifications of the normative framework.
- Task 7.3 - Networking activities to transfer the proposals in the related standard committees to motivate them for the reworking of the existing standard or to create new once.

The goal of the gap analysis of the pantograph corresponds to Task 7.1 and shall provide the necessary information's to define clearly the open items in the existing normative framework.

2.2 Scope

The scope of work is to execute the GA of the pantograph based on the present normative framework for the safe use electrically railway technology and if available hydrogen technology in different kinds of railway applications across Europe. It considers the European railway network in the scope of the interoperability directive EU 2016/797 and the underlying regulations for vehicles, operations and infrastructure, such as the technical specification for interoperability (TSI) for locomotives and passenger rolling stock (TSI LOC&PAS), EU 1302/2014, for the energy of the rail system (TSI ENE), EU 1301/2014 and the relevant EN standards.
The gap analysis of the pantograph is focused on the electrically actuated vehicle and the integration of a FCHPP. It should also consider the external vehicles interfaces and the impact of this technology on the operations, the infrastructure, such as tracks, stations, the maintenance intervals, procedures, and infrastructure, etc. if possible
The GA shall deliver the following results:

- Provide a baseline conformity matrix, for the standards that are applicable,
- List the technical and risk areas where no specific railway requirement currently exists,
- Make reference, where possible, and applicable to related industry standards

2.3 Planned Issue

The gap analysis is based on an evaluation of railway standards concerning the pantograph. All relevant chapters in the standards relating to the pantograph have been reviewed and the consequences for the systems vehicle and infrastructure in the event of non-compliance have been demonstrated.

2.4 Support of other parties

The assessment was executed under support of the HRP of the company Stemmann-Technik (A Wabtec Company) and the committee of FCH2RAIL. The quality system of Stemmann-Technik is certified according to International Railway Industry Standard (IRIS) and ISO 9001.

2.5 List of references

The following documents were used as references

Table 2 – List of references

Author	Title
Carlos Fúnez	CNH2 TPL_FCH2Rail_Presentation WP7 KoM.pdf
Carlos Fúnez	CNH2 FCH2RAIL_20210126 WP7_KoM_vf.pptx
Author not known	Task and Subtask WP7_20210126.xlsx
Paul Simmons	CN9.96.708.01 FCH2RAIL Legislative Gap Analysis Rev_.pdf
Tolga Wichmann	CN9.96.708.01 Appendix A CZ98349T_FCH2RAIL_GA_V1.1.pdf
Tolga Wichmann	CN9.96.708.01 Appendix A CZ98349T_FCH2RAIL_GA_V1.1_Appendices.pdf

2.6 Classification RCS-List

The RCS, which have been identified so far as potentially applicable can be found in chapter 6.
Up to the current stage, a total of 10 RCS are listed, which were identified by HRP in an internal investigation relating to the pantograph. The list provides the code, the full title and current release date.
In the GA are considered the following types of RCS:

- Test standard
- Design standard
- Legislation (Conditions to obey, mostly European directives or regulations)

The GA was done in chapter 6 and lists the generic hazards and reason for the mitigation.

2.7 Analyzed RCS

The RCS, which have been analyzed for gaps and their suitability to mitigate hazards, have for the most part been referenced by the input documents and are listed below in table 3. This table will extend in the planned second and third issue of the GA.

Table 3 – Regulations, Codes and Standards

Stanadard	Date	Title
EN 50206-1	2010	Railway applications – Rolling stock – Pantographs: Characteristics and tests – Part 1: Pantographs for main line vehicles
EN 50367	2020	Railway applications – Fixed installations and rolling stock – Criteria to achieve technical compatibility between pantographs and overhead contact line;

EN 50405	2016	Railway applications – Current collection systems – Pantographs, testing methods for contact strips
1302/2014/EC	2014	COMMISSION REGULATION (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the 'rolling stock — locomotives and passenger rolling stock' subsystem of the rail system in the European Union
1301/2014/EC	2014	COMMISSION REGULATION (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the 'rolling stock — locomotives and passenger rolling stock' subsystem of the rail system in the European Union
1303/2014/EC	2014	COMMISSION REGULATION (EU) No 1303/2014 of 18 November 2014 concerning the technical specification for interoperability relating to 'safety in railway tunnels' of the rail system of the European Union
EN 50215	2009	Railway applications – Rolling stock – Testing of rolling stock on completion of construction and before entry into service
EN 50124-1	2017	Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment
EN 50124-2	2017	Railway applications – Insulation coordination – Part 2: Overvoltages and related protection; German version EN 50124-2:2017
EN 50126-1	2017	Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1: Generic RAMS Process; German version EN 50126-1:2017
EN 12663-1	2015	Railway applications — Structural requirements of railway vehicle bodies — Part 1: Locomotives and passenger rolling stock (and alternative method for freight wagons)
EN 45545-1	2013	Railway applications – Fire protection on railway vehicles – Part 1: General
EN 45545-2	2020	Railway applications – Fire protection on railway vehicles – Part 2: Requirements for fire behavior of materials and components;
EN 45545-3	2013	Railway applications - Fire protection on railway vehicles - Part 3: Fire resistance requirements for fire barriers;
EN 45545-4	2015	Railway applications – Fire protection on railway vehicles – Part 4: Fire safety requirements for rolling stock design
EN 45545-5	2016	Railway applications – Fire protection on railway vehicles – Part 5: Fire safety requirements for electrical equipment including that of trolley buses, track guided buses and magnetic leviation vehicles;

/// 3. Objective

3.1 General

The objective of the GA is the identification of the existing railway RCS that apply for a hybrid (H2 and electrically actuated by a pantograph) demonstrator vehicle and its integration into the railway environment to analyze the gaps in the current applicable regulatory and voluntary framework (TSI and EN).
This shall be done by evaluation of all RCS referenced as a code of practice to mitigate specific hazards and assess their suitability.
Stemmann-Technik is a manufacturer of pantographs and associated equipment for trams up to high speed railway vehicle and executes the GA additionally with their experience.

3.2 Execution of GA

The GA is based on the relevant standards and guidelines for pantographs used on heavy railway applications.

The GA is performed in five main steps:
1. Determine generic Hazards, related Faults and related Causes, which are to be expected with the applied technology,

2. List and categorize all RCS from input documents and amend those by RCS which may apply for the pantograph application.

3. Analyze the RCS and if applicable, allocate either to:
- Preferably prevent/avoid causes to occur or, if not sufficiently achievable.
- Limit adequately the severeness or probability of the occurrence and assess their suitability.

4. Extract applicable RCS, that are suitable to prevent the cause or limit the consequence:
- from railway industry, where no modification is required:
- from railway industry, where modification is required including a description of the identified gap,

/// 4. Findings

4.1 Generic Hazards, Faults and Causes

The identified Hazard, Faults and Causes, are listed in the GA in chapter 6. They represent the current project stage and may be amended during the planned following issues of the GA or an execution of an analysis according EN 50126, EN 60812 or similar.
The assessment of severity and occurrence in the GA has to be done by CAF in the before mentioned analysis.

/// 5. Conclusion

From the GA executed in chapter 6 of this report, it can be concluded that the existing electrical European standards relating to the pantograph, mitigate the gaps.

During operation, the pantograph continuously causes arcing and abrasion of the wear material with varying intensity due to contact with the overhead contact line. This creates a dust of different carbon materials or metal alloys (mostly copper, copper, copper-steel alloys, etc.). Especially for metal alloys the use of additional grease is in use. Because of irregularities in the infrastructure, operation under icy overhead contact lines, etc. it is possible that larger parts of the wear detach from the contact strip und contact parts of the roof. The parts have a high temperature. The ignition energy, ignition temperature and other critical properties of hydrogen shall be considered. Because of the grown system of railway infrastructure and pantograph equipped vehicles and the financial consequences a solution is not realistic. Solutions could be

- Completely controlled pantograph (closed loop regulation) to reduce the wear and arcing
- Development of new wear materials with lower wear rate
- Development of new overhead contact line system to reduce the arcing and wear
- Battery equipped vehicles with loading only at standstill operation
- Modification of the contact strips to reduce the previously mentioned influences

From the moment is the only viewable short time solution is to protect the Fuel Cell Hybrid Power Pack against the previously mentioned influences.

Standards and guidelines for other vehicles like cars, busses, etc. which are powered by hydrogen have to be checked according to their applicability to the planed hybrid vehicle. The way of an innovative solution according to EU 1302/2014/EC in cooperation with a notified body should be followed to find a solution regarding the modification of existing standards and guidelines or to create new once.

/// 6. Appendix

6.1 Gap analysis EN 50206-1:2010; Railway applications – Rolling stock –Pantographs: Characteristics and tests – Part 1: Pantographs for main line vehicles

Relevant chapter of the standard	Designation of the chapter	Gap analysis	Measures to reduce the Gap
6.2.1	Visual inspection	The complete pantograph shall be free from physical defects and surface treatments shall have been carried out. Corrosion or damages could damage parts of the overhead contact line (OCL), parts of the vehicle and infrastructure.	Meeting the requirements.
6.2.2	Weighing	The mass of the pantograph shall comply with the contractual mass. Higher masses of the pantograph could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
6.2.3	Dimensions	The relevant dimensions have an influence of the air gap distance, mechanical distance to other parts on the vehicle and to the infrastructure and could occur damages and over flashes to parts of the vehicle and the infrastructure.	Meeting the requirements.
6.2.4	Identification	Missing or false identification data on the type plate can lead to an incorrect use of the pantograph. Incorrect use can lead to damage of the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
6.2.5	Functional check of Automatic Dropping Device (A.D.D.)	The functionality of the A.D.D system guarantees in the most cases of an accident between OCL and parts of the collector head or abnormal wear could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
6.2.6	Functional check of A.D.D.	The functionality of the A.D.D system guarantees in the most cases of an accident between OCL and parts of the collector head or abnormal wear could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
6.3.1	Measurement of static contact force at ambient	The compliance of the static contact force curve has an influence of the behavior of interaction of pantograph and OCL. In case of to low contact forces arcing will be occurred and to high contact forces could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.

6.3.2	Checking of the operating system of the pantograph	A smooth, steady rise and lowering movement demonstrates that the pantograph has a good working performance over the hole working range. Irregularities during the raising and lowering movement of the pantograph will damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
6.3.3	Operating climatic test	A smooth, steady rise and lowering movement demonstrates that the pantograph has a good working performance over the hole working range and the required climatic and pneumatically electrically power supply conditions. Irregularities during the raising and lowering movement of the pantograph could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.3.4	Measurement of mean static contact force at ambient temperature	The compliance of the static contact force curve including the damper system has an influence of the behavior of interaction of pantograph and OCL. In case of to low contact forces arcing will be occurred and to high contact forces will damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
6.4.1.1	Operation between housed position and upper operating position	A smooth, steady rise and lowering movement demonstrates that the pantograph has a good working performance over the hole working range. The constancy over the requested time, defined by the maintenance intervals is very important. Irregularities, damages, etc. during the raising and lowering movement of the pantograph could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.4.1.2	Operation within working range	A smooth, steady rise and lowering movement demonstrates that the pantograph has a good working performance over the hole working range. The constancy over the requested time, defined by the maintenance intervals is very important. Irregularities, damages, etc. during the raising and lowering movement of the pantograph could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.4.2	Collector head suspension	The functionality of the collector head suspension is very important for the interaction of pantograph and OCL. A collapse of this system could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

6.4.3.1	General	The robustness of the pantograph during the specific loads against vibrations occurred during the operation in heavy railway infrastructure is very important for the interaction of pantograph and OCL. A collapse of this system could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.4.3.2	Measurement of natural transverse frequency of the pantograph (Fo)	The robustness of the pantograph during the specific loads against vibrations occurred during the operation in heavy railway infrastructure collector head is very important for the interaction of pantograph and OCL. A collapse of this system could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements. Meeting the requirements.
6.4.3.3	Transverse vibration tests		
6.5	Resistance to shocks	The robustness of the pantograph during the specific loads against shocks occurred during the raising movement in heavy railway infrastructure is very important for the interaction of pantograph and OCL. A collapse of this system could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.6	Transverse rigidity test	The stiffness of the pantograph in lateral direction occurred by the loads during the operation in heavy railway infrastructure is very important for the interaction of pantograph and OCL. A weaker stiffness than required will damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
6.7.2	Air tightness tests on operating device cylinder	The air tightness of the actuation system is important for the function of the ADD system. In case of a too high leakage the pantograph will lower and create a stop on the line with the vehicle or that the pantograph will not raise.	Meeting the requirements.
6.7.3	Air tightness climatic test		
6.8	Measurement of degrees of freedom of collector head	The functionality of the collector head is very important for the interaction of pantograph and OCL. A collapse of this system could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.9	Measurement of housing force	A defined housing force is necessary to prevent an unintentional raising of the pantograph during operation. Unintentional raising could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.10	Total mean uplift force	It is necessary to respect the limits of the mean uplift force according to the standards, guide lines, national regulations. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

6.11	Total contact force	It is necessary to respect the limits of the total contact force according to the standards, guidelines, national regulations. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.12	Current collection tests	It is necessary to respect the limits of the uplift force and other criteria according to the standards, guidelines, national regulations. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.13.1	Heating tests: rated and maximum current, vehicle at standstill	The limited temperatures from contact wire and carbon contact strip have to be respected during the current transfer at standstill operation. An exceeding of the limit could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.13.2	Heating test: simulation of running vehicle	The limited temperatures from the current transferring parts of the pantograph have to be respected during the current transfer at driving operation. An exceeding of the limit could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.13.3	Field test	The collector head has to transfer the necessary power during operation of the vehicle without any damages or exceeding of the temperature limits of the used materials. Damages on the collector head could additionally damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
6.14	Check of operating system at maximum speed	It is necessary that a pantograph lowers during maximum operation speed in a defined time a defined distance between pantograph and contact wire. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
7	Inspection plan	An inspection plan has to be created, where all maintenance activities and the associated time intervals have to be listed. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
8	Reliability	The necessary RAMS/LCC documents have to be created with the relevant values of MTBF, etc.. The values will describe the risk of a damage and the associated consequences.	Meeting the requirements.
9.1	Structure	The lifetime of the pantograph structure has to be respected. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

9.2	Collector head structure	The lifetime of the collector head structure has to be respected. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
9.3	Maintainability	Manual, other maintenance documents and RAM/LCC documents have to be respected. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

6.2 Gap analysis EN 50367:2020; Railway applications – Fixed installations and rolling stock – Criteria to achieve technical compatibility between pantographs and overhead contact line

Relevant chapter of the standard	Designation of the chapter	Gap analysis	Measures to reduce the Gap
5.2.5.1	General	The manufacturer of the pantograph must supply the necessary values for the calculation. With the vehicle data the manufacturer of the vehicle has to execute the necessary calculations. A weaker stiffness of the system vehicle, pantograph and infrastructure than required will damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
5.2.5.2	Limit of dewirement – limit of stability for lateral interaction	The manufacturer of the pantograph must supply the necessary values for the calculation. With the vehicle data the manufacturer of the vehicle has to execute the necessary calculations. A weaker stiffness of the system vehicle, pantograph and infrastructure than required will damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
5.2.5.3	Serviceability limit state	The manufacturer of the pantograph must supply the necessary values for the calculation. With the vehicle data the manufacturer of the vehicle has to execute the necessary calculations. A weaker stiffness of the system vehicle, pantograph and infrastructure than required will damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
5.2.6	Contact wire uplift	It is necessary to respect the limits of the maximum allowed uplift of the OCL according the standards, guide lines, national regulations. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.2.7	Neutral sections	The manufacturer of the pantograph must supply the necessary values for the calculation. With the vehicle data the manufacturer of the vehicle has to execute the necessary calculations. A bypass of the neutral section of the could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.

5.2.8	Change over area between pantograph profiles	The manufacturer of the pantograph must supply the necessary values for the calculation. With the vehicle data the manufacturer of the vehicle has to execute the necessary calculations. A weaker stiffness of the system vehicle, pantograph and infrastructure than required could damage the OCL and further parts of infrastructure and vehicle. The new pantograph shall not be raised before the other is in housed position. A operation with two different pantograph designs could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
5.3.1	General	The manufacturer of the pantograph must supply the necessary values. With the vehicle data the manufacturer of the vehicle has to execute the necessary calculations. An exceeding of the required values of the system vehicle, pantograph and infrastructure could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
5.3.2.2	Continuous pantograph head profile (without independent suspended contact strips)	The manufacturer of the pantograph must execute the necessary investigations. An not respecting of requirements could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
5.3.2.3	Non-continuous pantograph head profile (independent suspended collector strips)	The manufacturer of the pantograph must execute the necessary investigations. An not respecting of requirements could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
5.3.3	Conducting range	The contact range is important for the current transfer between pantograph and OCL. A not respecting of requirements could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
6.1	General	The requirements for current transfer between carbon contact strip and contact wire have to be respected. A not respecting of requirements could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.

6.2	Contact wire	The requirements for current transfer regarding the contact wire have to be respected. A not respecting of requirements could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
6.3	Carbon contact strips	The requirements for current transfer regarding the carbon contact strip have to be respected. A not respecting of requirements could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
7.1	General	The requirements of collector head gauge and vehicle gauge have to be respected. A not respecting of requirements could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
7.2	Static contact force and current capacity	The requirement regarding static contact force, design of OCL, transferred current have to be respected. A not respecting of requirements could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.
7.3	Dynamic behaviour and quality of current collection	It is necessary to respect the limits contact force percentage of arcs, uplift of the contact wire, standard deviation according the standards, guide lines, national regulations. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
8.1	Requirements for pantograph	Requirements regarding ADD, actuation system. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
8.2.1	General	Distances between more than one pantographs in operation and the electrical connections between the pantographs have to be respected. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
8.2.2	Design of overhead contact lines	The standards, guide lines, national regulations have to be respected by the design of the OCL. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

8.2.3	Formation of train with multiple pantographs - Arrangement of pantographs	Distances between more than one pantographs in operation and the electrical connections between the pantographs have to be respected. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
9.1	General	Relevant standards, guide lines, national regulations have to be respected by the evaluation of the interaction between pantograph and OCL. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
9.2.1.1	Simulation	Simulations regarding interaction of pantograph and OCL have to be executed according the relevant standards, guide lines, national regulations. A not respecting of the limits could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
9.2.1.2	Measurement	Test runs regarding interaction of pantograph and OCL have to be executed according the relevant standards, guide lines, national regulations. A not respecting of the limits could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
9.2.2	Integration of an assessed OCL into a network	Relevant standards, guide lines, national regulations have to be respected by the evaluation of the interaction between pantograph and OCL. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
9.3.1.1	Simulation	Simulations regarding interaction of pantograph and OCL have to be executed according the relevant standards, guide lines, national regulations. A not respecting of the limits could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

9.3.1.2	Measurement	Test runs regarding interaction of pantograph and OCL have to be executed according to the relevant standards, guide lines, national regulations. A not respecting of the limits could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
9.3.2	Integration of an assessed pantograph into a vehicle	Relevant standards, guidelines, national regulations have to be respected by the evaluation of the interaction between pantograph and OCL. A not respecting could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

6.3 Gap analysis EN 50405:2015; Railway applications – Current collection systems – Pantographs, testing methods for contact strips;

Relevant chapter of the standard	Designation of the chapter	Gap analysis	Measures to reduce the Gap
7.1.2	Determination of temperature behavior of the contact strip during current load	The limited temperatures from the current transferring parts of the contact strip have to be respected during the current transfer. An exceeding of the limit could damage parts of the contact strip, pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
7.2.2	High temperature test	The limited mechanical properties of the materials used for the contact strip have to be respected during the current transfer and the initiation of the force. An exceeding of the limits could damage parts of the contact strip, pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
7.2.3	Cold test	The limited mechanical properties of the materials used for the contact strip have to be respected during the current transfer and the initiation of the force. An exceeding of the limits could damage parts of the contact strip, pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
7.3	Bending behavior of conatct strip	The limited mechanical properties of the materials used for the contact strip have to be respected during the current transfer and the initiation of the force. An exceeding of the limits could damage parts of the contact strip, pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
7.4	Shear strength of contact strip	The limited mechanical properties of the materials used for the contact strip have to be respected during the current transfer and the initiation of the force. An exceeding of the limits could damage parts of the contact strip, pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
7.5	Test of the sensor of the Automatic Dropping Device (ADD)	The functionality of the A.D.D system guarantees in the most cases of an accident between OCL and parts of the collector head or abnormal wear could damage the OCL and further parts of infrastructure and vehicle.	Meeting the requirements.

7.6	Mechanically fatigue resistance of carbon contact strip	The robustness of the contact strip during the specific loads against vibrations occurred during the operation in heavy railway infrastructure is very important for the interaction of pantograph and OCL. A collapse of this system could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
7.7	Electrical resistance of contact strip	The electrical resistance is responsible for the heating within the contact strip. An overheating could damage the contacts strip, pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
7.8	Metal content in metal impregnated carbon contact strip	The metal content in metal impregnated contact strip is responsible for electrical resistance and heating within the contact strip. An overheating could damage the contact strip, pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
7.9	Friction value	A high friction will generate high forces in x and y direction (EN 12663) of the vehicle. Additionally, the contact wire of the OCL will be more worn. A defective OCL could damage the contact strip, pantograph, vehicle and further parts of infrastructure.	Meeting the requirements.
7.10	Resistance to impact of the carbon material	Impacts from the OCL, pantograph, vehicle, infrastructure could damage the contact strip. A defective contact strip could damage the OCL, pantograph, vehicle and further parts of infrastructure.	Meeting the requirements.
7.11	Thermal fatigue properties of the contact strip	The limited mechanical, electrical and thermal properties of the materials used for the contact strip have to be respected during heating up process. An exceeding of the limits could damage parts of the contact strip, pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

6.4 Gap analysis 1302/2014/EC; COMMISSION REGULATION (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the ‘rolling stock —locomotives and passenger rolling stock’ subsystem of the rail system in the European Union;

Relevant chapter of the standard	Designation of the chapter	Gap analysis	Measures to reduce the Gap
4.2.10.2.1	Material requirements	The selection of materials and components shall take into account their fire behavior properties, such as flammability, smoke opacity and toxicity. An exceeding of the limits of the flammability temperature could damage parts of the contact strip, pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.3.10, 4.2.8.2.1	General	The pantograph has to be designed to fulfill the requirements for the operation of the high voltage systems of EN 50163. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.3.10, 4.2.8.2.9.2	Pantograph head geometry	The design of the collector head has to respect the requirements of EN 50206-1 and EN 50367. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.3.10, 4.2.8.2.4	Maximum power and current from the overhead contact line	The pantograph has to be designed to fulfill the requirements for the current transfer during operation according EN 50206-1. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.3.10, 4.2.8.2.5.	Maximum current at standstill for DC systems	The pantograph has to be designed to fulfill the requirements for the current transfer during standstill operation according EN 50206-1, EN 50367. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.3.10, 4.2.8.2.9.5.	Pantograph static contact force	The pantograph has to be designed to fulfill the requirements for the static contact force according EN 50206-1, EN 50367. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

5.3.10, 4.2.8.2.9.6	Pantograph contact force and dynamic behavior	The pantograph has to be designed to fulfill the requirements for contact force and dynamic behavior according EN 50206-1, EN 50367. EN 50318, EN 50317. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.3.10, 4.2.8.2.9.1.2	Working range in height of pantograph	The pantograph has to be designed to fulfill the requirements regarding the working range according EN 50206-1, EN 50367. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.3.11, 4.2.8.2.1	General	The contact strip has to be designed to fulfill the requirements for the operation of the high voltage systems of EN 50163. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.3.11, 4.2.8.2.9.4.1	Contact strip geometry	The design of the contact strip has to respect the requirements of EN 50405 and EN 50367 regarding the geometry. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.3.11, 4.2.8.2.9.4.2, 6.1.3.8	Contact strip material	The contact strip has to be equipped with the requested wear materials according to the requirements of TSI, EN 50405 and EN 50367. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.3.11, 4.2.8.2.4	Maximum power and current from the overhead contact line	The contact strip has to be designed to fulfill the requirements for the current transfer during operation according EN 50206-1and EN 50405. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
5.3.11, 4.2.8.2.5	Maximum current at standstill for DC systems	The contact strip has to be designed to fulfill the requirements for the current transfer during standstill operation according EN 50405, EN 50206-1, EN 50367. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

6.5 Gap analysis 1301/2014/EC; COMMISSION REGULATION (EU) No 1301/2014 of 18 November 2014 on the technical specifications for interoperability relating to the ‘energy’ subsystem of the rail system in the Union

Relevant chapter of the standard	Designation of the chapter	Gap analysis	Measures to reduce the Gap
4.2.7	Electrical protection coordination arrangements	The relevant parts without wear parts have to be designed to withstand the requested short circuit current according EN 50388. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

6.6 Gap analysis 1303/2014/EC; COMMISSION REGULATION (EU) No 1303/2014 of 18 November 2014 concerning the technical specification for interoperability relating to 'safety in railway tunnels' of the rail system of the European Union

Relevant chapter of the standard	Designation of the chapter	Gap analysis	Measures to reduce the Gap
4.2.3.1.1	Material requirements	Please note comments 1302/2014/EC, 4.2.10.2.1	Meeting the requirements.
4.2.3.1.2	Specific measures for flammable liquids	Please note comments 1302/2014/EC, 4.2.10.2.1	Meeting the requirements.
4.2.3.3.4	Running capability	Please note comments 1302/2014/EC, 4.2.10.2.1	Meeting the requirements.
7.1.2.	New rolling stock	Please note comments 1302/2014/EC, 4.2.10.2.1	Meeting the requirements.
7.2.1.	Upgrade or renewal of rolling stock	Please note comments 1302/2014/EC, 4.2.10.2.1	Meeting the requirements.
7.3.2. (a)	Operational rules related to trains running in tunnels Specific case Italy	Please note comments 1302/2014/EC, 4.2.10.2.1	Meeting the requirements.
7.3.2. (b)	Operational rules related to trains running in tunnels Specific case Channel Tunnel	Please note comments 1302/2014/EC, 4.2.10.2.1	Meeting the requirements.

6.7 Gap analysis EN 50215:2009; Railway applications – Rolling stock – Testing of rolling stock on completion of construction and before entry into service

Relevant chapter of the standard	Designation of the chapter	Gap analysis	Measures to reduce the Gap
8.2.2.4	Tests of the pantograph at standstill	It is necessary that the pantograph mounted on the vehicle respects the gauge profile of EN 15273 at standstill operation. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
9.11	Kinematic gauge	It is necessary that the pantograph mounted on the vehicle respects the gauge profile of EN 15273 at operation under different conditions in the designated infrastructures. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.
9.13	Tests of compatibility of pantograph and power supply	It shall be verified if the pantograph is able to fulfill the technical requirements and if the vehicle is compatible with the electrically supply system of the infrastructure. Among others have to considered the standards EN 50206-1, EN 50367, EN 50317, multiple traction. Additionally have to be checked a fulfillment of the gauge profile according EN 15273 or if necessary UIC 505. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

6.8 Gap analysis EN 50124-1:2017; Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment

Relevant chapter of the standard	Designation of the chapter	Gap analysis	Measures to reduce the Gap
All	Insulation coordination	Insulation and creepage distances shall be coordinated according to this standard. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

6.9 Gap analysis EN 12663-1:2015; Railway applications – Structural requirements of railway vehicle bodies – Part 1: Locomotives and passenger rolling stock (and alternative method for freight wagons)

Relevant chapter of the standard	Designation of the chapter	Gap analysis	Measures to reduce the Gap
All	Structural requirements of railway vehicle bodies	Minimum requirements for the strength of car bodies for rail vehicles shall be fulfilled according this standard. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

6.10 Gap analysis EN 45545-2; Railway applications – Fire protection on railway vehicles – Part 2: Requirements for fire behavior of materials and components

Relevant chapter of the standard	Designation of the chapter	Gap analysis	Measures to reduce the Gap
All	Fire protection on railway vehicles	Measures and requirements which are aimed at to protect passengers and personnel in railway vehicles in the event of a fire on board shall be fulfilled according to this standard. A not fulfillment could damage parts of the pantograph, vehicle, OCL and further parts of infrastructure.	Meeting the requirements.

ANNEX_D – DLR Report FCH2RAIL_LGA

FCH2Rail
Deliverable 7.1
Annex D - TSI Analysis DLR

DLR

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1. TSI LOC&PAS (Locomotives and Passenger Rolling Stock)

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis
3.2.1.4.1	Requirements not covered by this TSI: Environmental protection	The environmental impact of establishment and operation of the rail system must be assessed and taken into account at the design stage of the system in accordance with the Community provisions in force. This essential requirement is covered by the relevant European provisions in force.	Which is the regulation for this point? Is it also applicable for Hydrogen trains?	Analysis/Tests if the train operation causes unusual environmental impact
3.2.1.4.3	Requirements not covered by this TSI: Environmental protection	The rolling stock and energy-supply systems must be designed and manufactured in such a way as to be electromagnetically compatible with the installations, equipment and public or private networks with which they might interfere. This essential requirement is covered by the relevant European provisions in force.	Which is the regulation for this point? Is there interference resulting from the new train design?	Analysis/Tests if the train operation causes unusual eletromagnetic effects. Includes Hydrogen refueling stations
3.2.1.4.5	Requirements not covered by this TSI: Environmental protection	Operation of the rail system must not give rise to an inadmissible level of ground vibrations for the activities and areas close to the infrastructure and in a normal state of maintenance. This essential requirement is in the scope of the Infrastructure.	Which is the regulation for this point? Is there interference resulting from the new train design?	Analysis/Tests if the train operation causes unusual vibrations
4.1.4.	Categorisation of the rolling stock for fire safety	For units designed to carry passengers or haul passenger carriages, and subject to the application of this TSI, category A is the minimum category to be selected by the party asking for assessment; the criteria for selecting category B are given in the TSI SRT.	Train must comply to Category A requirements - are these categories still applicable for hydrogen trains?	according to system definition: operation category 3 (covers Category A and B)
4.2.3.1.5	Pantograph interface	The voltage of the power supply is considered in the infrastructure gauge in order to ensure the proper insulation distances between the pantograph and fixed installations.	Is the compliance to the referenced specification (ID 14 in the harmonised table) sufficient for our system?	
4.2.6.2.1	Slipstream effects on passengers on platform and on workers trackside	see values in Table 4, see also following chapters concerning aerodynamic effects	Are there increased effects by or on the additional equipment on the roof?	The TSI regulations don't apply because of max speed 120 km/h

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis
4.2.8.2.9.9	Insulation of pantograph from vehicle	The pantographs shall be assembled on an electric unit in a way that ensures the current path from collector head to vehicle equipment is insulated. The insulation shall be adequate for all system voltages the unit is designed for.	Is that sufficiently the case for the additional installations on the roof?	
4.2.8.3	Diesel and other thermal traction systems	Diesel engines are to comply with the Union legislation concerning exhaust (composition, limit values).	Are hydrogen trains part of that classification? If yes: what are these regulations? If not: should they be included here in a similar fashion as diesel engines?	Hydrogen powered will have to have a new category
4.2.10.2.2	Specific measures for flammable liquids	(1)Railway vehicles shall be provided with measures preventing a fire from occurring and spreading due to leakage of flammable liquids or gases.	Is this requirement fully applicable and sufficient for hydrogen applications? (At least the chapter title is not sufficient)	
4.2.10.2.2	Specific measures for flammable liquids	(2) Flammable liquids used as cooling medium in high voltage equipment of freight locomotives shall be compliant to the requirement R14 of the specification referenced in Appendix J-1, index 59.	System definition foresees cooling system on the roof. Are liquids/gases involved in the cooling system that also require this or additional precautions analog to this?	More detailed analysis of the cooling system needed
4.2.10.3.1	Portable Fire extinguishers	Water plus additive type fire extinguishers are deemed to be adequate for on-board rolling stock purposes	Are a special kind of portable fire extinguishers necessary for fires involving Hydrogen and pantograph?	Check with experts
4.2.10.3.2	Fire detection systems	(1) The equipment and the areas on rolling stock that intrinsically impose a fire risk shall be equipped with a system that will detect fire at an early stage. (2) Upon fire detection the driver shall be notified and appropriate automatic actions shall be initiated to minimize the subsequent risk to passengers and train staff.	Appropriate system as well as operational procedures, both covering the specific hazards, have to be implemented	

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis
4.2.10.3.4	Fire containment and control systems for passenger rolling stock	(2) The unit shall be equipped with adequate measures to control the spread of heat and fire effluents through the train. (3) The conformity with this requirement shall be deemed to be satisfied by the verification of conformity to the following requirements: - The unit shall be equipped with full cross section partitions within passenger/staff areas of each vehicle, with a maximum separation of 30 meters which shall satisfy requirements for integrity for a minimum of 15 minutes (assuming the fire can start from either side of the partition), or with other Fire Containment and Control Systems (FCCS). - The unit shall be equipped with fire barriers that shall satisfy requirements for integrity and heat insulation for a minimum of 15 minutes at the following locations (where relevant for the concerned unit): — Between the drivers cab and the compartment to the rear of it (assuming the fire starts in the rear compartment). — Between combustion engine and adjacent passenger/staff areas (assuming the fire starts in the combustion engine). — Between compartments with electrical supply line and/or traction circuit equipment and passenger/staff area (assuming the fire starts in the electrical supply line and/or the traction circuit equipment). (4) If other FCCS are used instead of full cross section partitions within passenger/staff areas, the following requirements shall apply: — They shall be installed in each vehicle of the unit, which is intended to carry passengers and/or staff, — They shall ensure that fire and smoke will not extend in dangerous concentrations over a length of more than 30 m within the passenger/staff areas inside the unit, for at least 15 minutes after the start of a fire.	Are there additional measures necessary to protect passengers and staff taking into account e. g. electrical/battery fires, hydrogen fires or explosions?	Analysis if there are additional hazards, e. g. from burning/exploding hydrogen that require additional measures

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis
4.2.10.4.2	Emergency Smoke Control	(2) To prevent outside smoke from entering the unit, it shall be possible to switch off or close all means of external ventilation. (3) To prevent smoke that could be inside a vehicle from spreading, it shall be possible to switch off the ventilation and recirculation at vehicle level, this may be achieved by switching off the ventilation.	The ventilation of the hydrogen related equipment is safety relevant. Could switching off this ventilation due to smoke control influence these safety measures positively or negatively? Do Hydrogen fumes behave differently than "traditional" smoke?	Further Analysis on how hydrogen related ventilation is influencing smoke control emergency situations
4.2.10.4.4	Emergency Running Capability	(2) The unit shall be designed so that, in the event of fire on-board, the running capability of the train will enable it to run to a suitable firefighting point. [...]: — braking for rolling stock of fire safety category A: this function shall be assessed for a duration of 4 minutes. — braking and traction for rolling stock of fire safety category B: these functions shall be assessed for a duration of 15 minutes at a minimum speed of 80 km/h.	As the firefighting requirements may be different from traditional trains, these suitable firefighting points could be further away than usually. The emergency running capabilities of the train then would have to be higher.	Has to be in line/coordinated with the infrastructure manager/emergency management plan
4.2.11.6	special requirements for stabling of trains	(1) This clause is applicable to units intended to be powered while stabled, (2) The unit shall be compatible with at least one of the following external power supply systems, and shall be equipped (where relevant) with the corresponding interface for electrical connection to that external power supply (plug), (3) Power supply contact line (see clause 4.2.8.2.9 'Requirements linked to pantograph') (4) 'Single pole' power supply line (AC 1 kV, AC/DC 1,5 kV, DC 3 kV), in accordance with the specification referenced in Appendix J-1, index 111, (5) Local external auxiliary power supply 400 V that can be connected to socket type '3P+ground' according to the specification referenced in Appendix J-1, index 65.	Generally: are there subsystems that have to be powered when stabled (generally or after a certain time when the battery would run out)? For example hydrogen ventilation systems?	This is no gap in the regulation

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis
4.2.11.7.	Refuelling equipment		There is no mention of fuels other than diesel in this chapter.	Gap should be closed with (trainside) interoperability requirements/standards for hydrogen refuelling

2. TSI Energy

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis
2.1	Definition	(1) This TSI covers all fixed installations necessary to achieve interoperability that are required to supply traction energy to a train.	The pantograph is part of the scope of the TSI ENE (at least as interface), refuelling stations are not	Requirements for refuelling stations should be part of TSI INF
4.2.10	Pantograph gauge	(1) No part of the energy sub-system shall enter the mechanical kinematic pantograph gauge [...] except for the contact wire and steady arm	In the remaining room above the roof there could be (electrical / mechanical) trackside equipment extending into the room above the roof.	It is assumed that system design will consider possible interactions with installations on the roof

3. TSI Infrastructure

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis
2.1	Definition of the infrastructure subsystem	This TSI covers: (a) the infrastructure structural subsystem (b) the part of the maintenance functional subsystem relating to the infrastructure subsystem (that is: washing plants for external cleaning of trains, water restocking, refuelling, fixed installations for toilet discharge and electrical shore supplies).	The infrastructure subsystem includes refuelling stations, does not include catenary (that is included in TSI ENE)	Requirements for Hydrogen refuelling stations have to be part of the TSI INF
4.2.12.5	Refuelling	Refuelling equipment shall be compatible with the characteristics of the fuel system specified in the LOC & PAS TSI.	No requirements (diesel or hydrogen) in this TSI	Closing the gap with new requirements here or in the LOC & PAS TSI

4. TSI Noise

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis
2.(a)	Definition of the subsystem	The requirements of this TSI apply to the following categories of rolling stock set out in section 2 in Annex I of Directive (EU) 2016/797: (a) Locomotives and passenger rolling stock including thermal or electric traction units, self-propelling thermal or electric passenger trains, and passenger coaches. This category is further defined in chapter 2 in the annex to Regulation (EU) No 1302/2014 and shall be referred to in this TSI as locomotives, electric multiple units (EMU), diesel multiple units (DMU) and coaches;	If Hydrogen trains are new category, alongside for example DMU, the mentioned regulations have to be streamlined	Hydrogen trains could be new category, then they have to be included in this list and the referenced regulations
4.2	Functional and technical specifications of the subsystems	The following parameters have been identified as critical for the interoperability (basic parameters): (a) 'stationary noise'; (b) 'starting noise'; (c) 'pass-by noise'; (d) 'driver's cab interior noise'. The corresponding functional and technical specifications allocated to the different categories of rolling stock are set out in this section. In case of units equipped with both thermal and electric power the relevant limit values under all normal operation modes shall be respected. If one of these operation modes foresees the use of both thermal and electric power at the same time the less restrictive limit value applies.	The chapter lists the different limit values that are varying for the numerous train types (EMU, DMU, etc.).	Determine in which categories the Hydrogen train fits, or create new category. Conformity to the requirements has to be determined in tests
6.2.3	Simplified evaluation	Instead of the test procedures as set out in point 6.2.2, it is permitted to substitute some or all of the tests by a simplified evaluation. The simplified evaluation consists of acoustically comparing the unit under assessment to an existing type (further referred to as the reference type) with documented noise characteristics. The simplified evaluation may be used for each of the applicable basic parameters 'stationary noise', 'starting noise', 'pass-by noise' and 'driver's cab interior noise' autonomously and shall consist of providing evidence that the effects of the differences of the unit under assessment do not result in exceeding the limit values set out in Section 4.2.	Simplified evaluation could be a way to simplify the noise tests for a changed vehicle, especially if the wheel type and brake block are not changed, the max unit speed is below 160 km/h and the weight is less than 20% more than before (see Table 7)	This could be a way to assess the changed vehicle in our project. However for the authorisation process there are tests to carry out anyway.

5. TSI SRT (Safety in Railway Tunnels)

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis
2.2.1 (b)	"Hot" incidents - Fire starts on a train	Ventilation is shut down to prevent smoke distribution. For rolling stock of category B, the passengers in the affected area will move to a non-affected area of the train where they are protected from fire and fumes	Concerning fires on hydrogen trains, could it be safer to not shut down ventilation completely?	Maybe it could be safer to also apply the category B requirements to (otherwise) category A trains when hydrogen is involved
2.2.2 (b)	"Cold" incidents	The difference compared to the hot incidents is that there is no time constraint due to the presence of a hostile environment created by a fire.	If Hydrogen is leaking out after a collision, the incident could be just as dangerous as a "Hot" incident	Check if in case of collision requirements for "Hot" incidents could also be applicable "Cold" incidents. Especially explosion risks
6.2.7.2 (1)	Fire resistance of tunnel structures	To demonstrate that the integrity of the tunnel lining is maintained during a period of time that is sufficiently long to permit self-rescue, evacuation of passengers and staff and intervention of the emergency response services, demonstration that the tunnel lining can withstand a temperature of 450 °C at ceiling level during that same period of time is sufficient.	Are the heat resisstance requirements suited for fires involving hydrogen?	Are fires involving hydrogen hotter than other assumed fires?

6. TSI OPE (Operation and Traffic Management)

The TSI OPE references other TSIs in certain aspects (that were already analyzed), but no additional possible gaps were found in the analysis.

7. TSI PRM (Persons with Reduced Mobility)

No possible gaps were found in the analysis of the TSI PRM