D7.4– Complementary gaps in analysis framework

WP 7–Normative Framework

Task 7.1–Identification of Gaps in regulatory framework

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Date	09/01/2024	
Document ID	FCH2RAIL-823879026-334	
Document Status	X	Draft prepared for final review within task / WP
	X	Finalised draft document at Task / WP level
	X	Document after quality check
	X	Document approved by SC
	X	Document approved by TMT
	X	Document submitted to FCH-JU

Dissemination Level	
PU: Public	**X**
CO: Confidential, only for members of the consortium (including the Commission Services):	

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Document Status History

Status Description	Date	Partner	Status Code in Filename
Draft prepared for final review within task	17.12.2023	Esteban Rodriguez, Beatriz Nieto, CNH2	Draft_final_review_task
Finalized draft document at WP level	18.12.2023	Esteban Rodríguez, Beatriz Nieto, CNH2	WP_final_draft
Document after quality check	09.01.2024	Stefanie Schöne, DLR	QC
Document approved by SC	25.01.2024	SC	Approved_SC
Document approved by TMT	25.01.2024	TMT	Approved_TMT
Document submitted to FCH-JU	30.01.2024	Maike Vogt, DLR	Submitted

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	Gaps analysis related to infrastructure
RENFE	Review of the deliverable
IP	Preparation of the deliverable
STT	Gaps analysis related to the pantograph

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No. 101006633. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

Executive Summary

This document is Deliverable D7.4: ‘Complementary gaps in analysis framework, 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 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 reflect any lessons from the full demonstrator trial and identify any additional gap found as a result of the experience of full demonstrator trial, in order to increase the knowledge of gaps related to the current regulatory framework orientated to the integration of H_2 technologies in the railway systems developed on D7.1.

Next steps are followed:

- Assessing the requirements relating to the gap 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 TSI documents 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, encompassing all the components that constitute the project within the railway sector.

This document complements gaps found on deliverable 7.1. The final goal is be able to collect all the normative gaps from a theoretical and practical point of view.

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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
EN	Euro Norm
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
RCS	Regulations Codes & Standards
WP	Work Package

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

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Contents

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1. Background

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. 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 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
- 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 task.

Within the task 7.1, complementary to the identification of Gaps in the Regulatory Framework, this text has integrated new gaps found are assessed based on the experience obtained with the demonstrator train on field.

2. Objective

This document provides the final issue of the Legislative Gap Analysis (LGA), 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.

Each partner in the project has examined their 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 will give 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 H2 in the integration of rail vehicles.
- DLR has reviewed the relevant TSIs and relevant railway regulations, as for example EN and ERA regulations, mainly from a railway systems point of view.
- STT has identified regulatory gaps for the interaction of pantograph-H2 system within the scope of this project.

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- 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 H2, focus on identifying legislative gaps related to the implementation of Hydrogen Refuelling Stations.

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, complementing the *D7.1. Gaps in regulatory framework prior to the demonstrator train test*. 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 Specifications for Interoperability (TSI).

This work must 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, including inputs and outputs from testing in Zaragoza.

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 criteria and following the points that it considers necessary, defining the work methodology used specifically in the following analysis section.

5. Analysis of Regulatory Gaps

5.1 Analysis related to the Train

The objective of this section 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 final issue, including inputs and outputs from testing in Zaragoza.

5.1.1 Scope

The Legislative Gap Analysis has been presented in three distinct issues:

1. 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.

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2. Issue 2 - '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.

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

5.1.2 Methodology

The methodology used to undertake the LGA is fully described in the report at Annex 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 ap-plication.
5. Add a list of those hazards where currently no applicable RCS exist.

5.1.3 Summary of findings

The report at Appendix A concludes that a total of 90 Regulations, Codes and Standards (RCS) – of which more than half are Railway Regulations Codes & Standards (RCS) – have been allocated 360 times to 26 generic Causes.

- 16 Railway RCS (3 new ones) were identified that require no modification as they adequately mitigate the related hazards, when applied.
- 16 Railway RCS (3 new ones) were identified that require modification in order to achieve an acceptable mitigation.
- 56 Non-railway RCS (26 new ones) 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.
- 18 Technical issues (9 new ones) 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

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regarding hydrogen refuelling, since these aspects will be key for an 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 considered, including inputs and outputs from testing in Zaragoza.

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 H2 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:

- Determination of the generic dangers, related faults and related causes, which are expected with the applied technology.
- Enumeration and categorisation 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:
    - RCS that do not require modification
    - 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 and the causes that generate it.

As a complement, technical issues and others scenarios have surged from the experience on field with the demonstrator train. These have been collected as a supplement of the Annex B, where most of them have been solved by experience based on other application fields or by calculation.

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5.2.3 Summary of findings

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. In these 7 RCS, 4 new gaps have been identified within the RCS analyzed based on field experience with the train demonstrator.
- 4 technical issues have been found where currently there is no RCS that specifies how to mitigate the effects that may generate a hazard, a new one found based on field experience with the train demonstrator.

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

A demonstrator railway vehicle, based on an existing's design, equipped with a hybrid (H2 and electrically actuated by a pantograph) drive system was refurbished by CAF. The vehicle is since summer 2023 in operation in the Spanish infrastructure. Based on the experience of the executed test runs and the resulting experiences the existing gap analysis related to the pantograph (Task 7.1) must be reviewed and if necessary revised.

5.3.2 Methodology

The existing gap analysis of the existing standard framework related to the pantograph (D7.1 Identification of Gaps in regulatory framework regarding the pantograph) is the basic for an investigation to compare it with the experience received from the test runs with the demonstrator railway vehicle. The present standard framework 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), for the energy of the rail system (TSI ENE), EU 1301/2014 and the relevant EN standards.

New or reworked standards shall be reviewed too.

5.3.3 Summary of Findings

The identified hazards, faults and causes, are listed in the Annex C. The assessment of severity and occurrence will be done in an analysis according EN 50126, EN 60812 or similar. From a total of 18 RCS, 6 old RCS were modified according to the new amendment, and 3 new RCS have been analysed.

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5.4 Analysis related to TSI´s

5.4.1 Methodology

For the Deliverable 7.1 we analyzed the existing TSI landscape to identify possible gaps regarding the new technologies developed in FCH2Rail. However, in the meantime, there were substantial changes made in the analyzed TSIs, so that for this Deliverable, we researched if there are new gaps stemming from these changes, or if any gaps were closed. Additionally, for a few of the major findings in the analysis in Deliverable 7.1, we added a few more information and sources to where possible risks and gaps in the TSIs could be. The resulting, updated analysis can be found in Annex D.

5.4.2 Summary of findings

The ERA presented the key changes in the new TSI versions, concerning Rolling Stock [3], none of which affect the gaps concerning possible hydrogen technologies presented in Deliverable 7.1.

To have an impression of what are the changes that are already considered to be part of future TSIs, additionally an analysis of the Change Request list was carried out. In order to change a regulation in the TSI, an official Change Request (CR) has to be made, which can be submitted by certain bodies representing the rail industry in Europe and is then processed in working groups at ERA. What ways are available for addressing the gaps found in this project, will be further described in Deliverable 7.2. CAF provided the DLR with a version of the current Change Request List dated March 2023 (source not published).

- Discussions about the charging of battery powered trains are carried out as CR 350 and seem to be in early stages. The FCH2Rail technologies do not rely on the charging of batteries directly from the infrastructure side, but rather via fuel cells on the train. However, observing the discussions could be helpful to find a good way to implement changes needed for hydrogen trains because of parallels in level of innovation and procedures needed to change the normative framework.
- CR 306 stipulates, in a very broad and general way, to consider innovative means of energy sources for trains, explicitly naming fuel cells as an example. The timeline is not defined and so, in the authors opinion, it can be seen as a general aspiration for TSI changes. It is, however, explicitly stated that input from Shift2Rail and FCH projects are awaited and that ERA is to follow up the matter.

5.5 Analysis related to infrastructure

5.5.1 Scope

As the Spanish rail infrastructure manager, ADIF carries out the analysis of interfaces between the new train concept and the infrastructure, such as, the hydrogen refuelling system, its location, and the affection it will have in the infrastructure.

For this reason, since the start of the project in January 2021, ADIF has been working on the location of the hydrogen refuelling points that will be used to install the portable Hydrogen Refuelling Station

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(HRS) supplied by CNH2 to the CIVIA prototype during the project tests. Based on the experience of the experience, ADIF has found a normative gap that could affected the installation of the HRS.

5.5.2 Methodology

During the search and location of a suitable area for the installation of the HRS, ADIF has found new gaps caused by the changes that would have to be made to adapt the railway infrastructure to the HRS. In this case, it was discovered that the gaps found were not closed as similar situations had not occurred before within ADIF. These results of the analysis can be found in Annex E of the document.

5.5.3 Summary of findings

With the experience acquired by ADIF in the search for a location that meets the characteristics of the portable refuelling installation, the inconveniences encountered during this search and the resolution of the same. ADIF has found several regulatory gaps that can be summarised as follows, the full explanation of which can be found in Annex E of this document. The findings can summarize by:

- ***Documentation for legalisation of a portable hydrogen system***. Authorisation for hydrogen supply installations on railway infrastructure lacks defined procedures due to the absence of prior installations. To address this regulatory gap, efforts will be made to align with existing authorisation processes, such as those for diesel supply. However, critical aspects like ATEX zones and electrical installation effects will require specific projects and singular authorizations, with UNE-ISO 19880-1 serving as a reference standard.
- ***Application of the Royal Decree of the European Union RUE 402/2013*** to a railway refuelling installation: Railway infrastructure changes must adhere to the safety methods outlined in RD 402/2013 and Directive (EU) 2016/798, which detail procedures for risk evaluation and assessment. Common Safety Methods (CSMs) per Article 6 specify the assessment processes, safety target achievement, and conformity evaluation methods. However, a regulatory gap exists in determining the applicable safety certification for cases involving new propulsion elements, like hydrogen cells, and related infrastructure. To address this, ASBOs and ISAs, independent bodies authorised for risk and safety analysis, will play a crucial role, following specified regulations and standards.
- ***Lighting Arrester***. A regulatory gap is evident concerning the installation of lightning conductors in the vicinity of hydrogen refuelling stations. While the Technical Building Code (CTE) and UNE 21186:2011 are reference standards, the gap involves determining the necessity or obligation of installing a lightning conductor and the recommended distance. Additionally, there's uncertainty regarding portable HRS and whether complementary measures suffice. The UNE-ISO 19880-1 standard may guide decisions, stating lightning protection is needed as required. A detailed analysis is pending on the benefits and drawbacks of installing lightning arresters, considering factors such as operational restrictions during climatic events. Further clarification is needed to differentiate between provisional and definitive installations, as their characteristics may influence the necessity of a lightning protection system.

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- ***Grounding points***. A regulation is essential to define the maximum ground resistivity, preventing unwanted shunts or discharges from lightning strikes. This is crucial for the FCH2Rail project's Portable Hydrogen Refuelling System, where the resistivity of the terrain requires deep trench installation of earthing systems to avoid interference with control, command, signalling elements, and track circuits during hydrogen generation.
- ***Safety distances to railway elements***. Hydrogen refuelling station incorporates venting systems activated in case of issues with the pressurized system or the release of hydrogen in a defined Explosive Atmospheres Zone (ATEX). However, a regulatory gap exists in railway regulations, lacking delimitation of safety zones between the Refuelling System, Railway Safety Zone, and potential access points to the ATEX zone. A necessary regulation is required to establish safety distances within a railway environment for hydrogen installations, encompassing storage and refuelling systems.
- ***Passage through underground stations and tunnels***. A regulatory gap is evident in the transit of hydrogen trains through urban areas like tunnels, underground stations, and bathtubs, lacking specific rules for trains propelled by hydrogen. Precautionary measures are currently applied during tests to avoid potential risks, resembling aspects of the Dangerous Goods regulation (RD 412/2001) for rail transport. However, since hydrogen, in this context, is not classified as dangerous goods but as self-consumed fuel, a specific regulatory framework is required. The existing RD 412/2001 outlines general rules for stopping, emergency procedures, and authority actions, emphasizing the need for specialised regulations in these unique urban environments.
- ***Emergency Protocol***. A regulatory gap is identified regarding the absence of a standard necessitating a specific regulation for an emergency protocol. This protocol aims to coordinate the hydrogen train operating company, emergency services, and infrastructure management company. To address this gap, the FCH2Rail project creates a Self-Protection Protocol, facilitating coordination between RENFE, emergency services, and local authorities during tests where formal regulations are lacking.
- ***Train - Hydrogen Refuelling Station Interface***. The rail infrastructure manager aims to establish a Hydrogen Refuelling System for fuel cell-powered trains, emphasizing the need for a secure and efficient refuelling process. Identifying a new regulatory gap, there is a requirement for a protocol and regulations to ensure a communication system that records essential data during refuelling. The proposed regulation should adopt an open-source format for data collection to foster international interoperability, encouraging widespread adoption of this technology and enhancing safety and efficiency in the process.
- ***Train - Infrastructure Interface.*** A regulatory gap is identified in the absence of traction technology standards for rolling stock that combines pantograph, hydrogen, and batteries. Current Control, Command, and Signalling (CMS) lack provisions to communicate with safety systems for pantograph adjustment when transitioning between electrified and non-electrified sections. The regulation must address this, ensuring seamless signalling and recording changes in the catenary, with safety systems beacons playing a key role in alerting and managing pantograph actions.

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.

Complementary, and with the objective to enlarge information related to those normative gaps found on the regulatory framework review, new gaps have been assessed based on the experience obtained with the demonstrator train tests on field.

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 must be considered in the design, e.g. the effect of solar radiation falling on the train, which can trigger a fire and/or explosion due to 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.

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 documents, all the critical points related to the implementation of this technology in the railway sector have been analysed in a general manner.

Most significant TSI documents have been analysed, where the most important points to be dealt within the technical regulations reveal interoperability requiring some type of modification, matters such as environmental 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.

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Additionally, greenhouse effect due to the hydrogen venting has also been considered. Fire detection and extinguishing, due to see-through property hydrogen when it is released or ignited, constitutes a challenge does not contemplated on TSI documents yet.

The demonstrator train experience has also proven valuable in identifying new regulatory gaps that are not currently taken into consideration.. Issues related to grounding connection, lightning conductor requirement, HRS settings when the refuelling process is carried out, safety distances among the different elements that make up the train with the HRS and the surrounded infrastructure, have been, among others, the main difficulties found with the demonstrator train in practice.

A noteworthy finding is the large number of obstacles pertaining to the projects legalisation of the HRS installation.

7. References

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

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

[3] Webinar "TSI Revision Package 2023 Key Changes - Part I Rolling stock and CCS (15 June 2023)", European Union Agency for Railways, recording available at https://www.era.europa.eu/content/free-webinar-tsi-revision-package-2023-key-changes-part-i-rolling-stock-and-ccs

A.1 LIST OF ANNEXES

ANNEX_A – CAF Report FCH2RAIL_CGA

ANNEX_B – CNH2 Report FCH2RAIL_CGA

ANNEX_C – STT Report FCH2RAIL_CGA

ANNEX_D – DLR Report FCH2RAIL_CGA

ANNEX_E – ADIF Report FCH2RAIL_CGA

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ANNEX_A – CAF Report FCH2RAIL_CGA

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EDITION CONTROL

Edition	REASON	Date
_	First Planned Issue	13/04/22
A	Second Planned Issue	28/09/22
B	Final Issue	18/10/23
C	Updated due to CHN2 comments	04/12/23

Prepared by:	Reviewed by:	Approved by:
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Index:

Title:	Legislative Gap Analysis.
Reference:	CN9.96.708.01
Issue:	C
Date:	04/12/2023
Redaction:	Ainara Astigarraga
Verified:	Eva Terron
Approved:	Ainara Gonzalez
Amendments:	None, first issue

1 Introduction

This document provides the final 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 final issue (see Section 4), including inputs and outputs from testing in Zaragoza.

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.

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

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- 18 Technical issues (9 new ones) 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 3.0

LEGISLATIVE GAP ANALYSIS

FCH2RAIL
Work Package 7.1

Report-No.: CZ98349T, Report Date: 2023-09-22
Revision: 3.0, Pages: 42

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Order Date: 2021-05-12
Project No.: 717523125

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Revision history

Revision	Status	Date	Author	Modified clauses	Modifications
0.1	Draft	2022-02-22	Tolga Wichmann	---	Initial
1.0	Withdrawn	2022-03-31	Tolga Wichmann	All	Review comments
1.1	Withdrawn	2022-04-06	Tolga Wichmann	All	Editorial changes and corrections, added ISO 17268, deleted UN 38.3
2.0	Withdrawn	2022-09-19	Tolga Wichmann	All	1.6, 1.7, 4, 5 – additional 13 RCS analysed
2.1	Withdrawn	2022-09-23	Tolga Wichmann	All	Editorial changes and corrections
3.0	Released	2023-09-22	Tolga Wichmann	All	Additional 32 RCS analysed

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 ran in parallel with the project as it depended on the results of documents that are produced along the progress of the project. For this reason, there were intermediate issues of the LGA before it was released in this 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-authorization for demonstrator trials, including outputs and return of experience from the trial, analysis of the vehicle safety case and commissioning / 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

Table 2: Abbreviations

Abbreviation	Definition
ENE	Energy (here related to EU 1301/2014)
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, 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	A	2023-02-16
[D03]	Hazard Log FCH2Rail – Civia H2	C.N9.96.908.00	CAF	I	2023-06-14
[D04]	Hazard Log – FCH2RAIL - Integration of TOYOTA FCM into Civia H2	---	TME	2	26.10.2022
[D05]	Project Hazard Log - Cover Sheet CAF FCH2RAIL – Civia H2 350 Bar Hydrogen System	---	LUXFER	C	2022-07-11

Table 3: Documents

ID	Document Title	Doc./File ID	Author	Rev.	Date
[D06]	Hazard Log CIVIA H2 Project RAMS	QB0000000073	CAF	0.4	2022-06-06
[D07]	ESSENTIAL OUTSOURCED ITEM SPECIFICATION (EEFAE) – FUEL CELL SYSTEM – FCH2RAIL PROJECT	C.N9.94.113.01	CAF	---	27.01.2021
[D08]	ESSENTIAL OUTSOURCED ITEM SPECIFICATION (EEFAE) – FUEL CELL COOLING SYSTEM – RENFE H2 PROTOTYPE	C.N9.94.111.03	CAF	A	22.04.2021
[D09]	ESSENTIAL OUTSOURCED ITEM SPECIFICATION (EEFAE) – FUEL CELL HYDROGEN STORAGE SYSTEM – RENFE H2 PROTOTYPE	C.N9.94.113.02	CAF	---	15.03.2021
[D10]	Legislative Framework - Generic EU EMU	---	CAF	---	2021-10-21
[D11]	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 been either referenced by the input documents [D02] to [D11] or have been identified along the project and are listed below in table 4. The decision for including an RCS in the analysis was mainly taken on the following criteria:

- it has been applied within the FCH2RAIL Project and is referenced in either one of the aforementioned documents,
- it can be allocated to alternative propulsion with hydrogen or lithium-ion-battery-systems and has a potential to mitigate or prevent certain hazard and/or
- it is an international EN, ISO or IEC, SAE, UN code or European Regulation or Directive.

The complete list of RCS, including those that have not been included in the analysis can be found in appendix II. For further information on the list of RCS, please refer to section 5.2.

All standards listed below are referenced in the original version instead of the national version to avoid any translation issues and deviating issue dates.

Table 4: Regulations, Codes and Standards

No.	Standard	Date	Title
[R01]	1999/92/EC	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

Table 4: Regulations, Codes and Standards

No.	Standard	Date	Title
[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]	2014/30/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)
[R04]	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
[R05]	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
[R06]	EC 79/2009	2009-01-14 (withdrawn)	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]	EU 1299/2014	2014-11-18	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
[R08]	EU 1301/2014	2019-06-16	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
[R09]	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
[R10]	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
[R11]	EU 406/2010	2010-04-26 (withdrawn)	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
[R12]	EN 894-1	1997 A1:2008	Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 1: General principles for human interactions with displays and control actuators

Table 4: Regulations, Codes and Standards

No.	Standard	Date	Title
[R13]	EN 1127-1	2019	Explosive atmospheres - Explosive prevention and protection - Part 1: Basic concepts and methodology
[R14]	EN 1779	1999	Non-destructive testing - Leak testing - Criteria for the method and technique selection
[R15]	EN 10216-5	2021	Seamless steel tubes for pressure purposes - Technical delivery conditions - Part 5: Stainless steel tubes
[R16]	EN 12245	2022	Transportable gas cylinders - Fully wrapped composite cylinders
[R17]	EN 12663-1	2010 A1: 2014	Railway applications - Structural requirements of railway vehicle bodies - Part 1: Locomotives and passenger rolling stock
[R18]	EN 13480-2	2017	Metallic industrial piping - Part 2: Materials
[R19]	EN 13480-3	2017	Metallic industrial piping - Part 3: Design and calculation
[R20]	EN 15085-series	2021	Railway applications - Welding of railway vehicles and components - series
[R21]	EN 15227	2020	Railway applications - Crashworthiness requirements for rail vehicles
[R22]	EN 16404	2016	Railway applications - Re-railing and recovery requirements for railway vehicles
[R23]	EN 17124	2018	Hydrogen fuel - Product specification and quality assurance - Proton exchange membrane (PEM) fuel cell applications for road vehicles
[R24]	EN 17127	2018	Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols
[R25]	EN 17339	2020	Transportable gas cylinders - Fully wrapped carbon composite cylinders and tubes for hydrogen
[R26]	EN 45545-1	2013	Railway applications - Fire protection on railway vehicles - Part 1: General
[R27]	EN 45545-2	2020	Railway applications - Fire protection on railway vehicles - Part 2: Requirements for fire behaviour of materials and components
[R28]	EN 45545-3	2013	Railway applications - Fire protection on railway vehicles - Part 3: Fire resistance requirements for fire barriers
[R29]	EN 45545-4	2013	Railway applications - Fire protection on railway vehicles - Part 4: Fire safety requirements for rolling stock design;
[R30]	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
[R31]	EN 45545-6	2013	Railway applications - Fire protection on railway vehicles - Part 6: Fire control and management systems

Table 4: Regulations, Codes and Standards

No.	Standard	Date	Title
[R32]	EN 45545-7	2013	Railway applications - Fire protection on railway vehicles - Part 7: Fire safety requirements for flammable liquid and flammable gas installations
[R33]	EN 50121-3-1	2015	Railway applications - Electromagnetic compatibility - Part 3-1: Rolling stock - Train and complete vehicle
[R34]	EN 50121-3-2	2016	Railway applications - Electromagnetic compatibility - Part 3-2: Rolling stock - Apparatus
[R35]	EN 50122-1	2017	Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 1: Protective provisions against electric shock
[R36]	EN 50124-1	2017	Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment
[R37]	EN 50124-2	2017	Railway applications - Insulation coordination - Part 2: Overvoltages and related protection
[R38]	EN 50125-1	2014	Railway applications - Environmental conditions for equipment - Part 1: Rolling stock and on-board equipment
[R39]	EN 50128	2011 A1:2020	Railway applications - Communication, signalling and processing systems - Software for railway control and protection systems
[R40]	EN 50129	2018 AC:2019	Railway applications - Communication, signalling and processing systems - Safety related electronic systems for signalling
[R41]	EN 50153	2014 A1:2017 A2:2020	Railway applications - Rolling stock - Protective provisions relating to electrical hazards
[R42]	EN 50155	2017	Railway applications - Rolling stock - Electronic equipment
[R43]	EN 50215	2010	Railway applications - Rolling stock - Testing of rolling stock on completion of construction and before entry into service
[R44]	EN 50343	2014 A1:2017	Railway applications - Rolling stock - Rules for installation of cabling
[R45]	EN 50553	2012 AC:2013 A1:2016 A2:2020	Railway applications - Requirements for running capability in case of fire on board of rolling stock
[R46]	EN 50657	2017	Railways Applications - Rolling stock applications - Software on Board Rolling Stock
[R47]	EN 60079-7	2015	Explosive atmospheres - Part 7: Equipment protection by increased safety "e"

Table 4: Regulations, Codes and Standards

No.	Standard	Date	Title
[R48]	EN 60529	1999 A1:2000 A2:2013	Degrees of protection provided by enclosures (IP Code)
[R49]	EN 61373	2010	Railway applications - Rolling stock equipment - Shock and vibration tests
[R50]	EN 61508-series	2010	Functional safety of electrical/electronic/programmable electronic safety-related systems - series
[R51]	EN IEC 60068-2-11	1999	Environmental testing - Part 2: Tests; test Ka: Salt mist
[R52]	EN IEC 60079-10-1	2020	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres - Edition 3.0
[R53]	EN IEC 62619	2022	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications
[R54]	EN IEC 62864-1	2016	Railway applications - Rolling stock - Power supply with onboard energy storage system - Part 1: Series hybrid system
[R55]	EN IEC 62928	2018	Railway applications - Rolling stock - Onboard lithium-ion traction batteries
[R56]	EN IEC 62282-2-100	2020	Fuel cell technologies - Part 2-100: Fuel cell modules - Safety
[R57]	EN IEC 62282-3-100	2020	Fuel cell technologies - Part 3-100: Stationary fuel cell power systems - Safety
[R58]	EN IEC 62282-4-101	2022	Fuel cell technologies - Part 4-101: Fuel cell power systems for electrically powered industrial trucks - Safety
[R59]	EN IEC 62443-series	2023	Security for industrial automation and control systems - series
[R60]	EN ISO 4126-1	2013 A1:2016	Safety devices for protection against excessive pressure - Part 1: Safety valves
[R61]	EN ISO 9223	2012	Corrosion of metals and alloys - Corrosivity of atmospheres - Classification, determination and estimation
[R62]	EN ISO 9227	2022	Corrosion tests in artificial atmospheres - Salt spray tests
[R63]	EN ISO 11114-1	2020	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 1: Metallic materials
[R64]	EN ISO 11114-2	2021	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 2: Non-metallic materials
[R65]	EN 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

Table 4: Regulations, Codes and Standards

No.	Standard	Date	Title
[R66]	EN ISO 11114-5	2022	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 5: Test methods for evaluating plastic liners
[R67]	EN ISO 11623	2023	Gas cylinders - Composite construction - Periodic inspection and testing
[R68]	EN ISO 13849-2	2012	Safety of machinery - Safety-related parts of control systems - Part 2: Validation
[R69]	EN ISO 17268	2016	Gaseous hydrogen land vehicle refuelling connection devices
[R70]	EN ISO 20485	2018	Non-destructive testing - Leak testing - Tracer gas method
[R71]	EN ISO 24431	2016	Gas cylinders - Seamless, welded and composite cylinders for compressed and liquefied gases (excluding acetylene) - Inspection at time of filling
[R72]	GB/T 26779	2021	Hydrogen fuel cell electric vehicle refueling receptacle
[R73]	ISO 12619-series	2017	Road vehicles - Compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blend fuel system components - series
[R74]	ISO 14687	2019	Hydrogen fuel quality - Product specification
[R75]	ISO/TR 15916	2015	Basic considerations for the safety of hydrogen systems
[R76]	ISO/TS 19016	2019	Gas cylinders - Cylinders and tubes of composite construction - Modal acoustic emission (MAE) testing for periodic inspection and testing
[R77]	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
[R78]	ISO 19880-1	2020	Gaseous hydrogen - Fuelling stations - Part 1: General requirements
[R79]	ISO 19880-5	2019	Gaseous hydrogen - Fuelling stations - Part 5: Dispenser hoses and hose assemblies
[R80]	ISO 19880-8	2019 A1:2021	Gaseous hydrogen - Fuelling stations - Part 8: Fuel quality control
[R81]	ISO 19881	2018	Gaseous hydrogen - Land vehicle fuel containers
[R82]	ISO 19882	2018	Gaseous hydrogen - Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers
[R83]	ISO 20485	2017	Non-destructive testing - Leak testing - Tracer gas method
[R84]	SAE J2579	2018-09	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles
[R85]	SAE J2600	2015-10	Compressed Hydrogen Surface Vehicle Fueling Connection Devices
[R86]	SAE J2601	2020-05	Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles

Table 4: Regulations, Codes and Standards

No.	Standard	Date	Title
[R87]	SAE J2601-2	2023-07	Fuelling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles
[R88]	SAE J2799	2019-12	Hydrogen Surface Vehicle to Station Communications Hardware and Software
[R89]	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
[R90]	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 of 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 H2 demonstrator, TÜV SÜD shall, based on its hydrogen project experience and expert knowledge, enhance the analysis to generalise the results for hydrogen vehicles as well as for a wider range of interfaces with the infrastructure and environment.

3. Methodology

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 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).

4. Disclaimer

The alternative propulsion technology based on hydrogen systems and lithium-ion-batteries, which is integrated into a railway vehicle and into the rail system is a highly complex technical subject. Hence, the number of theoretical gaps in existing requirements depends on the individual system solution and can be infinite.

The findings of this LGA cannot be taken as a sole basis to achieve an adequate level of safety, when designing and validating a railway vehicle with an alternative propulsion system. Furthermore, the extent to which specific hazards are mitigated depends on how conscientious and accurate RCS have been implemented.

The findings are based on a generic hazard analysis and can be considered as obvious and easily remediable gaps in the scope of identified RCS. They are directed to standardization bodies, expert committees and legislators for further discussion in ongoing or future standardisation or legislation activities.

5. Findings

5.1. 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.

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 [R75] 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 compressed hydrogen storage system (CHSS), 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], [R11], [R55] to [R58], [R75], [R90] 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** **Ice forming / freezing components** (of pipes, components or tanks)
- **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 26 generic **Causes** or triggers of these failures were analyzed in a next step (mainly based on [R75] and [D03]).

- **C1** **External fire / internal ignition source** (from inside 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 / material embrittlement**
- **C8** **Corrosion** (dusts, aerosols, humidity, chemicals)
- **C9** **Human error** (manufacturing, operation, maintenance)
- **C10** **Unsuitable mechanical design** (includes also tightness, ventilation, etc.)
- **C11** **Unsuitable electrical design** (excluding functional safety)

- **C12 Crash / Derailment / mechanical impact** (caused by vehicle movement)
- **C13 External short circuit / arcing** (from a defective component or outside)
- **C14 Excessive charging / discharging voltages / currents** (for batteries)
- **C15 Clogging or unsuitable design of natural / forced ventilation**
- **C16 Over filling / charging** (by refueling station / by power source)
- **C17 Filling / draining with excessive mass flow** (of the pressure system)
- **C18 Deep discharge / low residual pressure** (of batteries or pressure tanks)
- **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 / improper maintenance**
- **C23 Excessive number of filling / duty cycles** (of tanks and components)
- **C24 Unsuitable functional hardware integrity**
- **C25 Unsuitable functional software integrity**
- **C26 Manufacturing / quality defect**

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.

5.2. 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.

A total of 149 RCS are listed, which were derived from the input documents [D02] to [D11] or identified by TÜV SÜD in an internal investigation. The list provides the code, the full title and 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** (T) – describing a test procedure or validation method,
- **Design / Product standard** (D) – providing requirements regarding technical characteristics, safety aspects, etc.,
- **Process / Quality standard** (P) – defining a process to follow or organizational structures to apply,
- **Legislation** (L) – conditions to obey, mostly European directives or regulations.

The list also marks those standards that have gone through the legislative gap analysis, which is 90 out of 149 RCS. Table 4 in section 1.7 of this report lists those 90 RCS.

5.3. 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 clause of each RCS is given.

The suitability for mitigation of the hazard is assessed in a narrative way and in additionally with a qualitative classification in “None”, “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 user 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.

5.4. 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	Suitable to prevent / mitigate	Suitability for mitigation
1	EN 12663-1	C4 Operational shock & vibration C10 Unsuitable mechanical design C12 Crash / derailment / mechanical impact	High High High
2	EN 15085-series	C10 Unsuitable mechanical design	High
3	EN 16404	C10 Unsuitable mechanical design	High
4	EN 45545-4	C1 External fire / internal ignition source	Medium
5	EN 50121-3-1	C5 Electromagnetic emission / interference C11 Unsuitable electrical design	High High
6	EN 50121-3-2	C5 Electromagnetic emission / interference C11 Unsuitable electrical design	High
7	EN 50122-1	C13 External short circuit / arcing	Low

Table 5: Railway RCS without modification

	Standard	Suitable to prevent / mitigate	Suitability for mitigation
8	EN 50124-1	C11 Unsuitable electrical design C13 External short circuit / arcing	High High
9	EN 50124-2	C13 External short circuit / arcing	High
10	EN 50125-1	C1 External fire / internal ignition source C2 Thermal impact / over temperature C3 Cold impact / under temperature C8 Corrosion C11 Unsuitable electrical design C13 External short circuit / arcing	High High High High High High
11	EN 50126-2	C24 Unsuitable functional hardware integrity	High
12	EN 50128	C25 Unsuitable functional software integrity	High
13	EN 50129	C24 Unsuitable functional hardware integrity	High
14	EN 50153	C11 Unsuitable electrical design C13 External short circuit / arcing C21 Residual voltage	High High High
15	EN 50343	C11 Unsuitable electrical design C13 External short circuit / arcing	High High
16	EN 50657	C25 Unsuitable functional software integrity	High

5.5. Railway RCS with need for modification

The following Railway RCS are partially or could potentially be 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.	RCS	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 arrangement of any hydrogen or battery components in the deformation zones of the car body.
2	EN 45545-1	C1	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

Table 6: Railway RCS with need for modification

No.	RCS	Causes where Gaps have been identified	Suitability for mitigation	Identified Gap
				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 CFRP 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	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 C12	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	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

Table 6: Railway RCS with need for modification

No.	RCS	Causes where Gaps have been identified	Suitability for mitigation	Identified Gap
				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.
9	EN 50215	C26	Medium	EN 50215 addresses 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 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.
11	EN 61373	C1 C4 C10	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 EN 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 EN 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt EN 61373 and EN 50155 and define additional requirements.
	EN IEC 62864-1	C10 C11 C12 C14 C16 C18		IEC 62864-1 does not adequately address the mechanical integration of energy storage systems (ESS) and primary power sources (PPS). The integration of ESS and PPS requires validation of its housing and the car body connection acc. to the loads defined by EN 12663-1. IEC 62864-1 does not comprehensively address safety

Table 6: Railway RCS with need for modification

No.	RCS	Causes where Gaps have been identified	Suitability for mitigation	Identified Gap
		C22 C26		aspects in the electrical integration of ESS, PSS and traction or auxiliary inverters. The voltage and current limitations are a basic electrical interface to be aligned between manufacturer and integrator and must be ensured with adequate safety integrity, based on the overall risk analysis. In addition, the usable SOC range must be respected by the vehicle with adequate safety integrity, based on the overall risk analysis. IEC 62864-1 does not address or make reference to the electrical interface between the infrastructure and the onboard energy storage system (ESS). At least the vehicle side electrical compatibility and protection measures should be defined. IEC 62864-1 should address the need for inspection and maintenance documentation by the manufacturer and the integrator. IEC 62864-1 should require additional safety related routine tests with regards to the functional interfaces between vehicle and energy storage system (ESS) / primary power source (PPS) .
	EN IEC 62928	C1 C2 C4 C9 C12 C19		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 the referenced standards EN 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

Table 6: Railway RCS with need for modification

No.	RCS	Causes where Gaps have been identified	Suitability for mitigation	Identified Gap
				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.
	EU 1299/2014	C6 C14 C16 C17 C18 C19		TSI INF should define requirements for hydrogen filling stations, such as the required purity of supplied hydrogen and filling station side protection functions and protocols to ensure a safe implementation of the vehicle into the rail system. TSI INF should also define requirements for clearing track side vegetation to reduce the probability of collisions with objects.
12	EU 1302/2014	C14 C16	High	TSI ENE should define requirements for catenary islands or electrants and the interface to the railway vehicle with an onboard energy storage system (ESS) to ensure a safe implementation of the vehicle into the rail system.
13	EU 1302/2014	C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C11 C12 C13 C14 C15 C20 C21 C22 C26	Low	TSI LOC&PAS should define generic requirements for alternative propulsion with traction batteries and/or hydrogen systems 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,

Table 6: Railway RCS with need for modification

No.	RCS	Causes where Gaps have been identified	Suitability for mitigation	Identified Gap
				- 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.

5.6. 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.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
1	1999/92/EG	C9 C10 C13 C15 C21 C22	Low Medium Low Low Low 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	C1 C2 C3 C4 C5 C7 C8 C9 C10 C11 C21	Low Low Low Low Low Low Low Low Low Low 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.

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
3	2014/30/EU	C5	Medium	2014/30/EU specifically describes principal requirements for electrical devices with regards to Electromagnetic 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 fulfilment 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	C9 C10 C11 C13	Low Medium Medium Low	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	C10 C26	High 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. CE-certification is done by a notified body on single component or assembly level per individual acceptance based on documented routine tests. The certification scheme requires a continuous production monitoring. Besides many generic safety 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. 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 for PED to certify the assembly.

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
6	EC 79/2009	C1 C2 C3 C4 C7 C8 C10 C11 C12 C13 C16 C19 C23 C26	High High High Low High High High Low Medium Low High Medium High High	EC 79/2009 and its implementation directive EU 406/2010 for hydrogen road vehicles were withdrawn and are replaced by UN ECE R134. Tightness of tanks and components and their media compatibility under the defined operating conditions is sufficiently proven by EC 79 type approval. More details see implementation directive EU 406/2010.
7	EU 406/2010	C1 C2 C3 C4 C7 C8 C10 C11 C12 C13 C15 C16 C18 C19 C23 C26	High High High Low High High High Low Medium Low Medium High Low Medium High High	EC 79/2009 and its implementation directive EU 406/2010 for hydrogen road vehicles were withdrawn and are replaced by UN ECE R134. Tightness of tanks and components and their media compatibility under the defined 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 in combination with adequate tightness tests, - 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, as well as - environmental and electrical requirements acc. to EN 50155. 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 integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. 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. The filling protocol requires adequate margin for excessive gas temperatures >85 °C from fast filling with regards to

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				plastic liners. 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.
8	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 referring to several international and north American standards. For metallic materials it refers to test according to ISO 11114-4. It closes a gap after withdrawal of EC79, since R134 does not specify requirements for hydrogen compatibility.
9	EN 894-1	C9 C22	High High	EN 894-1 provides general principles for human interactions with displays and control actuators, which may reduce human failures by ensuring cognitive ergonomics for staff in all operation, inspection and maintenance activities.
10	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 on railway vehicles. Adopting EN 1127-1 principles for railway vehicles requires consideration of railway specific boundary conditions and a solid evidence as well as adequate maintenance plans and instructions.
11	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.
12	EN 10216-5	C8 C10	High High	EN 10216-5 is a product standard for seamless stainless-steel pipes. It provides lists of alloys with reference to their tested resistance to intracrystalline corrosion (tables 6 to 8) with temperature thresholds in tables 9 to 11. The mechanical properties of the alloys can be found in clause 8.3 and the referenced tables. Additional tests for material strength are defined in chapter 11.
13	EN 12245	C1 C2 C3 C4 C7 C10 C12	Medium Low High Medium High High Medium	Adopting EN 12245 requires an assessment of the gaps with the boundary conditions from railway application and closing of those with additional tests and design rules from existing (e.g., EN 45545-x) and still to be developed railway standards, such as IEC 63341-2. EN 12245 is open with regards to TPRDs and would generally allow alternative methods. The validation

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
		C16 C18 C19 C23 C26	Medium High Medium High High	method is similar to tests from automotive regulations. This requires an assessment of the residual risk for railway application under consideration of potential fire scenarios. The maximum temperature of 65 °C defined by EN 12245 is not compatible with the expected gas temperature during (fast) refuelling of fixed installed tanks for propulsion in mobile applications, which is generally defined with 85 °C. The minimum temperature of -40 °C is compatible with the expected gas temperature during defueling or refuelling with precooled hydrogen in mobile applications. Adopting tanks acc. to EN 12245 may require additional shock & vibration tests in assembled condition acc. to EN 61373 and/or aa validationof the fixations in assembled condition acc. to EN 12663-1. The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. It also requires an assessment of the interface with the refuelling station and the safety margins (pressure and temperature) and protection measures with regards to over filling. The standard foresees a vacuum load cycle conditioning test, which demonstrates liner integrity under low pressure condition, which may serve as mitigation for low residual pressures with Type 4 tanks.
14	EN 13480-2	C7 C8	Medium Medium	EN 13480-2 is a product standard for stainless steel pipes, which may be compatible with hydrogen. The standard only implicitly refers to the correct material choice with regards to hydrogen embrittlement and corrosion in clause 4.2.1.1, but does not provide a whitelist of alloys to use.
15	EN 13480-3	C10	High	EN 13480-series is a product standard for stainless steel pipes. The requirements for materials of pressure bearing pipes can be found in chapter 4 and further tables and material tests can be found in annexes A and B.
16	EN 17124	C6	Low	EN 17124 defines methods how to check the quality of the hydrogen especially used with PEM-fuel cells and also delivers 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.
17	EN 17127	C16 C17	Medium Low	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

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				protocol the standard refers to SAE J2601 (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. The refuelling protocols acc. to SAE J2601 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.
18	EN 17339	C1 C2 C3 C4 C7 C10 C12 C16 C18 C19 C23 C26	Medium Low High Low High High Low Medium High Low High High	Adopting EN 17339 requires an assessment of the gaps with the boundary conditions from railway application and closing of those with additional tests and design rules from existing (e.g., EN 45545-x) and still to be developed railway standards, such as IEC 63341-2. EN 17339 is open with regards to TPRDs and would generally allow alternative methods. The validation method is similar to tests from automotive regulations. This requires an assessment of the residual risk for railway application under consideration of potential fire scenarios. The maximum temperature of 65 °C defined by EN 17339 is not compatible with the expected gas temperature during (fast) refuelling of fixed installed tanks for propulsion in mobile applications, which is generally defined with 85 °C. The minimum temperature of -40 °C is compatible with the expected gas temperature during defueling or refuelling with precooled hydrogen in mobile applications. Adopting tanks acc. to EN 17339 may require additional shock & vibration tests in assembled condition acc. to EN 61373 and/or a validation of the fixations in assembled condition acc. to EN 12663-1. The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. It also requires an assessment of the interface with the refuelling station and the safety margins (pressure and temperature) and protection measures with regards to over filling. The standard foresees a vacuum load cycle conditioning test, which demonstrates liner integrity under low pressure condition, which may serve as mitigation for low residual pressures with Type 4 tanks.
19	EN 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

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				rather unlikely for hydrogen components due to the need to active and passive ventilation.
20	EN 61508-series	C24 C25	High High	EN 61508-series defines the rules for development and assessment of electric/electronic/programmable electronic functions (E/E/PE-functions) that are used to implement safety functions with a dedicated safety integrity level (SIL) in any product or system. EN 61508-series is references by EN 50126-2, EN 50128 and EN 50129.
21	EN IEC 60068-2-11	C8	High	EN IEC 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).
22	EN IEC 60079-10-1	C10 C15	High High	EN 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. The requirements for the design and assessment of natural and forced ventilation are provided in chapter 7. It refers to worst case assumptions in the estimation of flow rates and consideration of aerodynamic or environmental effects that may stop or invert the flow.
23	EN IEC 62282-2-100	C1 C2 C3 C4 C7 C9 C10 C11 C12 C13 C15 C22 C26	High Low Low Low Low Medium Medium Medium Low Medium Medium Low High	Adopting IEC 62282-2-100 requires an assessment of the gaps with the boundary conditions from railway application and closing these with additional tests and design rules from existing (e.g., EN 45545-x or EN 50155) and still to be developed railway standards, such as IEC 63341-1. This also applies for min./max. ambient temperatures and gas inlet temperatures. It also requires shock & vibration test acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11 for the assembly or functional parts of the fuel cell module - especially the fluidic part. It may also require additional validation of housing and fixations in assembled condition acc. to EN 12663-1. Compliance with IEC 62282-2-100 may require additional evidence for hydrogen compatibility for the fluidic part as those are not required by the standard. Potential failure modes that may lead to improper ventilation or critical hydrogen concentrations inside and outside of the fuel cell housing shall be determined by individual risk analysis. Active protection measures (e.g., detection and control functions) need to undergo

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				functional safety analysis based on the allocated safety requirement. The manufacturer of IEC 62282-2-100 compliant fuel cells must propose adequate preventive maintenance intervals and may also provide instruction for corrective maintenance. The maintenance documentation must contain safety related application conditions and warnings for maintenance staff.
24	EN IEC 62282-3-100	C1 C2 C3 C4 C5 C7 C8 C9 C10 C11 C12 C13 C15 C22 C26	High Medium Low Low High Medium Medium Medium Medium Low Low Low Medium Medium High	Adopting IEC 62282-3-100 requires an assessment of the gaps with the boundary conditions from railway application and closing these with additional tests and design rules from existing (e.g., EN 45545-x, EN 50155) and still to be developed railway standards, such as IEC 63341-1. This also applies for min./max. ambient temperatures and gas inlet temperatures. It also requires shock & vibration test acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11 for the assembly or functional parts of the fuel cell system - especially the fluidic part. It may also require additional validation of housing and fixations in assembled condition acc. to EN 12663-1. IEC 62282-3-100 compliant fuel cells may fulfil EMC-requirements of EN 50121-3-2, which must be confirmed by conformity assessment or additional test. Compliance with IEC 62282-3-100 may require additional evidence for hydrogen compatibility for the fluidic part as those are not required by the standard. Active protection measures (e.g., detection and control functions) need to undergo functional safety analysis based on the allocated safety requirement, when adopting IEC 62282-3-100 fuel cell systems. The manufacturer of IEC 62282-3-100 compliant fuel cells must propose adequate preventive maintenance intervals and may also provide instruction for corrective maintenance. The maintenance documentation must contain safety related application conditions and warnings for maintenance staff.
25	EN IEC 62282-4-101	C1 C2 C3 C4 C5 C6 C7 C8 C9	High Low Low High Low Medium Medium Medium Medium	Adopting IEC 62282-4-101 requires an assessment of the gaps with the boundary conditions from railway application and closing these with additional tests and design rules from existing (e.g., EN 45545-x, EN 50155) and still to be developed railway standards, such as IEC 63341-1. This also applies for min./max. ambient temperatures and gas inlet temperatures. It also requires shock & vibration test acc. to EN 61373

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
		C10 C11 C12 C13 C15 C22 C26	Medium Medium Medium Low Medium Medium High	including function tests acc. to EN 50155, 13.4.11 for the assembly or functional parts of the fuel cell module - especially the fluidic part. It may also require additional validation of housing and fixations in assembled condition acc. to EN 12663-1. Adopting IEC 62282-4-101 compliant fuel cells requires EMC test according to EN 50121-3-2. The standard generally defines the use of filters without defining the required mesh size or purity. This must be defined by the manufacturer. Active protection measures (e.g., detection and control functions) need to undergo functional safety analysis based on the allocated safety requirement, when adopting IEC 62282-4-101 fuel cell systems. The manufacturer of the fuel cell may need to define additional warnings for maintenance staff in maintenance documentation or on the fuel cell itself.
26	EN IEC 62443-series	C20 C25	High High	IEC 62442-series defines requirements for cyber security, which may also be applied on train control and management systems as well as on hydrogen filling station control and communication systems. The safety related software functions must be protected from critical manipulation.
27	EN ISO 4126-1	C10	High	ISO 4126-1 provides general rules for the mechanical design of safety valves in chapter 5. The standard is harmonized with 2014/68/EU.
28	EN ISO 9223	C8	High	ISO 9223 defines corrosivity categories for metals and atmospheres and makes specifications for material choice.
29	EN ISO 9227	C8	High	ISO 9227 defines a salt spray test as validation method for corrosion resistance which is referenced by several standards and may be chosen as alternative test method to IEC 60068-2-11.
30	EN 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.
31	EN 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,

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				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.
32	EN 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.
33	EN 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.
34	EN ISO 11623	C22	High	ISO 11623 provides a comprehensive guideline for periodic inspection, inspection methods and evaluation criteria of composite gas cylinders of all types and up to 3000 l. The application of this standard supports maintenance entities in proper inspection of CHSS and can be an adequate supplement to the maintenance documentation of the manufacturer.
35	EN ISO 13849-2	C24	High	ISO 13849-2 is standard which is harmonized with machinery directive 2006/42/EC and provides a validation method for safety related parts of controls. It may be applied for functions, which have been realized using electric, electronic, electromechanic or mechanic components.
36	EN ISO 17268	C6 C7 C8 C9 C17	High Medium High High 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 or SAE J 2601-2. Application of ISO 17268 does not provide adequate protection from particle ingress, since the filter mesh size is not defined and must be agreed with the refuelling receptacle manufacturer. It may also require additional evidence for hydrogen compatibility of the applied metals, as the standard is not prescriptive in the choice of hydrogen compatible metals.
37	EN ISO 24431	C22	High	ISO 24431 provides a guideline for inspection, inspection methods and evaluation criteria of composite gas

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				cylinders of all types up to 150 l and for single vessels exceptionally up to 450 l. It refers to ISO 11623 with regards to the inspection of the visual inspection and evaluation of damage patterns. The application of this standard supports maintenance entities in proper inspection of CHSS and can be an adequate supplement to the maintenance documentation of the manufacturer.
38	GB/T 26779	C7 C8	Medium High	GB/T 26779 does not clearly require the materials of the receptacle to be compatible with hydrogen. To demonstrate that non-metallic gaskets and materials are compatible with hydrogen, a dedicated test is defined in clause 6.9. In addition, sealing materials shall undergo oxygen ageing and ozone ageing tests acc. to tests as defined in clauses 6.7 and 6.8. Compliance with GB/T 26779 may require additional evidence for hydrogen compatibility of the applied metals.
39	ISO 12619-series	C2 C3 C4 C6 C7 C8 C10 C11 C12 C13 C23	High High High High High High High High Medium Medium High	ISO 12619-series defines a wide range of type test requirements for CGH2-components in mobile applications (except for tanks, TPRDs and receptacles). Part 1 defines the general boundary conditions, such as an operating temperature between +85 °C / +120 °C to -20 °C / -40 °C. Part 2 defines all generic type tests, while parts 3 to 16 address the respective fluidic component. Clause 9.2.3 of part 2 defines an maximum operating temperature cycling test. With regards to the maximum / minimum operating temperatures of +85 °C / +120 °C to -20 °C / -40 °C, the typical maximum operating temperatures for electrical or electro-mechanical railway components acc. to EN 50155 are fulfilled and excessive gas temperatures are covered with an adequate margin. The shock & vibration test defined by ISO 12619-2 provides a basic integrity against operational shock & vibration influences. Adopting ISO 12619-components on railway vehicles may require additional tests acc. to EN 61373, since the accelerations and test durations are lower. It may also require additional validation of the fixations in assembled condition acc. to EN 12663-1. ISO 12619-15 provides a comprehensive set of requirements for safe and reliable design of CGH2 filters. The actual mesh size must be chosen by the system integrator to ensure protection of functional components and fuel cells.

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
40	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).
41	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.
42	ISO 19880-1	C12 C16 C17	Medium Medium Low	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 (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. The refuelling protocols acc. to SAE J2601-2, which apply for railway vehicles, are not prescriptive. 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. Input from CNH2: One of the future objectives of ISO 19880-1 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 (e.g., by determination of protection from impact: Guard posts or other approved means, bumpers, buffers, protection structure, etc.) and the safety distances could be recalculated using a quantitative analysis.
43	ISO 19880-5	C10	Medium	ISO 19880-5 refers to 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. Input from CNH2: - 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

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				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.
44	ISO 19880-8	C6	Medium	ISO 19880-8 defines methods to control the hydrogen quality which is supplied from hydrogen filling stations. It may be applied by the filling station operator to ensure the required hydrogen quality, which is to be filled in railway vehicles with hydrogen systems.
45	ISO 19881	C1 C2 C3 C4 C7 C8 C10 C12 C16 C18 C19 C23 C26	High High High Medium High High High Medium High Low Medium High High	ISO 19881 was primarily made for CHSS in road vehicle application with strong analogies to R134. Adopting this standard 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 45545-x) and still to be developed railway standards, such as IEC 63341-2. Adopting TPRDs from automotive standards 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. ISO 19881 defines operating temperatures of to 85 °C to -40 °C. However, it requires an adequate margin for excessive gas temperatures >85 °C from false filling operation with regards to plastic liners. ISO 19881 does not define any requirements for liner softening temperatures. The standard defines a margin for colder temperatures up to -50 °C (e.g., caused by rapid defuelling). Adopting tanks acc. to ISO 19881 may require additional shock & vibration tests in assembled condition acc. to EN 61373. It may also require additional validation of the fixations in assembled condition acc. to EN 12663-1. The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. It may require additional evidence for hydrogen compatibility as the standard is not prescriptive in the choice of hydrogen compatible materials. The minimum allowable residual pressure of large

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				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.
46	ISO 19882	C1 C2 C3 C4 C7 C8 C10 C12 C19 C23 C26	High High High High High High High Medium Medium High High	ISO 19882 was primarily made for TPRDs road vehicle application. Adopting this standard 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 standards 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. The drop and vibration test defined by ISO 19882 provides a basic integrity against operational shock & vibration influences. Adopting TPRDs acc. to ISO 19882 on railway vehicles may require additional tests acc. to EN 61373, since the accelerations and test durations are not the same. It may also require additional validation of the fixations in assembled condition acc. to EN 12663-1. The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. Compliance with ISO 19882 may require additional evidence for hydrogen compatibility as the standard is not prescriptive in the choice of hydrogen compatible materials.
47	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.
48	ISO/TR 15916	C1 C2 C6 C7 C8 C9 C10 C11 C13 C15 C21	Medium Low High Medium Medium High High Low Low Low Low	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.).

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
49	ISO/TS 19016	C22	High	ISO/TS 19016 may propose an innovative method for periodic non-destructive inspection of composite tank condition. It may require further research and development and application experience to confirm the validity of the inspection results.
50	SAE J2579	C7	High	SAE J2579 provides a white list of hydrogen compatible metals in annex B.
51	SAE J2600	C9	High	SAE J2600 requires proper interchangeability to avoid nozzles dedicated to higher pressure levels being couples with receptacles of lower pressure levels by the mechanical shape.
52	SAE J2601	C2 C16 C17 C18	Low Low Low 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. Input from CNH2: The standard contains important limitations which require adaption 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.
53	SAE J2601-2	C2 C16 C17 C18	Low Low Low 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.
54	SAE J2799	C16 C17	Low 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

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				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. The IR-Emitter is not mechanically compatible with state of the art very high flow receptacles with a 12 to 14 mm bore.
55	UN ECE R 10	C5	Medium	The ECE R 10 describes tests in order to prove the electromagnetic compatibility of vehicles and components used in vehicles. It is possible to assess fulfilment 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.
56	UN ECE R 134	C1 C2 C3 C4 C8 C10 C11 C12 C13 C16 C18 C19 C23 C26	High High High Medium High High Medium High Medium High Low Medium High High	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. The tests defined by R 134 consider sequences where the test sample must undergo several different stresses to reflect a characteristic conservative load profile in road application. 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, as well as - environmental and electrical requirements acc. to EN 50155. The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. 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. The filling protocol requires adequate margin for

Table 7: Applicable RCS from other industries

No.	RCS	Applicable to mitigate haz. cause	Suitability for mitigation	Remarks
				excessive gas temperatures >85 °C from fast filling with regards to plastic liners. Type 4 tanks are more sensitive to over temperatures (max. 85°C), while both, Type 3 and Type 4 tanks maximum temperatures are limited by the given triggering temperature of the TPRDs.

5.7. 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	Description of technical issue
1	C1 External fire / internal ignition source	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	C1 External fire / internal ignition source	There is no RCS that describes a suitable alternative validation method for burst protection of CHSS systems installed on railway vehicles under with regards to possible heat and fire impact scenarios and under consideration of the existing barriers from railway design.
3	C2 Thermal impact / over temperature	There is no RCS that defines adequate measures to prevent hydrogen tanks from excessive sun radiation or heat dissipation.
4	C6 Hydrogen purity / particle ingress	There is no RCS that proposes adequate mesh sizes of filters for protection of valves and fuel cells under consideration of mass flow and pressure drop.
5	C9 Human error (manufacturing, operation, maintenance)	There is no RCS that requires leak test after any maintenance activity of the fluidic part and with reference to an adequate leak test method and pass/fail criteria.
6	C10 Unsuitable mechanical design	There is no RCS that requires vent upward facing vent lines (e.g. from TPRDs or PRVs) to be placed in such a way they neither damage an overhead wire above the vehicle nor reach any building or structures in the vicinity of the railway track.
7	C11 Unsuitable electrical design	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.
8	C15 Clogging or unsuitable design of natural / forced 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.

Table 8: List of Hazards where no applicable RCS exist

No.	Cause	Description of technical issue
9	C15 Clogging or unsuitable design of natural / forced ventilation	There is no RCS that prevents ingress or clogging of vent lines from TPRDs or pressure relieve valves.
10	C16 Over filling (CGH2) / charging (Batteries)	There is no RCS with applicable filling protocols that adequately prevents heavy-duty tank systems from over filling (cold case --> filling stops too late or gas is colder than expected).
11	C17 Filling / draining with excessive mass flow	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.
12	C17 Filling / draining with excessive mass flow	There is no RCS that adequately prevents fast refuelling of Type 4 tanks from critical temperatures during fast refuelling at ambient gas temperatures of heavy-duty tanks as the temperature development is more critical at lower starting pressures.
13	C17 Filling / draining with excessive mass flow	There is no RCS that adequately warns the user from deep discharge and at the same time critical low temperatures during flushing procedures (risk of liner damage).
14	C17 Filling / draining with excessive mass flow	There is no RCS that requires hydrogen filling station for railway vehicles to provide non-discriminatory access for any railway vehicles.
15	C18 Deep discharge	There is no RCS that adequately prevents fast refuelling of Type 4 tanks with an SOC of less than 10 to 20 bar. This may lead to liner damage and consequently leakage if not detected.
16	C19 Falling Objects	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).
17	C20 Vandalism / Terrorism	There is no RCS that adequately prevents vandalism or terrorism to hydrogen systems. It requires a security assessment due to potential catastrophic consequence.
18	C22 Wear / improper maintenance	There is no RCS that provides adequate guidance to define maintenance intervals of hydrogen tanks and components that are compatible with typical railway maintenance intervals.

6. Conclusion

From the findings listed in section 5 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 prevent 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 new standard forms the blueprint for future standards for components of the hydrogen system and gives an outlook how IEC 63341-1 and IEC 63341-2 for FCS and CHSS might close most of the existing gaps.

The TSI LOC&PAS currently reveals a large number of gaps for the assessment of a hydrogen fuel cell power pack 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 safety and can be adopted in railways in combination with railway suitability standards.

In numbers, a total of 90 Regulations, Codes and Standards (RCS) have been allocated 360 times to 26 generic hazard causes.

- **16 Railway RCS were identified that require no modification** as they can adequately prevent the related causes, when correctly applied.
- **16 Railway RCS were identified that require modification** in order to acceptably prevent the related causes.
- **56 Other RCS were identified** that are partially or fully suitable to mitigate the related hazards, however with some implications or constraints, that require amendment by combination railway RCS.

In addition to those gaps:

- **18 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, the creation of a new standard or amending existing ones might be appropriate. The identified gaps regarding hydrogen refuelling are a good example since these aspects will be key for an economic and successful application of the new technology.

Nevertheless, 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 identification of the requirement and verification of its fulfilment is more demanding for the applicant.

TÜV SÜD Rail GmbH

Berlin, 2023-09-22

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7. 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**

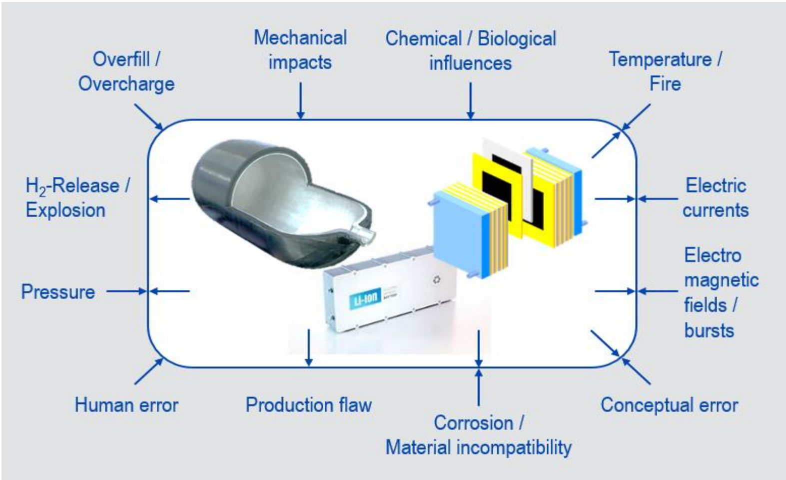
VII **List of Hazards where no applicable RCS exists**

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, C22, C23
F2	Venting	C1, C2, C6, C9, C16, C20, C22, C23, C24, C25
F3	Bursting	C1, C2, C7, C10, C12, C16, C19, C20, C23
F4	Overpressure	C1, C2, C6, C7, C16
F5	Overtemperature	C1, C2, C13, C16, C17
F6	Component defect (other than vessels)	C1 to C17, C19, C20, C22, C23
F7	Ice forming / freezing components	C3, C8, C9, C17
F8	Internal short circuit	C1, C2, C3, C4, C9, C10, C11, C12, C13, C14, C18, C26
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	External fire / internal ignition source
C2	Thermal impact / over temperature
C3	Cold impact / under temperature
C4	Operational shock & vibration
C5	Electromagnetic emission / interference
C6	Hydrogen purity / particle ingress
C7	Hydrogen incompatibility / material embrittlement
C8	Corrosion (dusts, aerosols, humidity, chemicals)
C9	Human error (manufacturing, operation, maintenance)
C10	Unsuitable mechanical design
C11	Unsuitable electrical design
C12	Crash / derailment / mechanical impact (caused by vehicle movement)
C13	External short circuit / arcing
C14	Excessive charging / discharging voltages / currents
C15	Clogging or unsuitable design of natural / forced ventilation
C16	Over filling (CGH2) / charging (Batteries)
C17	Filling / draining with excessive mass flow
C18	Deep discharge / low residual pressure
C19	Falling objects
C20	Vandalism / Terrorism
C21	Residual voltage
C22	Wear / improper maintenance
C23	Excessive number of filling / duty cycles
C24	Unsuitable functional hardware integrity
C25	Unsuitable functional software integrity
C26	Manufacturing / quality defect



Generic system interfaces, which have been considered in the analysis

Railway Infrastructure:
- Tunnel tracks (with / without galleries)
- Bridges or elevated track sections
- Underground / Indoor stations
- Railway crossings
- Catenary
- Electrants (battery charging)
- Filling Stations

Depots / Workshops:
- Commissioning workshops (incl. staff)
- Indoor depots (incl. staff)
- Maintenance workshops (incl. staff)
- Outdoor depots / sidings

Operational:
- Train driver
- Train staff
- Passengers (incl. PRM)
- Uninvolved third parties

Emergencies:
- Operational instructions
- Rescue forces

II List of input Regulation, Codes and Standards

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

No.	Publisher	Standard	Title	Date	Origin	Topic	Category (T/D/P/L)	Railway application	Analysed	Ref. SRR from Hazard Log	IEC-Reference	Comments
1	EU	1999/92/EC	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	1999-12-16	Europe	Explosion Protection	L		yes			
2	EU	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	Europe	Workers Safety	L		yes			
3	EU	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	Europe	Pressure Equipment	L		no			TPED regulates the certification of transportable pressure equipment. The LGA is primarily made for fixed installed hydrogen fuel systems.
4	EU	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	Europe	EMC	L		yes			
5	EU	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	Europe	Explosion Protection	L		yes			
6	EU	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	Europe	Pressure Equipment	L		yes			
7	several	AD 2000-Code	The collection for pressure equipment, pressure vessels, steam boilers, pipelines and the plant engineering sector.	2020	Germany	Pressure Equipment	D		no			National codes are not analysed.
8	EU	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 (withdrawn)	Europe	Hydrogen Road Vehicles	L		yes	001, 046, 074		
9	EU	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	Europe	Rail System	L	yes	yes	120		
10	EU	EU 1301/2014	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	2019-06-16	Europe	Rail System	L	yes	yes			
11	EU	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	Europe	Rail System	L	yes	yes			
12	EU	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	Europe	Rail System	L	yes	see EU 1302/2014			TSI SRT is covered by TSI LOC&PAS with regards to vehicles
13	EU	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	Europe	Rail System	L		no			CSM is a mandatory safety management process to optain by any vehicle manufacturer. Hence there are no technical requirements included.
14	EU	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	Europe	Rail System	L	yes	no			Interoperability Regulation is a mandatory top level regulation for the rail system in Europe. It contains generic safety requirements but no technical requirements.
15	EU	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	Europe	Hydrogen Road Vehicles	L		yes			
16	EU	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 (withdrawn)	Europe	Hydrogen Road Vehicles	L		yes			
17	GAR	GTR 13	Global technical regulation on hydrogen and fuel cell vehicles	2013-07	Global	Hydrogen Road Vehicles	D		see UN ECE R134			The technical report of GTR13 was used in the development of UN ECE R134 and will be input to future international standardization projects.
18	ANSI	C18.2M, Part 1	Portable Rechargeable Cells and Batteries - General and Specifications	2019	North America	Batteries	D		no			Amercian RCS not included in the LGA.
19	ANSI	C18.2M, Part 2	Portable Rechargeable Cells and Batteries - Safety Standards	2021	North America	Batteries	D		no			Amercian RCS not included in the LGA.
20	ANSI	HGV 2	Compressed Hydrogen Gas Vehicle Fuel Containers	2023	North America	Pressure Vessels	D		no			Amercian RCS not included in the LGA. However, HGV2 is very similar to EC79.
21	ANSI	HGV 3.1	Fuel System Components for Compressed Hydrogen Gas Powered Vehicles	2019	North America	Gas Components	D		no			Amercian RCS not included in the LGA. However, HGV3.1 is very similar to EC79.
22	ANSI/CSA	FC 3	Portable Fuel Cell Power Systems	2004-01	North America	Fuel Cells	D		no			Amercian RCS not included in the LGA.
23	ANSI/CSA	CHMC 1	Test Method for Evaluating Material Compatibility in Compressed Hydrogen Applications - Metals	2014	North America	Material Compatibility	T		no			Amercian RCS not included in the LGA.
24	ANSI/CSA	HGV 4.10	Fittings for Compressed Hydrogen Gas and Hydrogen Rich Gas Miyestures	2020	North America	Fittings	D		no			Amercian RCS not included in the LGA.
25	ANSI/CSA	HPRD 1	Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	2021	North America	TPRD	D		no			Amercian RCS not included in the LGA.
26	ANSI/NACI	TM0284	Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen Induced cracking.	2016	North America	Piping	D		no			Amercian RCS not included in the LGA.
27	API	RP 941	Steels for Hydrogen Service at Elevated Temperatures and Pressures	2020	North America	Material Compatibility	D		no			Amercian RCS not included in the LGA.
28	ASME	B31.12	Hydrogen Piping and Pipelines - ASME Code for Pressure Piping	2019	North America	Piping	D		no			Amercian RCS not included in the LGA.
29	ASME	B31.3	Process Piping	2018-01	North America	Piping	P		no			Amercian RCS not included in the LGA.
30	ASTM	F1387-99	Standard Specification for Performance of Piping and Tubing Mechanically Attached Fittings	2012-01	North America	Piping	D		no			Amercian RCS not included in the LGA.
31	ASTM	G129	Standard Practice for Slow Strain Rate Testing to Evaluate the Susceptibility of Metallic Materials to Environmentally Assisted Cracking	2021	North America	Material Compatibility	T		no			Amercian RCS not included in the LGA.
32	CGA	S-1.1	Pressure Relief Device Standards - Part 1: Cylinders for Compressed Gases	2019-01	North America	Gas Components	D		no			Amercian RCS not included in the LGA.
33	CGA	TB-25	Design Considerations for Tube Trailers	2013-01	North America	Pressure Vessels	D		no			Amercian RCS not included in the LGA.

No.	Publisher	Standard	Title	Date	Origin	Topic	Category (T/D/P/L)	Railway application	Analysed	Ref. SRR from Hazard Log	IEC-Reference	Comments
34	EN	894-1	Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 1: General principles for human interactions with displays and control actuators	1997 A1:2008	Europe	Workers Safety	D		yes			
35	EN	1127-1	Explosive atmospheres - Explosive prevention and protection - Part 1: Basic concepts and methodology	2019	Europe	Explosion Protection	D		yes	001, 009, 074		
36	EN	1363-1	Fire resistance tests - Part 1: General requirements	2021	Europe	Fire Safety	D	yes	see EN 45545-3			
37	EN	1779	Non-destructive testing - Leak testing - Criteria for the method and technique selection	1999	Europe	Tightness Test	T		yes			
38	EN	10216-5	Seamless steel tubes for pressure purposes - Technical delivery conditions - Part 5: Stainless steel tubes	2021	Europe	Piping	D		yes			
39	EN	12245	Transportable gas cylinders - Fully wrapped composite cylinders	2022	Europe	Pressure Vessels	D		yes			
40	EN	12663-1	Railway applications - Structural requirements of railway vehicle bodies - Part 1: Locomotives and passenger rolling stock	2010 A1: 2014	Europe	Mechanical Strength	D	yes	yes	001, 056, 111, 116, 117, 118		
41	EN	13480-1	Metallic industrial piping - Part 1: General	2017	Europe	Piping	D		no			see EN 13480 Parts 2 and 3
42	EN	13480-2	Metallic industrial piping - Part 2: Materials	2017	Europe	Piping	D		yes			
43	EN	13480-3	Metallic industrial piping - Part 3: Design and calculation	2017	Europe	Piping	D		yes			
44	EN	15085-series	Railway applications - Welding of railway vehicles and components - series	2021	Europe	Mechanical Strength	D	yes	yes			
45	EN	15227	Railway applications - Crashworthiness requirements for rail vehicles	2020	Europe	Mechanical Strength	D	yes	yes	001, 116		
46	EN	16404	Railway applications - Re-railing and recovery requirements for railway vehicles	2016	Europe	Rail System	D		yes			
47	EN	17124	Hydrogen fuel - Product specification and quality assurance - Proton exchange membrane (PEM) fuel cell applications for road vehicles	2018	Europe	Fuel Cells	T		yes			
48	EN	17127	Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols	2018	Europe	Hydrogen Refuelling	D		yes			
49	EN	17339	Transportable gas cylinders - Fully wrapped carbon composite cylinders and tubes for hydrogen	2020	Europe	Pressure Vessels	D		yes			
50	EN	45545-1	Railway applications - Fire protection on railway vehicles - Part 1: General	2013	Europe	Fire Safety	D	yes	yes	001, 023, 073, 137		
51	EN	45545-2	Railway applications - Fire protection on railway vehicles - Part 2: Requirements for fire behaviour of materials and components	2020	Europe	Fire Safety	D	yes	yes	001, 023, 073, 137		
52	EN	45545-3	Railway applications - Fire protection on railway vehicles - Part 3: Fire resistance requirements for fire barriers	2013	Europe	Fire Safety	D	yes	yes	001, 023, 073, 137		
53	EN	45545-4	Railway applications - Fire protection on railway vehicles - Part 4: Fire safety requirements for rolling stock design;	2013	Europe	Fire Safety	D	yes	yes	001, 023, 073, 137		
54	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	Europe	Fire Safety	D	yes	yes	001, 023, 073, 137		
55	EN	45545-6	Railway applications - Fire protection on railway vehicles - Part 6: Fire control and management systems	2013	Europe	Fire Safety	D	yes	yes	001, 023, 073, 137		
56	EN	45545-7	Railway applications - Fire protection on railway vehicles - Part 7: Fire safety requirements for flammable liquid and flammable gas installations	2013	Europe	Fire Safety	D	yes	yes	001, 023, 073, 137		
57	EN	50121-3-1	Railway applications - Electromagnetic compatibility - Part 3-1: Rolling stock - Train and complete vehicle	2015	Europe / International	EMC	T	yes	yes	001, 101	IEC 62236-3-1	
58	EN	50121-3-2	Railway applications - Electromagnetic compatibility - Part 3-2: Rolling stock - Apparatus	2016	Europe / International	EMC	T	yes	yes	001, 101	IEC 62236-3-2	
59	EN	50122-1	Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 1: Protective provisions against electric shock	2017	Europe / International	Electrical Safety	D	yes	yes		IEC 62128-1	
60	EN	50124-1	Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment	2017	Europe / International	Electrical Safety	D	yes	yes	145	IEC 62497-1	
19	ANSI	C18.2M, Part 2	Portable Rechargeable Cells and Batteries - Safety Standards	2021	North America	Batteries	D		no		IEC 62497-2	
62	EN	50125-1	Railway applications - Environmental conditions for equipment - Part 1: Rolling stock and on-board equipment	2014	Europe / International	Functional Safety	D	yes	yes	001	IEC 62498-1	
63	EN	50126-1	Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1: Generic RAMS Process	2017	Europe / International	Functional Safety	P	yes	no		IEC 62278	EN 50126-series is a process standard that can be applied for safety management in the development of railway vehicles and components. It does not contain an direct technical requirements.
64	EN	50126-2	Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 2: Systems Approach to Safety	2017	Europe / International	Functional Safety	P	yes	no		IEC 62278-2	EN 50126-series is a process standard that can be applied for safety management in the development of railway vehicles and components. It does not contain an direct technical requirements.
65	EN	50128	Railway applications - Communication, signalling and processing systems - Software for railway control and protection systems	2011 A1:2020	Europe / International	Functional Safety	P	yes	yes		IEC 62279	
66	EN	50129	Railway applications - Communication, signalling and processing systems - Safety related electronic systems for signalling	2018 AC:2019	Europe / International	Functional Safety	P	yes	yes		IEC 62425	
67	EN	50153	Railway applications - Rolling stock - Protective provisions relating to electrical hazards	2014 A1:2017 A2:2020	Europe / International	Electrical Safety	D	yes	yes	001, 100, 143	IEC 61991	
68	EN	50155	Railway applications - Rolling stock - Electronic equipment	2017	Europe / International	Functional Safety	T	yes	yes		IEC 60571	
69	EN	50163	Railway applications - Supply voltages of traction systems	2004 A1:2007 A2:2020	Europe / International	Electrical Safety	D	yes	no		IEC 60850	
70	EN	50215	Railway applications - Rolling stock - Testing of rolling stock on completion of construction and before entry into service	2010	Europe / International	Commissioning	T	yes	yes		IEC 61133	
71	EN	50343	Railway applications - Rolling stock - Rules for installation of cabling	2014 A1:2017	Europe / International	Electrical Safety	D	yes	yes		IEC 62995	
72	EN	50547	Railway applications - Batteries for auxiliary power supply systems	2013	Europe / International	Batteries	D	yes	no		IEC 62973-1	The standard does not cover Lithium-Ion batteries and does not go beyond what is required by EN IEC 62928.
73	EN	50553	Railway applications - Requirements for running capability in case of fire on board of rolling stock	2012 AC:2013 A1:2016 A2:2020	Europe	Fire Safety	D	yes	yes	136		
74	EN	50657	Railways Applications - Rolling stock applications - Software on Board Rolling Stock	2017	Europe	Functional Safety	D		yes			
75	EN	60068-2-64	Environmental testing - Part 2-64: Tests - Test Fh: Vibration, broadband random and guidance	2008 A1:2019	Europe / International	Railway Suitability	T		see EN 61373		IEC 60068-2-64	
76	EN	60077-1	Railway applications - Electric equipment for rolling stock - Part 1: General service conditions and general rules	2017	Europe / International	Electrical Safety	D	yes	no		IEC 60077-1	
77	EN	60079-7	Explosive atmospheres - Part 7: Equipment protection by increased safety "e"	2015	Europe / International	Explosion Protection	D		yes		IEC 60079-1	
78	EN	60529	Degrees of protection provided by enclosures (IP Code)	1999 A1:2000 A2:2013	Europe / International	Railway Suitability	T		yes		IEC 60529	
79	EN	61373	Railway applications - Rolling stock equipment - Shock and vibration tests	2010	Europe / International	Mechanical Strength	T	yes	yes	001	IEC 61373	
80	EN	61508-series	Functional safety of electrical/electronic/programmable electronic safety-related systems - series	2010	Europe / International	Functional Safety	D		yes		IEC 61508 series	
81	EN	62282-3-200	Fuel cell technologies - Part 3-200: Stationary fuel cell power systems - Performance test methods	2016	Europe / International	Fuel Cells	T		no		IEC 62282-3-200	Performance standard without safety related requriements.

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82	EN IEC	60068-2-11	Environmental testing - Part 2: Tests; test Ka: Salt mist	1999	Europe / International	Railway Suitability	T		yes		IEC 60068-2-11	
83	EN IEC	60079-10-1	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres - Edition 3.0	2020	Europe / International	Explosion Protection	D		yes	018	IEC 60079-10-1	
85	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	Europe / International	Batteries	D		yes		IEC 62619	
86	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	Europe / International	Batteries	D		no		IEC 62620	Performance standard without safety related requriements.
87	EN IEC	62660-2	Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 2: Reliability and abuse testing	2019	Europe / International	Batteries	T		no		IEC 62660-2	The EN IEC 62660-series is referenced by EN IEC 62619.
88	EN IEC	62660-3	Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 3: Safety requirements	2017	Europe / International	Batteries	D		no		IEC 62660-3	The EN IEC 62660-series is referenced by EN IEC 62619.
89	EN IEC	62864-1	Railway applications - Rolling stock - Power supply with onboard energy storage system - Part 1: Series hybrid system	2016	Europe / International	Batteries	D	yes	yes		IEC 62864-1	
90	EN IEC	62928	Railway applications - Rolling stock - Onboard lithium-ion traction batteries	2018	Europe / International	Batteries	D	yes	yes		IEC 62928	
91	EN IEC	62282-2-100	Fuel cell technologies - Part 2-100: Fuel cell modules - Safety	2020	Europe / International	Fuel Cells	D		yes		IEC 62282-2-100	
92	EN IEC	62282-3-100	Fuel cell technologies - Part 3-100: Stationary fuel cell power systems - Safety	2020	Europe / International	Fuel Cells	D		yes		IEC 62282-3-100	
93	EN IEC	62282-4-101	Fuel cell technologies - Part 4-101: Fuel cell power systems for electrically powered industrial trucks - Safety	2022	Europe / International	Fuel Cells	D		yes		IEC 62282-4-101	
84	EN IEC	62443-series	Security for industrial automation and control systems - series	2023	Europe / International	Functional Safety	D		yes		IEC 62443-series	
94	EN ISO	4126-1	Safety devices for protection against excessive pressure - Part 1: Safety valves	2013 A1:2016	Europe / International	Gas Components	D		yes			
95	EN ISO	9223	Corrosion of metals and alloys - Corrosivity of atmospheres - Classification, determination and estimation	2012	Europe / International	Material Compatibility	T		yes			
96	EN ISO	9227	Corrosion tests in artificial atmospheres - Salt spray tests	2022	Europe / International	Material Compatibility	T		yes			
97	EN ISO	11114-1	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 1: Metallic materials	2020	Europe / International	Material Compatibility	D		yes			
98	EN ISO	11114-2	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 2: Non-metallic materials	2021	Europe / International	Material Compatibility	D		yes			
99	EN 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	Europe / International	Material Compatibility	T		yes			
100	EN ISO	11114-5	Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 5: Test methods for evaluating plastic liners	2022	Europe / International	Material Compatibility	T		yes			
101	EN ISO	11623	Gas cylinders - Composite construction - Periodic inspection and testing	2023	Europe / International	Pressure Vessels	T		yes			
102	EN ISO	13849-2	Safety of machinery - Safety-related parts of control systems - Part 2: Validation	2012	Europe / International	Functional Safety	D		yes			
103	EN ISO	17268	Gaseous hydrogen land vehicle refuelling connection devices	2016	Europe / International	Hydrogen Refuelling	D		yes	085		
104	EN ISO	20485	Non-destructive testing - Leak testing - Tracer gas method	2018	Europe / International	Leackage	T		yes			
105	EN ISO	24431	Gas cylinders - Seamless, welded and composite cylinders for compressed and liquefied gases (excluding acetylene) - Inspection at time of filling	2016	Europe / International	Pressure Vessels	P		yes			
106	GB/T	26779	Hydrogen fuel cell electric vehicle refueling receptacle	2021	China	Hydrogen Refuelling	T		yes			The national standard is considered as it is also used for very high flow receptacles, which are currently not covered by ISO 17268.
107	IEC/CD	63341-1	Railway applications - Fuel Cell System - Part 1 - Fuel Cell Power System (Committee Draft)	2023	International	Fuel Cells	D	yes	no	014, 018, 065, 066, 068		IEC 63341-series is made to close the gaps for hydrogen application in railway vehicles, hence it is not analysed here.
108	IEC/CD	63341-2	Railway applications - Fuel Cell System - Part 2 - Hydrogen Storage System (Committee Draft)	2023	International	Hydrogen Storages Systems	D	yes	no	032, 038		IEC 63341-series is made to close the gaps for hydrogen application in railway vehicles, hence it is not analysed here.
109	IEEE	1478	IEEE Standard for Environmental Conditions for Transit Railcar Electronic Equipment	2013	International	Electrical Safety	D	yes	no			The latest version of this standard is 2013 and the requirements to not go beyond EN 50155.
110	ISO	11515	Gas cylinders - Refillable composite reinforced tubes of water capacity between 450 L and 3000 L. Design, construction and testing	2022	International	Pressure Vessels	D		no			The standard has only little market relevance and the requirements do not go beyond EC79, R134 or ISO 19881.
111	ISO	11119-3	Gas cylinders - Design, construction and testing of refillable composite gas cylinders and tubes. Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450 l with non-load-sharing metallic or non-metallic liners or without liners	2020 A1:2021	International	Pressure Vessels	D		no			The standard has only little market relevance and the requirements do not go beyond EC79, R134 or ISO 19881.
112	ISO	12619-series	Road vehicles - Compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blend fuel system components - series	2017	International	Gas Components	T		yes			
113	ISO	14687	Hydrogen fuel quality - Product specification	2019	International	Hydrogen Quality	P		yes			
114	ISO/TR	15916	Basic considerations for the safety of hydrogen systems	2015	International	Hydrogen Systems	D		yes	001, 003, 005, 011, 023, 029, 042, 059, 062, 063, 064, 065		
115	ISO/TS	19016	Gas cylinders - Cylinders and tubes of composite construction - Modal acoustic emission (MAE) testing for periodic inspection and testing	2019	International	Pressure Vessels	T		yes			
116	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	International	Batteries			yes			
117	ISO	19880-1	Gaseous hydrogen - Fuelling stations - Part 1: General requirements	2020	International	Hydrogen Refuelling	D		yes			
118	ISO	19880-5	Gaseous hydrogen - Fuelling stations - Part 5: Dispenser hoses and hose assemblies	2019	International	Hydrogen Refuelling	D		yes			
119	ISO	19880-8	Gaseous hydrogen - Fuelling stations - Part 8: Fuel quality control	2019 A1:2021	International	Hydrogen Quality	P		yes			
120	ISO	19881	Gaseous hydrogen - Land vehicle fuel containers	2018	International	Pressure Vessels	D		yes			
121	ISO	19882	Gaseous hydrogen - Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	2018	International	TPRD	T		yes			
122	ISO/DIS	19885-1	Gaseous hydrogen - Fuelling protocols for hydrogen-fuelled vehicles - Part 1: Design and development process for fuelling protocols	2023	International	Hydrogen Refuelling	D		no			The ISO 19885-series will close gaps with regards to heavy duty filling of compressed hydrogen. Since it will still undergo changes, it is not analysed here.
123	ISO/DIS	19887	Gaseous Hydrogen - Fuel system components for hydrogen fuelled vehicles	2023	International	Hydrogen Components	D		no			The ISO 19887-series will close gaps with regards to integrity of system components and will replace EC79 and ISO 12619-series. Since it will still undergo changes, it is not analysed here.
124	ISO	20485	Non-destructive testing - Leak testing - Tracer gas method	2017	International	Tightness Test	T		yes			

No.	Publisher	Standard	Title	Date	Origin	Topic	Category (T/D/P/L)	Railway application	Analysed	Ref. SRR from Hazard Log	IEC-Reference	Comments
125	ISO	21266-1	Road vehicles - Compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blends fuel systems - Part 1: Safety requirements	2018	International	Hydrogen Road Vehicles	D		no			No new safety requirements have been identified.
126	ISO	23273	Fuel cell road vehicles - Safety specifications - Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen	2013	International	Hydrogen Road Vehicles	D		no			No new safety requirements have been identified.
127	NFPA	130	Fiyesed Guideway Transit and Passenger Rail Systems	2020-01	North America	Fire Safety	D	yes	no			Amercian RCS not included in the LGA.
128	NFPA	2	Hydrogen Technologies Code	2023	North America	Hydrogen Systems	D		no			Amercian RCS not included in the LGA.
129	NFPA	55	Compressed Gases and Cryogenic Fluids Code	2023	North America	Hydrogen Systems	P		no			Amercian RCS not included in the LGA.
130	SAE	J2464	Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing	2021-08	International	Batteries	T		no			The standard does not go beyond what is required by EN IEC 62928.
131	SAE	J2517	Performance Test Procedure of PEM Fuel Cell Stack Subsystem for Automotive Application	2016-08	International	Fuel Cells	T		no			Performance standard without safety related requriements.
132	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	International	Hydrogen Road Vehicles	P		no			Performance standard without safety related requriements.
133	SAE	J2574	Fuel Cell Vehicle Terminology	2011-09	International	Fuel Cells	D		no			Terminology standard without safety related requirements.
134	SAE	J2579	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles	2018-09	International	Fuel Cells	D		yes			
135	SAE	J2600	Compressed Hydrogen Surface Vehicle Fueling Connection Devices	2015-10	International	Hydrogen Refuelling	D		yes			
136	SAE	J2601	Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles	2020-05	International	Hydrogen Refuelling	D		yes			
137	SAE	J2601-2	Fuelling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles	2023-07	International	Hydrogen Refuelling	D		yes			
138	SAE	J2615	Testing Performance of Fuel Cell Systems for Automotive Applications	2011-10	International	Fuel Cells	T		no			Performance standard without safety related requriements.
139	SAE	J2719	Hydrogen Fuel Quality for Fuel Cell Vehicles	2020-03	International	Hydrogen Quality	P		no			The standard does not go beyond what is required by EN ISO 14687.
140	SAE	J2799	Hydrogen Surface Vehicle to Station Communications Hardware and Software	2019-12	International	Functional Safety	D		yes			
141	SAE	J2929	Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells	2013-02	International	Batteries	D		no			The standard does not go beyond what is required by EN IEC 62928.
142	TRGS	722	Technische Regeln für Gefahrstoffe - Vermeidung oder Einschränkung gefährlicher explosionsfähiger Gemische	2021-02-01	Germany	Explosion Protection	D		no			National codes are not analysed.
143	UL	1642	Lithium Batteries	2020	North America	Batteries	D		no			North Amercian RCS were not included in the LGA.
144	UL	1973	Batteries for Use in Stationary, Vehicle Auyesiliary Power and Light Electric Rail (LER) Applications	2018-02	North America	Batteries	D		no			North Amercian RCS were not included in the LGA.
145	UL	1998	Standard for software in programmable components	2018-01	North America	Functional Safety	D		no			North Amercian RCS were not included in the LGA.
146	UL	991	Standard for Tests for Safety-Related Controls Employing Solid-State Devices	2004-10	North America	Functional Safety	T		no			North Amercian RCS were not included in the LGA.
147	UN	38.3	Recommendations on the Transport of dangerous goods	6th revised edition	International	Batteries	L		see EN IEC 62919			The test requirements of UN 38.3 are almost identical with EN IEC 62619.
148	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	International	EMC	L		yes			
149	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	International	Hydrogen Road Vehicles	L		yes			

III Analysis for Suitability of applicable RCS

			Mitigation				Evaluation			
No.	**ID**	**Cause / Trigger**	**Allocated RCS**	**Applicable clauses**	**Assessment of suitability**	**Suitability**	**Identified gap**	**Railway application**	**Result**	**Priority**
1	C1	External Fire / internal ignition source	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 its implementation directive EU 406/2010 for hydrogen road vehicles were withdrawn and are replaced by UN ECE R134. 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 45545-x) and still to be developed railway standards, such as IEC 63341-2.	no	Other RCS	N/A
2	C1	External Fire / internal ignition source	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 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 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 45545-x) 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.	no	Other RCS	N/A
3	C1	External Fire / internal ignition source	UN ECE R 134	Chapters 5 to 7 and Annex 3 to 4	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. 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 45545-x) 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.	no	Other RCS	N/A
4	C1	External Fire / internal ignition source	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	no	Other RCS	N/A
5	C1	External Fire / internal ignition source	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	no	Other RCS	N/A
6	C1	External fire / internal ignition source	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.	yes	Modification	Medium
7	C1	External fire / internal ignition source	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 CFRP 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).	yes	Modification	Low
8	C1	External fire / internal ignition source	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.	yes	Modification	High
9	C1	External fire / internal ignition source	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 fulfill 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 fulfill railway suitability requirements of EN 50155.	yes	Modification	Medium
10	C1	External fire / internal ignition source	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.	yes	Modification	Medium
11	C1	External fire / internal ignition source	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.	yes	Modification	High
12	C1	External fire / internal ignition source	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.	yes	Modification	High
13	C1	External fire / internal ignition source	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	yes	No Modification	N/A
14	C1	External fire / internal ignition source	EN 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 EN 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 EN 61373 only, would not cover this aspect. In order to prove permanent 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 EN 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt EN 61373 and EN 50155 and define additional requirements.	yes	Modification	High
15	C1	External fire / internal ignition source	EU 1302/2014	4.2.10.	TSI LOC&PAS 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.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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)	yes	Modification	High
16	C1	External fire / internal ignition source	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.	yes	Modification	Medium
17	C1	External fire / internal ignition source	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	yes	No Modification	N/A
18	C1	External fire / internal ignition source	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	yes	No Modification	N/A

			Mitigation				Evaluation			
No.	**ID**	**Cause / Trigger**	**Allocated RCS**	**Applicable clauses**	**Assessment of suitability**	**Suitability**	**Identified gap**	**Railway application**	**Result**	**Priority**
19	C1	External Fire / internal ignition source	EN 12245	5.2.12, Annex D	The scope of EN 12245 has its focus on composite tanks for any compressed, liquified or dissolved gases in transportation of dangerous goods. It does not include the tank valve. It was not made for fixed installations in propulsion systems, but the tanks are not excluded for such use. EN 12245 requires a bonfire test in clause 5.2.12, which is less challenging compared to EC79 or R134, as the lower temperature limit is 590 °C and the time threshold for not bursting is only 5 min (for tanks >150 l). The standard does not strictly require TPRDs but instead generally refers to pressure relief components without specifying them. It describes TPRDs only in an informative Annex D.	Medium	Adopting EN 12245 requires an assessment of the gaps with the boundary conditions from railway application and closing of those with additional tests and design rules from existing (e.g., EN 45545-x) and still to be developed railway standards, such as IEC 63341-2. EN 12245 is open with regards to TPRDs and would generally allow alternative methods. The validation method is similar to tests from automotive regulations. This requires an assessment of the residual risk for railway application under consideration of potential fire scenarios.	no	Other RCS	N/A
20	C1	External Fire / internal ignition source	EN 17339	6.2.11	The scope of EN 17339 has its focus on composite tanks for any CGH2 in transportation of dangerous goods. It does not include the tank valve. It was not made for fixed installations in propulsion systems, but the tanks are not excluded for such use. EN 17339 requires a bonfire test in clause 6.2.11, which is less challenging compared to EC79 or R134, as the lower temperature limit is 590 °C and the time threshold for not bursting is only 5 min. The standard does not strictly require TPRDs but instead generally refers to pressure relief components without specifying them.	Medium	Adopting EN 17339 requires an assessment of the gaps with the boundary conditions from railway application and closing of those with additional tests and design rules from existing (e.g., EN 45545-x) and still to be developed railway standards, such as IEC 63341-2. EN 17339 is open with regards to TPRDs and would generally allow alternative methods. The validation method is similar to tests from automotive regulations. This requires an assessment of the residual risk for railway application under consideration of potential fire scenarios.	no	Other RCS	N/A
21	C1	External Fire / internal ignition source	ISO 19881	17.3.8	ISO 19881 defines requiremens of CHSS primarily for road vehicle application. It does not include the tank valve. The fire test required by ISO 19881 in clause 17.3.8 is similar to R134. It also requires TPRDs to prevent tanks form bursting under direct fire impact, with reference to ISO 19882. Please refer to the analysis done for R134.	High	ISO 19881 was primarily made for CHSS in road vehicle application with strong analogies to R134. Adopting this standard 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 45545-x) and still to be developed railway standards, such as IEC 63341-2. Adopting TPRDs from automotive standards 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.	no	Other RCS	N/A
22	C1	External Fire / internal ignition source	ISO 19882	all	ISO 19882 defines a wide range of design qualification tests, inspection test as well as routine tests for TPRDs. The requirements even go beyond the requirements from EC79 and R134 and serve to achieve the required safety and reliability of the TPRD in mobile application and under all boundary conditions for road vehicle application.	High	ISO 19882 was primarily made for TPRDs road vehicle application. Adopting this standard 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 standards 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.	no	Other RCS	N/A
23	C1	External Fire / internal ignition source	EN IEC 62282-2-100	4.2.5	IEC 62282-2-100 defines safety requirements for fuel cell modules in any field of application. It refers to the safety requirements of the individual industry standard and only defines generic requirements to avoid fire development in clause 4.2.5. The requriements are not prescriptive, except for the use of non metallic materials with low flammability acc. to IEC 60695-x (V0, V1, V2-rating).	High	IEC 62282-2-100 defines generic fire safety requirements for fuel cell modules. Adopting this standard requires an assessment of the gaps with the boundary conditions from railway application and closing these with additional tests and design rules from existing (e.g., EN 45545-x) and still to be developed railway standards, such as IEC 63341-1.	no	Other RCS	N/A
24	C1	External Fire / internal ignition source	EN IEC 62282-3-100	4.6.1	IEC 62282-3-100 defines safety requirements for stationary fuel cell systems. It defines a set of prescriptive fire and explosion safety requirements in clause 4.6.1, which generally apply regardless of the use case of the fuel cell.	High	IEC 62282-3-100 defines fire safety requirements for stationary fuel cell systems. Adopting this standard requires an assessment of the gaps with the boundary conditions from railway application and closing these with additional tests and design rules from existing (e.g., EN 45545-x) and still to be developed railway standards, such as IEC 63341-1.	no	Other RCS	N/A
25	C1	External Fire / internal ignition source	EN IEC 62282-4-101	5.15	IEC 62282-4-101 defines safety requirements for fuel cell energy systems of industrial trucks. Other than some electric requirements in clause 5.15, it does not have a dedicated clause for fire protection.	High	IEC 62282-4-101 defines fire safety requirements for fuel cell energy systems of industrial trucks. Adopting this standard requires an assessment of the gaps with the boundary conditions from railway application and closing these with additional tests and design rules from existing (e.g., EN 45545-x) and still to be developed railway standards, such as IEC 63341-1.	no	Other RCS	N/A
26	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 its implementation directive EU 406/2010 for hydrogen road vehicles were withdrawn and are replaced by UN ECE R134. The detailed requirements are defined in EU 406/2010.	no	Other RCS	N/A
27	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. With regards to the maximum operating temperatures of up to 85 °C, the typical maximum operating temperatures for electrical or electro-mechanical railway components acc. to EN 50155 are fulfilled. However, it requires an adequate margin for excessive gas temperatures >85 °C from fast filling with regards to plastic liners. 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.	no	Other RCS	N/A
28	C2	Thermal impact / over temperature	UN ECE R 134	Clauses 5 to 7 and Annex 3 to 4	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. 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. With regards to the maximum operating temperatures of up to 85 °C, the typical maximum operating temperatures for electrical or electro-mechanical railway components acc. to EN 50155 are fulfilled. However, it requires an adequate margin for excessive gas temperatures >85 °C from false filling operation with regards to plastic liners. R134 does not define any requirements for liner softening temperatures. 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.	no	Other RCS	N/A
29	C2	Thermal impact / over temperature	SAE J2601	all	SAE J2601 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 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 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. Input from CNH2: The standard contains important limitations which require adaption 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 refueling process, - Maximum admissible flow during refuelling, - Characteristic curves for the refuelling process.	no	Other RCS	N/A
30	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 could 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.	no	Other RCS	N/A
31	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	no	Other RCS	N/A
32	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.	no	Other RCS	Medium
33	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.	yes	Modification	Low
34	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.	yes	Modification	Medium
35	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 should define requirements for alternative propulsion systems 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.	yes	Modification	Low
36	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	yes	No Modification	N/A
37	C2	Thermal impact / over temperature	EN 12245	5.2.11	The scope of EN 12245 has its focus on composite tanks for any compressed, liquified or dissolved gases in transportation of dangerous goods. It does not include the tank valve and was not made for fixed installations in propulsion systems, but the tanks are not excluded for such use. The maximum gas temperature as well as the equivalent maximum test pressure is set to 65°C. The test defined in clause 5.2.11.2 requires cycling of the tank with temperatures between +60 °C and -40 °C.	Low	The maximum temperature of 65 °C defined by EN 12245 is not compatible with the expected gas temperature during (fast) refuelling of fixed installed tanks for propulsion in mobile applications, which is generally defined with 85 °C.	no	Other RCS	N/A
38	C2	Thermal impact / over temperature	EN 17339	6.2.10	The scope of EN 17339 has its focus on composite tanks for any CGH2 in transportation of dangerous goods. It does not include the tank valve and was not made for fixed installations in propulsion systems, but the tanks are not excluded for such use. The maximum gas temperature as well as the equivalent maximum test pressure is set to 65°C. The test defined in clause 6.2.10 requires cycling of the tank with temperatures between +65 °C and -40 °C.	Low	The maximum temperature of 65 °C defined by EN 17339 is not compatible with the expected gas temperature during (fast) refuelling of fixed installed tanks for propulsion in mobile applications, which is generally defined with 85 °C.	no	Other RCS	N/A
39	C2	Thermal impact / over temperature	ISO 19881	4.4, 6.6, 6.7, 17.3.4, 17.5.4	ISO 19881 defines requirements of CHSS primarily for road vehicle application. It does not include the tank valve. It limits the maximum operating temperature to +85 °C in clause 4.4 and requires a minimum glass transition temperature of the resin of 105 °C in clause 6.6. The minimum softening temperature of the non-metallic liner (applies to Type 4 tanks) shall at least meet the operating temperatures and hence does not foresee a safety margin by definition. The type tests defined in clause 17.3.4 and 17.5.4 require extreme temperature cycling up to the maximum operating temperatures and are similar to those required by R134. ISO 19881 also requires to use of TPRDs as per ISO 19882, see below.	High	ISO 19881 defines a maximum operating temperatures of up to 85 °C. However, it requires an adequate margin for excessive gas temperatures >85 °C from false filling operation with regards to plastic liners. ISO 19881 does not define any requirements for liner softening temperatures.	no	Other RCS	N/A
40	C2	Thermal impact / over temperature	ISO 19882	4.5, 7.4	ISO 19882 defines a wide range of design qualification tests, inspection test as well as routine tests for TPRDs. It limits the maximum operating temperature to +85 °C in clause 4.5. The type tests defined in clause 7.4 requires thermal cycling within the range of the maximum and minimum operating temperatures and are similar to those required by R134 or EC79.	High	None	no	Other RCS	N/A

			Mitigation				Evaluation			
No.	ID	Cause / Trigger	Allocated RCS	Applicable clauses	Assessment of suitability	Suitability	Identified gap	Railway application	Result	Priority
41	C2	Thermal impact / over temperature	EN IEC 62282-2-100	4.2.8	IEC 62282-2-100 defines safety requirements for fuel cell modules in any field of application. It does not specify requirements maximum operating temperatures or any measures for detection or protection from excessive temperatures. General safety requirements are specified in clause 4.2.8 with reference to the individual industry standards.	Low	Adopting this standard requires an assessment of the gaps with the boundary conditions from railway application (e.g. max. ambient temperature or gas inlet temperature) and closing these with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-1.	no	Other RCS	N/A
42	C2	Thermal impact / over temperature	EN IEC 62282-3-100	4.9, 5.12	IEC 62282-3-100 defines safety requirements for stationary fuel cell systems. It does not specify requirements maximum operating temperatures or gas inlet temperatures. In clause 4.9 the active protection measures from critical deviations are generally defined. In addition clause 5.12 defines a type test for surface determine maximum surface temperatures, which shall not exceed 50 to 60 °C.	Medium	Adopting this standard requires an assessment of the gaps with the boundary conditions from railway application (e.g. max. ambient temperature or gas inlet temperature) and closing these with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-1.	no	Other RCS	N/A
43	C2	Thermal impact / over temperature	EN IEC 62282-4-101	4.4	IEC 62282-4-101 defines safety requirements for fuel cell energy systems of industrial trucks. It does not specify requirements maximum operating temperatures or gas inlet temperatures. As the standard also considers the tank system of the industrial truck, clause 4.4 refers to the use of TPRDs but does not specify limits for the fuel cell.	Low	Adopting this standard requires an assessment of the gaps with the boundary conditions from railway application (e.g. max. ambient temperature or gas inlet temperature) and closing these with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-1.	no	Other RCS	N/A
44	C2	Thermal impact / over temperature	ISO 12619-series	Part 2 - 6.4.3, 9.2.3	ISO 12619-series defines a wide range of type test requirements for CGH2-components in mobile applications (except for tanks, TPRDs and receptacles). Part 1 defines the general boundary conditions, such as an operating temperature between +85 °C / +120 °C to -20 °C / -40 °C. Part 2 defines all generic type tests, while parts 3 to 16 address the respective fluidic component. Clause 9.2.3 of part 2 defines an maximum operating temperature cycling test.	High	With regards to the maximum operating temperatures of +85 to 120 °C, the typical maximum operating temperatures for electrical or electro-mechanical railway components acc. to EN 50155 are fulfilled and excessive gas temperatures are covered with an adequate margin.	no	Other RCS	N/A
45	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 its implementation directive EU 406/2010 for hydrogen road vehicles were withdrawn and are replaced by UN ECE R134. 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.	no	Other RCS	N/A
46	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.	no	Other RCS	N/A
47	C3	Cold impact / under temperature	UN ECE R 134	Clauses 5 to 7 and Annex 3 to 4	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. 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.	no	Other RCS	N/A
48	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	no	Other RCS	N/A
49	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.	yes	Modification	Low
50	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	yes	No Modification	N/A
51	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 should define requirements for alternative propulsion systems 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.	yes	Modification	Low
52	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	yes	No Modification	N/A
53	C3	Cold impact / under temperature	EN 12245	5.2.11	The scope of EN 12245 has its focus on composite tanks for any compressed, liquified or dissolved gases in transportation of dangerous goods. It does not include the tank valve. It was not made for fixed installations in propulsion systems, but the tanks are not excluded for such use. The minimum gas temperature is set to -40 °C. The test defined in clause 5.2.11.2 requires cycling of the tank with temperatures between +60 °C and -40 °C.	High	The minimum temperature of -40 °C defined by EN 12245 is compatible with the expected gas temperature during defuelling or refuelling with precooled hydrogen in mobile applications.	no	Other RCS	N/A
54	C3	Cold impact / under temperature	EN 17339	6.2.10	The scope of EN 17339 has its focus on composite tanks for any CGH2 in transportation of dangerous goods. It does not include the tank valve. It was not made for fixed installations in propulsion systems, but the tanks are not excluded for such use. The minimum gas temperature is set to -40 °C. The test defined in clause 6.2.10 requires cycling of the tank with temperatures between +65 °C and -40 °C.	High	The minimum temperature of -40 °C defined by EN 17339 is compatible with the expected gas temperature during defuelling or refuelling with precooled hydrogen in mobile applications.	no	Other RCS	N/A
55	C3	Cold impact / under temperature	ISO 19881	4.4, 6.7, 17.3.4, 17.5.4	ISO 19881 defines requiremens of CHSS primarily for road vehicle application. It does not include the tank valve. It limits the minimum operating temperature to -40 °C in clause 4.4. Non-metallic liners (applies to Type 4 tanks) shall sustain -50 °C and not embrittle or crack with reference to test acc. to ASTM D638. The type tests defined in clause 17.3.4 and 17.5.4 require extreme temperature cycling up to the minimum operating temperatures and are similar to those required by R134. ISO 19881 also requires to use of TPRDs as per ISO 19882, see below.	High	ISO 19881 defines a minimum operating temperatures of up to -40 °C with adequate margin for colder temperatures up to -50 °C (e.g., caused by rapid defuelling).	no	Other RCS	N/A
56	C3	Cold impact / under temperature	ISO 19882	4.5, 7.4	ISO 19882 defines a wide range of design qualification tests, inspection test as well as routine tests for TPRDs. It limits the minimum operating temperature to -40 °C in clause 4.5. The type tests defined in clause 7.4 requires thermal cycling within the range of the maximum and minimum operating temperatures and are similar to those required by R134 or EC79.	High	None	no	Other RCS	N/A
57	C3	Cold impact / under temperature	EN IEC 62282-2-100	5.14.7	IEC 62282-2-100 defines safety requirements for fuel cell modules in any field of application. It does not specify requirements minimum operating temperatures or any measures for detection or protection from excessive temperatures. General safety requirements are specified in clause 4.2.8 with reference to the individual industry standards.	Low	Adopting this standard requires an assessment of the gaps with the boundary conditions from railway application (e.g. min. ambient temperature or gas inlet temperature) and closing these with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-1.	no	Other RCS	N/A
58	C3	Cold impact / under temperature	EN IEC 62282-3-100	4.9	IEC 62282-3-100 defines safety requirements for stationary fuel cell systems. It does not specify requirements minimum operating temperatures or gas inlet temperatures. In clause 4.9 the active protection measures from critical deviations are generally defined.	Low	Adopting this standard requires an assessment of the gaps with the boundary conditions from railway application (e.g. min. ambient temperature or gas inlet temperature) and closing these with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-1.	no	Other RCS	N/A
59	C3	Cold impact / under temperature	EN IEC 62282-4-101	4.4	IEC 62282-4-101 defines safety requirements for fuel cell energy systems of industrial trucks. It does not specify requirements minimum operating temperatures or gas inlet temperatures.	Low	Adopting this standard requires an assessment of the gaps with the boundary conditions from railway application (e.g. min. ambient temperature or gas inlet temperature) and closing these with additional tests and design rules from existing (e.g., EN 50155) and still to be developed railway standards, such as IEC 63341-1.	no	Other RCS	N/A
60	C3	Cold impact / under temperature	ISO 12619-series	Part 2 - 6.4.1, 9.2.4, 19	ISO 12619-series defines a wide range of type test requirements for CGH2-components in mobile applications (except for tanks, TPRDs and receptacles). Part 1 defines the general boundary conditions, such as an operating temperature between +85 °C / +120 °C to -20 °C / -40 °C. Part 2 defines all generic type tests, while parts 3 to 16 address the respective fluidic component. Clause 9.2.4 of part 2 defines an minimum operating temperature cycling test. In addition the standard requires a pre-cooled exposure test in chapter 19.	High	With regards to the minimum operating temperatures of +20 to 40 °C, the typical minimum operating temperatures for electrical or electro-mechanical railway components acc. to EN 50155 are fulfilled and low gas temperatures are covered.	no	Other RCS	N/A
61	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.	no	Other RCS	Low
62	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 i) the H2-tank (type 3 and 4) must undergo a drop test.	Low	Adopting components with EC 79 type approval requires additional shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11 for any valve.	no	Other RCS	N/A
21	C1	External Fire / internal ignition source	ISO 19881	17.3.8	ISO 19881 defines requiremens of CHSS primarily for road vehicle application. It does not include the tank valve. The fire test required by ISO 19881 in clause 17.3.8 is similar to R134. It also requires TPRDs to prevent tanks form bursting under direct fire impact, with reference to ISO 19882. Please refer to the analysis done for R134.	High	ISO 19881 was primarily made for CHSS in road vehicle application with strong analogies to R134. Adopting this standard 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 45545-x) and still to be developed railway standards, such as IEC 63341-2. Adopting TPRDs from automotive standards 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.	no	Other RCS	N/A
64	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 additional shock and vibration tests acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11 for any valve.	no	Other RCS	N/A
65	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	no	Other RCS	N/A

			Mitigation				Evaluation			
No.	**ID**	**Cause / Trigger**	**Allocated RCS**	**Applicable clauses**	**Assessment of suitability**	**Suitability**	**Identified gap**	**Railway application**	**Result**	**Priority**
66	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 EN 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 EN 61373 only, would not cover this aspect. In order to prove permanent 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 EN 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt EN 61373 and EN 50155 and define additional requirements.	yes	Modification	Medium
67	C4	Operational shock & vibration	EN 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 EN 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 EN 61373 only, would not cover this aspect. In order to prove permanent 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 EN 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt EN 61373 and EN 50155 and define additional requirements.	yes	Modification	High
68	C4	Operational shock & vibration	EN IEC 62928	6.2 and 14.3.3	IEC 62928 requires shock and vibration test acc. to EN 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 EN 61373 test.	Medium	IEC 62928 and there referenced standards EN 61373 and IEC 60571 respectively do not foresee any functional tests during random vibration, as required by EN 50155, 13.4.11.	yes	Modification	Medium
69	C4	Operational shock & vibration	EU 1302/2014	all	TSI LOC&PAS does not require any shock and vibration test for safety relevant components.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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.	yes	Modification	High
70	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 EN 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	yes	No Modification	N/A
71	C4	Operational shock & vibration	EN 12245	5.2.9	EN 12245 does not specify any shock & vibration test for composite tanks, since the tank is a passive component and the tank valve is not in its scope. The standard defines a mechanical impact and drop test in clause 5.2.9.	Medium	Adopting tanks acc. to EN 12245 may require additional shock & vibration tests in assembled condition acc. to EN 61373.	no	Other RCS	N/A
72	C4	Operational shock & vibration	EN 17339	6.2.8	EN 17339 does not specify any shock & vibration test for composite tanks, since the tank is a passive component and the tank valve is not in its scope. The standard defines a mechanical impact test in clause 6.2.8.	Low	Adopting tanks acc. to EN 17339 may require additional shock & vibration tests in assembled condition acc. to EN 61373.	no	Other RCS	N/A
73	C4	Operational shock & vibration	ISO 19881	17.3.7, 17.3.10	ISO 19881 does not specify any shock & vibration test for composite tanks, since the tank is a passive component and the tank valve is not in its scope. The standard defines a drop test and a high strain rate impact test in clauses 17.3.7 and 17.3.10.	Medium	Adopting tanks acc. to ISO 19881 may require additional shock & vibration tests in assembled condition acc. to EN 61373.	no	Other RCS	N/A
74	C4	Operational shock & vibration	ISO 19882	7.9, Annex B.8	ISO 19882 requires a drop and vibration test for TPRDs in clause 7.9 which is conducted for 30 min in each axes with an acceleration of 1,5 g with a seep time of 10 min within a sinusodial frequency range of 10 to 500 Hz where the resonsance frequency shall be found and tested. Additional information can be found in Annex B.8.	High	The drop and vibration test defined by ISO 19882 provides a basic integrity against operational shock & vibration influences. Adopting TPRDs acc. to ISO 19882 on railway vehicles may require additional tests acc. to EN 61373, since the accelerations and test durations are not the same.	no	Other RCS	N/A
75	C4	Operational shock & vibration	EN IEC 62282-2-100	4.2.13, 5.2	IEC 62282-2-100 generally requires to design and test fuel cell modules for shock & vibration acc. to customer specification. There is no normative reference for the test.	Low	Adopting IEC 62282-2-100 requires shock & vibration test acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11 for the assembly or functional parts of the fuel cell module - especially the fluidic part.	no	Other RCS	N/A
76	C4	Operational shock & vibration	EN IEC 62282-3-100	4.2.3, 4.2.6	IEC 62282-3-100 refers to stationary fuel cell systems, hence shock & vibration influences are normally not considered. It refers to the physical environment in clause 4.2.3, which may induce vibrations from other machines or adjacent facilities. The standard requires to decouple the fuel cell from those vibrations in clause 4.2.6.	Low	Adopting IEC 62282-3-100 requires shock & vibration test acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11 for the assembly or functional parts of the fuel cell module - especially the fluidic part.	no	Other RCS	N/A
77	C4	Operational shock & vibration	EN IEC 62282-4-101	5.2	IEC 62282-4-101 generally requires to design and test fuel cell modules for shock & vibration acc. to customer specification in longitudinal and lateral axis. Clause 5.2 provides several generic requirements for the test condition and the required result after the test. The actual vibration profile may be defined by the user.	High	Adopting IEC 62282-4-101 requires shock & vibration test acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11 for the assembly or functional parts of the fuel cell module - especially the fluidic part.	no	Other RCS	N/A
78	C4	Operational shock & vibration	ISO 12619-series	Part 2 - 15	ISO 12619-2 requires a shock & vibration test for fluidic components in chapter 15 which is conducted for 30 min in each axes with an acceleration of 1,5 g with a seep time of 10 min within a sinusodial frequency range of 10 to 500 Hz where the resonsance frequency shall be found and tested.	High	The shock & vibration test defined by ISO 12619-2 provides a basic integrity against operational shock & vibration influences. Adopting ISO 12619-components on railway vehicles may require additional tests acc. to EN 61373, since the accelerations and test durations are lower.	no	Other RCS	N/A
79		Electro magnetic emission / interference	EC 79/2009	---	EC 79 and EU 406 respectively do not specify any EMC requirements.	None	Adopting components with EC 79 type approval requires conducting of additional EMC tests acc. to EN 50121-3-2.	no	Other RCS	N/A
80		Electro magnetic emission / interference	EU 406/2010	---	EC 79 and EU 406 respectively do not specify any EMC requirements.	None	Adopting components with EC 79 type approval requires conducting of additional EMC tests acc. to EN 50121-3-2.	no	Other RCS	N/A
81		Electro magnetic emission / interference	UN ECE R 134	---	R 134 does not specify any EMC requirments.	None	Adopting components with R 134 type approval requires conducting of additional EMC tests acc. to EN 50121-3-2.	no	Other RCS	N/A
82	C5	Electromagnetic emission / interference	UN ECE R 10	all	The ECE R 10 describes tests in order to prove the electromagnetic compatibility of vehicles and components used in vehicles. It is possible to assess fulfilment 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.	no	Other RCS	N/A
83	C5	Electromagnetic 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 fulfilment 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.	no	Other RCS	N/A
84	C5	Electromagnetic 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	no	Other RCS	N/A
85	C5	Electromagnetic 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	yes	No Modification	N/A
86	C5	Electromagnetic 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	yes	No Modification	N/A
87	C5	Electromagnetic 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 should define requirements for alternative propulsion systems 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.	yes	Modification	High
88	C5	Electromagnetic 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	yes	No Modification	N/A
89	C5	Electromagnetic 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	yes	No Modification	N/A
90	C5	Electromagnetic emission / interference	EN IEC 62282-3-100	4.8	IEC 62282-3-100 defines EMC tests for stationary fuel cell systems with reference to IEC 61000-series in clause 4.8. The actual test method must be agreed and depends on the individual use case.	High	IEC 62282-3-100 compliant fuel cells may fulfill EMC-requirements of EN 50121-3-2, which must be confirmed by conformity assessmen or additional test.	no	Other RCS	N/A
91	C5	Electromagnetic emission / interference	EN IEC 62282-4-101	4.14, 5.8	IEC 62282-4-101 generally requires to design and test fuel cell modules under consideration of EMC of the integrated control system as well as acc. to national requirements, see clause 4.14 and 5.8. It does not refer to any test methods or thresholds.	Low	Adopting IEC 62282-4-101 compliant fuel cells requires EMC test according to EN 50121-3-2.	no	Other RCS	N/A
92	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	no	Other RCS	N/A
93	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	no	Other RCS	N/A
94	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	no	Other RCS	N/A
95	C6	Hydrogen purity / particle ingress	EU 1299/2014	---	TSI INF does not define any requirements for hydrogen purity of hydrogen supplied by hydrogen filling stations in the railway infrastructure.	None	TSI INF should define requirements for hydrogen filling stations, such as the required purity of supplied hydrogen.	yes	Modification	Medium
96	C6	Hydrogen purity / particle ingress	EU 1302/2014	---	TSI LOC&PAS does not define any requirements for hydrogen purity or application of filters.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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.	yes	Modification	Medium
97	C6	Hydrogen purity / particle ingress	EN ISO 17268	5.7, 6.7	ISO 17268 generally requires to foresee adequate means to prevent ingress of particles in clauses 5.7 and 6.7, e.g. by use of filters. However, it is not prescriptive with regards to filter type and mesh size. The used filter must in any case fulfill the general material requirements and fulfill all design verification tests acc. to ISO 17268.	High	ISO 17268 provides a comprehensive set of requirements for safe and reliable design of refuelling connectors. Application of ISO 17268 however does not provide adequate protection from particle ingress, since the filter mesh size is not defined and must be agreed with the refuelling receptacle manufacturer.	no	Other RCS	N/A
98	C6	Hydrogen purity / particle ingress	ISO 12619-series	all	ISO 12619-15 defines general hardware integrity requirements for CGH2 filters. The individual mesh size is not defined as it depends on the required purity.	High	ISO 12619-15 provides a comprehensive set of requirements for safe and reliable design of CGH2 filters. The actual mesh size must be chosen by the system integrator to ensure protection of functional components and fuel cells.	no	Other RCS	N/A
99	C6	Hydrogen purity / particle ingress	ISO 19880-8	all	ISO 19880-8 defines methods to control the hydrogen quality which is supplied from hydrogen filling stations.	Medium	ISO 19880-8 may be applied by the filling station operator to ensure the required hydrogen quality, which is to be filled in railway vehicles with hydrogen systems.	no	Other RCS	N/A
100	C6	Hydrogen purity / particle ingress	EN IEC 62282-2-100	---	IEC 62282-2-100 does not define any requirements on the required hydrogen purity.	None	IEC 62282-2-100 does not define any requirements on the required hydrogen purity. This must be defined by the manufacturer.	no	Other RCS	N/A
101	C6	Hydrogen purity / particle ingress	EN IEC 62282-3-100	---	IEC 62282-3-100 does not define any requirements on the required hydrogen purity.	None	IEC 62282-3-100 does not define any requirements on the required hydrogen purity. This must be defined by the manufacturer.	no	Other RCS	N/A
102	C6	Hydrogen purity / particle ingress	EN IEC 62282-4-101	4.7	IEC 62282-4-101 generally defines the use of filters without defining the required mesh size or purity.	Medium	IEC 62282-4-101 generally defines the use of filters without defining the required mesh size or purity. This must be defined by the manufacturer.	no	Other RCS	N/A
103	C7	Hydrogen incompatibility / material embrittlement	EC 79/2009	Annex III	EC 79 generally, requires that hydrogen compatibility shall be proven. Details are outlined in EU 406.	High	None	no	Other RCS	N/A
104	C7	Hydrogen incompatibility / material embrittlement	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	no	Other RCS	N/A
105	C7	Hydrogen incompatibility / material embrittlement	UN ECE R 134	---	R 134 does not specify any requirements for hydrogen compatibility.	None	Adopting components with R 134 type approval may require additional evidence for hydrogen compatibility.	no	Other RCS	N/A

			Mitigation				Evaluation			
No.	ID	Cause / Trigger	Allocated RCS	Applicable clauses	Assessment of suitability	Suitability	Identified gap	Railway application	Result	Priority
106	C7	Hydrogen incompatibility / material embrittlement	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 a gap after withdrawal of EC79, since R134 does not specify requirements for hydrogen compatibility.	High	None	no	Other RCS	N/A
107	C7	Hydrogen incompatibility / material embrittlement	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	no	Other RCS	N/A
108	C7	Hydrogen incompatibility / material embrittlement	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	no	Other RCS	N/A
109	C7	Hydrogen incompatibility / material embrittlement	EU 1302/2014	---	TSI LOC&PAS does not define any requirements for hydrogen compatibility of materials.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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.	yes	Modification	High
110	C7	Hydrogen incompatibility / material embrittlement	EN 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	no	Other RCS	N/A
111	C7	Hydrogen incompatibility / material embrittlement	EN 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	no	Other RCS	N/A
112	C7	Hydrogen incompatibility / material embrittlement	EN 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	no	Other RCS	N/A
113	C7	Hydrogen incompatibility / material embrittlement	EN 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	no	Other RCS	N/A
114	C7	Hydrogen incompatibility / material embrittlement	ISO 19881	6.2	ISO 19881 requires all materials of the tank, especially the liner to be compatible with hydrogen in clause 6.2. It refers to international and north american standards or codes in a note but is not prescriptive.	High	Adopting tanks acc. to ISO 19881 may require additional evidence for hydrogen compatibility as the standard is not prescriptive in the choice of hydrogen compatible materials.	no	Other RCS	N/A
115	C7	Hydrogen incompatibility / material embrittlement	ISO 19882	6.1	ISO 19882 requires all materials of the TPRD to be compatible with hydrogen in clause 6.1. It refers to international and north american standards or codes in a note but is not prescriptive.	High	Compliance with ISO 19882 may require additional evidence for hydrogen compatibility as the standard is not prescriptive in the choice of hydrogen compatible materials.	no	Other RCS	N/A
116	C7	Hydrogen incompatibility / material embrittlement	EN 12245	4.2	EN 12245 refers to ISO 11114-series for the material of the liner in clause 4.2.	High	None	no	Other RCS	N/A
117	C7	Hydrogen incompatibility / material embrittlement	EN 17339	5.2	EN 17339 refers to ISO 11114-series for the material of the liner in clause 5.2.	High	None	no	Other RCS	N/A
118	C7	Hydrogen incompatibility / material embrittlement	EN IEC 62282-2-100	4.2.1	IEC 62282-2-100 implictly requires materials to be compatible with the fluid in clause 4.2.1, but is not prescriptive.	Low	Compliance with IEC 62282-2-100 may require additional evidence for hydrogen compatibility for the fluidic part as those are not required by the standard.	no	Other RCS	N/A
119	C7	Hydrogen incompatibility / material embrittlement	EN IEC 62282-3-100	4.3	IEC 62282-3-100 requires materials to be compatible with the fluid in clause 4.3 and refers to ISO/TR 15916 in an informative note.	Medium	Compliance with IEC 62282-3-100 may require additional evidence for hydrogen compatibility for the fluidic part as those are not required by the standard.	no	Other RCS	N/A
120	C7	Hydrogen incompatibility / material embrittlement	EN IEC 62282-4-101	4.2	IEC 62282-3-100 requires materials to be compatible with the fluid in clause 4.2 and explicitly refers to ISO/TR 15916, ISO 11114-4 or ISO 2626.	Medium	None	no	Other RCS	N/A
121	C7	Hydrogen incompatibility / material embrittlement	ISO 12619-series	Part 2 - 17, 18	ISO 12619-2 requires materials to fulfill ISO 11114-2 and 11114-4 in chapters 17 and 18.	High	None	no	Other RCS	N/A
122	C7	Hydrogen incompatibility / material embrittlement	EN ISO 17268	4.5, 7.14	ISO 17268 generally requires materials to be compliant with hydrogen at the expected pressures and temperatures, without being prescriptive in clause 4.5. To demonstrate that non-metallic gaskets and materials are compatible with hydrogen, a dedicated test is defined in clause 7.14.	Medium	Compliance with ISO 17268 may require additional evidence for hydrogen compatibility of the applied metals, as the standard is not prescriptive in the choice of hydrogen compatible metals.	no	Other RCS	N/A
123	C7	Hydrogen incompatibility / material embrittlement	GB/T 26779	6.9	GB/T 26779 does not clearly require the materials of the receptacle to be compatible with hydrogen. To demonstrate that non-metallic gaskets and materials are compatible with hydrogen, a dedicated test is defined in clause 6.9.	Medium	Compliance with GB/T 26779 may require additional evidence for hydrogen compatibility of the applied metals.	no	Other RCS	N/A
124	C7	Hydrogen incompatibility / material embrittlement	SAE J2579	4.1.3.1, Annex B	SAE J2579 provides a white list of hydrogen compatible metals in annex B.	High	None	no	Other RCS	N/A
125	C7	Hydrogen incompatibility / material embrittlement	EN 13480-2	4.2.1.1	EN 13480-series is a product standard for stainless steel pipes, which may be compatible with hydrogen. The standard only implicitly refers to the correct material choice with regards to hydrogen embrittlement in clause 4.2.1.1, but does not provide a white list of alloys to use.	Medium	None	no	Other RCS	N/A
126	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN 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	no	Other RCS	N/A
127	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN IEC 60068-2-11	all	EN IEC 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	no	Other RCS	N/A
128	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	no	Other RCS	N/A
129	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	no	Other RCS	N/A
130	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	no	Other RCS	N/A
131	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	no	Other RCS	N/A
132	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	no	Other RCS	N/A
133	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.	yes	Modification	Low
134	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 should define requirements for alternative propulsion systems 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.	yes	Modification	High
135	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	yes	No Modification	N/A
136	C8	Corrosion (dusts, aerosols, humidity, chemicals)	ISO 19881	6.2, 6.3	ISO 19881 requires all materials of the tank, especially the liner to be resistant to corrosion in clause 6.3. For aluminium a dedicated corrosion test acc. to ISO 7866, Annex A is required.	High	None	no	Other RCS	N/A
137	C8	Corrosion (dusts, aerosols, humidity, chemicals)	ISO 19882	6.1, 7.5, 7.8	ISO 19882 requires all materials of the TPRD to be resistant to corrosion in clause 6.1. It defines dedicated tests for accelerated cyclic corrosion and stress corrosion cracking in clauses 7.5 and 7.8.	High	None	no	Other RCS	N/A
138	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN IEC 62282-3-100	4.3	IEC 62282-3-100 generally requires to choose corrosion resistant materials for the fluidic part in clause 4.3, without being prescriptive.	Medium	None	no	Other RCS	N/A
139	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN IEC 62282-4-101	4.2.1	IEC 62282-4-101 generally requires to choose corrosion resistant materials for the fluidic part in clause 4.2.1, without being prescriptive.	Medium	None	no	Other RCS	N/A
140	C8	Corrosion (dusts, aerosols, humidity, chemicals)	ISO 12619-series	Part 2 - 10, 11, 12	ISO 12619-2 requires a salt spray test for 500 h acc. to ISO 9227 in chapter 10. In addition sealing materials shall undergo oxygen ageing and ozone ageing tests acc. to tests as defined in chapters 11 and 12.	High	None	no	Other RCS	N/A
141	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN ISO 17268	7.13, 7.17	ISO 17268 requires a salt spray test for 1000 h acc. to ISO 9227 in clause 7.17.3. In addition sealing materials shall undergo oxygen ageing and ozone ageing tests acc. to tests as defined in clause 7.13.	High	None	no	Other RCS	N/A
142	C8	Corrosion (dusts, aerosols, humidity, chemicals)	GB/T 26779	5.2.9, 6.11	GB/T 26779 requires a salt spray test for 500 h acc. to GB/T 10125 in clause 6.11. In addition sealing materials shall undergo oxygen ageing and ozone ageing tests acc. to tests as defined in clauses 6.7 and 6.8.	High	None	no	Other RCS	N/A
143	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN 13480-2	4.2.1.1	EN 13480-series is a product standard for stainless steel pipes. The standard only implicitly refers to the correct material choice with regards to corrosion under operational conditions in clause 4.2.1.1, but does not provide a white list of alloys to use.	Medium	None	no	Other RCS	N/A
144	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN 10216-5	8.4	EN 10216-5 is a product standard for seamless stainless steel pipes. It provides lists of alloys with reference to their tested resistance to intercrystalline corrosion (tables 6 to 8) with temperature thresholds in tables 9 to 11.	High	None	no	Other RCS	N/A
145	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN ISO 9223	all	ISO 9223 defines corrosivtiy categories for metals and atmospheres and makes specifications for material choice.	High	None	no	Other RCS	N/A
146	C8	Corrosion (dusts, aerosols, humidity, chemicals)	EN ISO 9227	all	ISO 9227 defines a salt spray test as validation method for corrosion resistance which is referenced by several standards and may be chosen as alternative test method to IEC 60068-2-11.	High	None	no	Other RCS	N/A

			Mitigation				Evaluation			
No.	ID	Cause / Trigger	Allocated RCS	Applicable clauses	Assessment of suitability	Suitability	Identified gap	Railway application	Result	Priority
147	C9	Human error (manufacturing, operation, maintenance)	1999/92/EC	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	no	Other RCS	N/A
148	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 fulfill 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	no	Other RCS	N/A
149	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.	no	Modification	Medium
150	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	no	Other RCS	N/A
151	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	no	Other RCS	N/A
152	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.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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.	yes	Modification	High
153	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	no	Other RCS	N/A
154	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	no	Other RCS	N/A
155	C9	Human error (manufacturing, operation, maintenance)	EN ISO 17268	5.1	ISO 17268 requires proper interchangeability to avoid nozzles dedicated to higher pressure levels being couples with receptacles of lower pressure levels by the mechanical shape.	High	None	no	Other RCS	N/A
156	C9	Human error (manufacturing, operation, maintenance)	SAE J2600	4.2.2	SAE J2600 requires proper interchangeability to avoid nozzles dedicated to higher pressure levels being couples with receptacles of lower pressure levels by the mechanical shape.	High	None	no	Other RCS	N/A
157	C9	Human error (manufacturing, operation, maintenance)	EN 894-1	all	EN 894-1 provides general principles for human interactions with displays and control actuators, which may reduce human failures by ensuring cognitive ergonomics for staff in all operation, inspection and maintenance activities.	High	None	no	Other RCS	N/A
158	C9	Human error (manufacturing, operation, maintenance)	EN IEC 62282-2-100	Annex B.3	In order to avoid any critical quality defects in manufacturing of fuel cell modules, IEC 62282-2-100 proposes a set of routine tests in annex B.3, such as pressure and tightness tests.	Medium	None	no	Other RCS	N/A
159	C9	Human error (manufacturing, operation, maintenance)	EN IEC 62282-3-100	6	In order to avoid any critical quality defects in manufacturing of fuel cell systems, IEC 62282-3-100 requires a set of routine tests in chapter 6, such as pressure and tightness tests	Medium	None	no	Other RCS	N/A
160	C9	Human error (manufacturing, operation, maintenance)	EN IEC 62282-4-101	6	In order to avoid any critical quality defects in manufacturing of fuel cell industrial trucks, IEC 62282-4-101 requires a set of routine tests chapter 6, such as leakage and dielectric tests.	Medium	None	no	Other RCS	N/A
161	C10	Unsuitable 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. 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 for PED to certify the assembly.	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.		Other RCS	N/A
162	C10	Unsuitable 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 avoid leakage 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.	no	Other RCS	N/A
163	C10	Unsuitable 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 avoid leakage 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.	no	Other RCS	N/A
164	C10	Unsuitable 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.	no	Other RCS	N/A
165	C10	Unsuitable mechanical design	1999/92/EC	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	no	Other RCS	N/A
166	C10	Unsuitable 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 fulfill 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	no	Other RCS	N/A
167	C10	Unsuitable 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	no	Other RCS	N/A
168	C10	Unsuitable 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 of any hydrogen installation on railway vehicles.	High	Adopting EN 1127-1 principles for railway vehicles requires consideration of railway specific boundary conditions and a solid evidence as well as adequate maintenance plans and instructions.	no	Other RCS	N/A
169	C10	Unsuitable mechanical design	EN IEC 60079-10-1	all	EN 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	no	Other RCS	N/A
170	C10	Unsuitable 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	yes	No Modification	N/A
171	C10	Unsuitable 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	no	Other RCS	N/A
172	C10	Unsuitable mechanical design	EN 50155	4.3.5 and 13.4.11	EN 50155 requires shock & vibration test acc. to EN 61373 with additional functional tests, see "C4 Operational shock & vibration". It provides further mechanical design and installation requirements for electronics, see "C11 Unsuitable electrical design".	High	See "C4 Operational shock & vibration"	yes	No Modification	N/A

			Mitigation				Evaluation			
No.	ID	Cause / Trigger	Allocated RCS	Applicable clauses	Assessment of suitability	Suitability	Identified gap	Railway application	Result	Priority
173	C10	Unsuitable mechanical design	EN 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 EN 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 EN 61373 only, would not cover this aspect. In order to prove permanent 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 EN 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt EN 61373 and EN 50155 and define additional requirements.	yes	Modification	High
174	C10	Unsuitable 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 should define requirements for alternative propulsion systems 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.	yes	Modification	High
175	C10	Unsuitable 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 EN 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	yes	No Modification	N/A
176	C10	Unsuitable 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	yes	No Modification	N/A
177	C10	Unsuitable mechanical design	EN 12245	4, 5	The scope of EN 12245 has its focus on composite tanks for any compressed, liquified or dissolved gases in transportation of dangerous goods. It does not include the tank valve and was not made for fixed installations in propulsion systems, but the tanks are not excluded for such use. The standard defines a wide range of design requirements in chapter 4 and comprehensive design qualification tests in chapter 5 to prove adequate mechanical integrity for the intended use. The minimum burst pressure is twice the test pressure, which is to be defined by the manufacturer.	High	None	no	Other RCS	N/A
178	C10	Unsuitable mechanical design	EN 17339	5, 6	The scope of EN 17339 has its focus on composite tanks for CGH2 in transportation of dangerous goods. It does not include the tank valve and was not made for fixed installations in propulsion systems, but the tanks are not excluded for such use. The standard defines a wide range of design requirements in chapter 5 and comprehensive design qualification tests in chapter 6 to prove adequate mechanical integrity for the intended use. The minimum burst pressure is twice the test pressure, which is 1.5 times the nominal working pressure.	High	None	no	Other RCS	N/A
179	C10	Unsuitable mechanical design	ISO 19881	6, 7, 17	ISO 19881 defines requiremens of CHSS primarily for road vehicle application. It does not include the tank valve. The standard defines a wide range of design requirements in chapters 6 and 7 and comprehensive design qualification tests in chapter 17 to prove adequate mechanical integrity for the intended use. The minimum burst pressure is 2.25 time the nominal working pressure.	High	None	no	Other RCS	N/A
180	C10	Unsuitable mechanical design	ISO 19882	6, 7	ISO 19882 defines requiremens of TPRDs primarily for road vehicle application. The standard defines a wide range of design requirements in chapters 6 and comprehensive design qualification tests in chapter 7 to prove adequate mechanical integrity for the intended use. The maximum allowable working pressure shall not be less than 1.5 time the nominal working pressure.	High	None	no	Other RCS	N/A
181	C10	Unsuitable mechanical design	EN IEC 62282-2-100	4.2.7, 5.8	IEC 62282-2-100 defines comprehensive design rules for pipes and fittings of fuel cell modules in clause 4.2.7. It also requires an over pressure test in clause 5.8.	Medium	None	no	Other RCS	N/A
182	C10	Unsuitable mechanical design	EN IEC 62282-3-100	4.5, 4.13, 5.5	IEC 62282-3-100 defines comprehensive design rules for pressure equipment and piping of fuel cell systems in clause 4.5. It also requires pressure tests in clause 5.5. There are also several design rules for the fuel cell system housing defined in clause 4.13, such as IP degree.	Medium	The integration of IEC 62282-3-100 compliant fuel cell systems in railway vehicles requires vaidation of its housing and the car body connection acc. to the loads defined by EN 12663-1.	no	Other RCS	N/A
183	C10	Unsuitable mechanical design	EN IEC 62282-4-101	4.13, 5.7, 5.18	IEC 62282-4-101 defines some design requirements for the fuel cell housing in clause 4.13 and additional validation requirements in clause 5.18. It also requires pressure tests in clause 5.7 with reference to IEC 62282-2-100.	Medium	The integration of IEC 62282-4-101 compliant fuel cell systems in railway vehicles requires vaidation of its housing and the car body connection acc. to the loads defined by EN 12663-1.	no	Other RCS	N/A
184	C10	Unsuitable mechanical design	ISO 12619-series	Part 2 - 5, 7, 8, 9	ISO 12619-2 requires several mechanical strength test, such as hydrostatic strength test in chapter 5, excess torque resistance test in chapter 7, bending moment test in chapter 8 as well as cycling test in chapter 9.	High	None	no	Other RCS	N/A
185	C10	Unsuitable mechanical design	EN 10216-5	8.3, 11	EN 10216-5 is a product standard for seamless stainless steel pipes. The mechanical properties of the alloys can be found in clause 8.3 and the referenced tables. Additional tests for material strength are defined in chapter 11.	High	None	no	Other RCS	N/A
186	C10	Unsuitable mechanical design	EN 13480-3	all	EN 13480-series is a product standard for stainless steel pipes. The requirements for materails of pressure bearing pipes can be found in chapter 4 and further tables and material tests can be found in annexes A and B.	High	None	no	Other RCS	N/A
187	C10	Unsuitable mechanical design	EN ISO 4126-1	5	ISO 4126-1 provides general rules for the mechanical design of safety valves in chapter 5. The standard is harmonized with 2014/68/EU.	High	None	no	Other RCS	N/A
188	C10	Unsuitable mechanical design	EN IEC 62864-1	6.1, 6.6.3	IEC 62864-1 provides basic requirements on the mechnical design of the energy storage systems (ESS) and primary power sources (PPS), such as IP protection and shock & vibration resistance.	Medium	IEC 62864-1 does not adequately address the mechanical integration of energy storage systems (ESS) and primary power sources (PPS). The integration of ESS and PPS requires vaidation of its housing and the car body connection acc. to the loads defined by EN 12663-1.	yes	Modification	N/A
189	C10	Unsuitable mechanical design	EN 16404	6	EN 16404 defines load cases for re-railing or lifting of car bodies in chapter 6. The load cases must be used to determine the potential mechanical stress (bending moments) on the hydrogen pipework and tanks, which are installed on the train.	High	None	yes	No Modification	N/A
	C10	Unsuitable mechanical design	ISO 19880-5	6	Input from CNH2: ISO 19880-5 refers to 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. The length is not limited in chapter 6.	Medium	Input from CNH2: Following gaps have been determined: - 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.	no	Other RCS	N/A
190	C11	Unsuitable electrical design	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 additional tests for safety relevant components, as defined by EN 50155.	no	Other RCS	N/A
191	C11	Unsuitable electrical design	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 additional tests for safety relevant components, as defined by EN 50155.	no	Other RCS	N/A
192	C11	Unsuitable electrical design	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.	no	Other RCS	N/A
193	C11	Unsuitable electrical design	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	no	Other RCS	N/A
194	C11	Unsuitable electrical design	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	no	Other RCS	N/A
195	C11	Unsuitable electrical design	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	no	Other RCS	N/A
196	C11	Unsuitable electrical design	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	yes	No Modification	N/A
197	C11	Unsuitable electrical design	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	yes	No Modification	N/A
198	C11	Unsuitable electrical design	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	yes	No Modification	N/A
199	C11	Unsuitable electrical design	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 should define requirements for alternative propulsion systems 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.	yes	Modification	Medium
200	C11	Unsuitable electrical design	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	yes	No Modification	N/A
201	C11	Unsuitable electrical design	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	yes	No Modification	N/A
202	C11	Unsuitable electrical design	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	yes	No Modification	N/A
203	C11	Unsuitable electrical design	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	yes	No Modification	N/A
204	C11	Unsuitable electrical design	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	yes	No Modification	N/A

			Mitigation				Evaluation			
No.	ID	Cause / Trigger	Allocated RCS	Applicable clauses	Assessment of suitability	Suitability	Identified gap	Railway application	Result	Priority
205	C11	Unsuitable electrical design	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	yes	No Modification	Low
207	C11	Unsuitable electrical design	EN IEC 62282-2-100	4.2.8, 4.2.9, 4.2.10, 4.2.11, 4.2.12, 5.9, 5.14.4, 6.3	IEC 62282-2-100 defines a comprehensive set of electrical design requirement in clauses 4.2.8 to 4.2.12. The final eletrical design standards to be applied depend on the industrial branch and are left open in clause 4.2.8. The standard also requires a dielectric strength test in clause 5.9 as well as a short circuit test in clause 5.14.4.	Medium	Adopting IEC 62282-2-100 compliant fuel cell modules requires additional electrical design validation tests as defined by EN 50155.	no	Other RCS	N/A
208	C11	Unsuitable electrical design	EN IEC 62282-3-100	4.7, 4.15.4, 5.7, 5.18, 6.3	IEC 62282-3-100 refers to eletrical design standards from the individual industrial branch in clause 4.7. The standard also requires an electrical over load test in clause 5.7 and refers to additional tests for electrical safety and dielectric strength with reference to the applicable standards acc. to clause 4.7.	Low	Adopting IEC 62282-3-100 compliant fuel cell systems requires additional electrical design validation tests as defined by EN 50155.	no	Other RCS	N/A
209	C11	Unsuitable electrical design	EN IEC 62282-4-101	4.14, 5.10, to 5.15, 5.22, 5.23, 6.2	IEC 62282-4-101 defines a comprehensive set of electrical design requirement in clauses 4.14. The standard also requires a number of validation tests in clauses 5.10 to 5.15, such as electrical continouity tests and dielectric strength tests.	Medium	Adopting IEC 62282-4-101 compliant fuel cell systems requires additional electrical design validation tests as defined by EN 50155.	no	Other RCS	N/A
210	C11	Unsuitable electrical design	ISO 12619-series	Part 2 - 13, 20	ISO 12619-2 defines an electrical over voltage test with 2 times the rated voltage in clause 13 and an isolation test at 1000 V DC in clause 20, which apply to automatic valves or sensors.	High	None	no	Other RCS	N/A
211	C11	Unsuitable electrical design	EN IEC 62864-1	6.3, 6.4, 6.6, 8.9, 9.2	IEC 62864-1 provides basic requirements for electrical integration of the energy storage systems (ESS) and primary power sources (PPS), such as bonding, IP protection, short circuit tests as well as the manual or automatic electrical separation.	Medium	None	yes	No Modification	N/A
212	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	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. The standard requires in chapter 5.1 that flammable gas installations shall not be integrated in crash zones. This requirement also applies for hydrogen installations.	High	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.	yes	Modification	High
213	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	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 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.	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.	no	Other RCS	N/A
214	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	EU 406/2010	Annex IV, Part 2, clauses 3 and 4, Part 3, clauses 3 and 4	The general safety target is to achieve 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.	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.	no	Other RCS	N/A
215	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	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.	no	Other RCS	N/A
216	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	EN 61373	all	The shock and vibration test acc. to EN 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/s² for 30 ms (see "C4 Operational shock & vibration").	High	See "C4 Operational shock & vibration"	yes	No Modification	N/A
217	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	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.	yes	Modification	Low
218	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	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 EN 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.	yes	Modification	Medium
219	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	EN 50155	4.3.5 and 13.4.11	EN 50155 requires shock & vibration test acc. to EN 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/s² for 30 ms (see "C4 Operational shock & vibration").	High	See "C4 Operational shock & vibration"	yes	No Modification	N/A
220	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	EU 1302/2014	4.2.2.5. and 4.2.2.7.	TSI LOC&PAS requires all vehicles to fulfill 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 should define requirements for alternative propulsion systems 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.	yes	Modification	Medium
221	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	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 EN 61373 in the corresponding class, they automatically comply with the requirements of EN 12663-1, chapter 6.5.2.	High	None	yes	No Modification	N/A
222	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	EN 12245	5.2.9	EN 12245 defines a mechanical impact and drop test in clause 5.2.9.	Medium	Adopting tanks acc. to EN 12245 may require additional validation of the fixations in assembled condition acc. to EN 12663-1.	no	Other RCS	N/A
223	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	EN 17339	6.2.8	EN 17339 defines a mechanical impact test in clause 6.2.8. A drop test is not required.	Low	Adopting tanks acc. to EN 17339 may require additional validation of the fixations in assembled condition acc. to EN 12663-1.	no	Other RCS	N/A
224	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	ISO 19881	17.3.7, 17.3.10	ISO 19881 defines a drop test and a high strain rate impact test in clauses 17.3.7 and 17.3.10.	Medium	Adopting tanks acc. to ISO 19881 may require additional validation of the fixations in assembled condition acc. to EN 12663-1.	no	Other RCS	N/A
225	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	ISO 19882	7.9, Annex B.8	ISO 19882 requires a drop and vibration test for TPRDs in clause 7.9 which is conducted for 30 min in each axes with an acceleration of 1,5 g. Additional information can be found in Annex B.8.	Medium	Adopting tanks acc. to ISO 19882 may require additional validation of the fixations in assembled condition acc. to EN 12663-1.	no	Other RCS	N/A
226	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	EN IEC 62282-2-100	4.2.13, 5.2	IEC 62282-2-100 generally requires to design and test fuel cell modules for shock & vibration acc. to customer specification. A dedicated crash test is not required.	Low	Adopting fuel cell modules acc. to IEC 62282-2-100 may require additional validation of housing and fixations in assembled condition acc. to EN 12663-1.	no	Other RCS	N/A
227	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	EN IEC 62282-3-100	4.2.3, 4.2.6	IEC 62282-3-100 refers to stationary fuel cell systems, hence crash impacts are normally not considered.	Low	Adopting fuel cell modules acc. to IEC 62282-3-100 may require additional validation of housing and fixations in assembled condition acc. to EN 12663-1.	no	Other RCS	N/A
228	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	EN IEC 62282-4-101	5.2, 5.3	IEC 62282-4-101 generally requires to design and test fuel cell modules for shock & vibration acc. to customer specification in longitudinal and lateral axis. Clause 5.2 provides several generic requirements for the test condition and the required result after the test. A dedicated crash test is not required.	Medium	Adopting fuel cell modules acc. to IEC 62282-4-101 may require additional validation of housing and fixations in assembled condition acc. to EN 12663-1.	no	Other RCS	N/A
229	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	ISO 12619-series	Part 2 - 15	ISO 12619-2 requires a shock & vibration test for fluidic components in chapter 15 which is conducted for 30 min in each axes with an acceleration of 1,5 g.	Medium	Adopting components acc. to ISO 12619-series may require additional validation of the fixations in assembled condition acc. to EN 12663-1.	no	Other RCS	N/A
230	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	EN IEC 62864-1	6.1, 6.6.3	IEC 62864-1 does not specify any mechanical crash loads or integration requirements to protect components of the energy storage systems (ESS) and primary power sources (PPS) from crash related deformation.	None	IEC 62864-1 does not adequately adress the mechanical integration of energy storage systems (ESS) and primary power sources (PPS). The integration of ESS and PPS requires vaidation of its housing and the car body connection acc. to the loads defined by EN 12663-1.	yes	Modification	Medium
	C12	Crash / derailment / mechanical impact (caused by vehicle movement)	ISO 19880-1	5.4, Annex G	Input from CNH2: ISO 19880-1 should provide a more up-to-date guide than developed in ISO TS 20100 (repealed in favor 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.	Medium	Input from CNH2: One of the future objectives of ISO 19880-1 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 (e.g., by determination of protection from impact: Guard posts or other approved means, bumpers, buffers, protection structure, etc.) and the safety distances could be recalculated using a quantitative analysis.	no	Other RCS	N/A
231	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.	no	Other RCS	N/A
232	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.	no	Other RCS	N/A
233	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.	no	Other RCS	N/A
234	C13	External short circuit / arcing	1999/92/EC	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	no	Other RCS	N/A
235	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 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	no	Other RCS	N/A
236	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	no	Other RCS	N/A

			Mitigation				Evaluation			
No.	**ID**	**Cause / Trigger**	**Allocated RCS**	**Applicable clauses**	**Assessment of suitability**	**Suitability**	**Identified gap**	**Railway application**	**Result**	**Priority**
237	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	yes	No Modification	N/A
238	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	yes	No Modification	N/A
239	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 seprately assessed under "C1 Fire or Ignition Sources (internal, external)".	Medium	None	yes	No Modification	N/A
240	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 should define requirements for alternative propulsion systems 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.	yes	Modification	Medium
241	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	yes	No Modification	N/A
242	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	yes	No Modification	N/A
243	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	yes	No Modification	N/A
244	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	yes	No Modification	N/A
245	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	yes	No Modification	N/A
246	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	yes	No Modification	N/A
247	C13	External short circuit / arcing	EN IEC 62282-2-100	4.2.11, 4.2.12, 5.9, 5.14.4, 6.3	IEC 62282-2-100 defines a comprehensive set of electrical design requirement in clauses 4.2.8 to 4.2.12. The final eletrical design standards to be applied depend on the industrial branch and are left open in clause 4.2.8. The standard also requires a dielectric strength in clause 4.2.11 with test defined in clause 5.9. Protective bonding is required in clause 4.2.12 with reference to applicable standard acc. to clause 4.2.8. A short circuit test is required in clause 5.14.4, which shall demonstrate the effectiveness of protective measures (e.g. fuses).	Medium	Adopting IEC 62282-2-100 compliant fuel cell modules requires additional electrical design validation tests as defined by EN 50155 and external short circuit tests as required by IEC 62864-1.	no	Other RCS	N/A
248	C13	External short circuit / arcing	EN IEC 62282-3-100	4.7, 6.3	IEC 62282-3-100 refers to eletrical design standards from the individual industrial branch in clause 4.7. The standard refers to additional tests for electrical safety and dielectric strength with reference to the applicable standards acc. to clause 4.7. However, there is no dedicated short circuit test defined.	Low	Adopting IEC 62282-3-100 compliant fuel cell modules requires additional electrical design validation tests as defined by EN 50155 and external short circuit tests as required by IEC 62864-1.	no	Other RCS	N/A
249	C13	External short circuit / arcing	EN IEC 62282-4-101	4.14.11, 5.12, 5.13, 5.14, 6.2	IEC 62282-4-101 defines a comprehensive set of electrical design requirement in clauses 4.14. The standard also requires a number of validation tests in clauses 5.10 to 5.15. The required tests in causes 5.13 and 5.14 on the electrical circuit and output power also consider the short circuit scenario.	Low	Adopting IEC 62282-4-101 compliant fuel cell modules requires additional electrical design validation tests as defined by EN 50155 and external short circuit tests as required by IEC 62864-1.	no	Other RCS	N/A
250	C13	External short circuit / arcing	ISO 12619-series	Part 2 - 13, 20	ISO 12619-2 defines an electrical over voltage test with 2 times the rated voltage in clause 13 and an isolation test at 1000 V DC in clause 20, which apply to automatic valves or sensors. Short circuit tests for small electrical low voltage consumers or sensors are generally not required and must be avoided by the electrical supply.	Medium	None	no	Other RCS	N/A
251	C13	External short circuit / arcing	EN IEC 62864-1	6.6.1, 6.6.4, 8.9	IEC 62864-1 provides basic requirements for electrical integration of the energy storage systems (ESS) and primary power sources (PPS), such as bonding, short circuit tests as well as the manual or automatic electrical separation.	Medium	None	yes	No Modification	N/A
252	C14	Excessive charging / discharging voltages / currents	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	yes	No Modification	N/A
253	C14	Excessive charging / discharging voltages / currents	EU 1299/2014	---	TSI INF does not define any requirements on the function of the hydrogen filling station in the railway infrastructure.	None	TSI INF should define requirements for hydrogen filling stations, such as the filling station side protection functions and protocols to ensure a safe implementation of the vehicle into the rail system.	yes	Modification	High
254	C14	Excessive charging / discharging voltages / currents	EU 1301/2014	---	TSI ENE does not define any requirements on charging of onboard energy storage systems (ESS) via catenary islands or electrants in the railway infrastructure.	None	TSI ENE should define requirements for catenary islands or electrants and the interface to the railway vehicle with an onboard energy storage system (ESS) to ensure a safe implementation of the vehicle into the rail system.	yes	Modification	High
255	C14	Excessive charging / discharging voltages / currents	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.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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.	yes	Modification	Medium
256	C14	Excessive charging / discharging voltages / currents	EN IEC 62864-1	8.3, 8.10	IEC 62864-1 does not specify any protective measures between energy storage systems (ESS) and primary power sources (PPS) and propulsion or auxiliary inverters to limit charging or discharging voltages or currents applied on the ESS.	None	IEC 62864-1 does not comprehensively adress safety aspects in the electrical integration of ESS, PSS and traction or auxiliary inverters. The voltage and current limitations are a basic electrical interface to be aligned between manufacturer and integrator and must be ensured with adequate safety integrity, based on the overall risk analysis.	yes	Modification	Medium
257	C15	Clogging or unsuitable design of natural / forced ventilation	1999/92/EC	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	no	Other RCS	N/A
258	C15	Clogging or unsuitable design of natural / forced ventilation	EN 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	no	Other RCS	N/A
259	C15	Clogging or unsuitable design of natural / 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	no	Other RCS	N/A
260	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.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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.	yes	Modification	Medium
261	C15	Clogging or unsuitable design of natural / forced ventilation	EU 406/2010	Annex IV, Part 1, 2.5	EU 406/2010 generally requires that the hydrogen storage system assembly for road vehicles shall not be installed in enclosed or poor ventilated enclosures. It does not specify any requirement for the effectiveness of the passive or active ventilation system.	Medium	None	no	Other RCS	N/A
262	C15	Clogging or unsuitable design of natural / forced ventilation	EN IEC 62282-2-100	4.2.5.1, 5.13	IEC 62282-2-100 generally requires to prevent formation of explosive atmospheres inside the fuel cell module in clause 4.2.5.1. It provides a test methode to validate the effectiveness of the ventilation system to stay below 25% LEL in clause 5.13. However, it only implicitly requires to foresee measures to detect insufficient ventilation, e.g. by gas detectors.	Medium	Adopting IEC 62282-2-100 compliant fuel cells requires a risk analysis to determine potential failure modes that may lead to improper ventilation or critical hydrogen concentrations inside and outside of the fuel cell housing. Active protection measures (e.g., detection and control functions) need to undergo functional safety analysis based on the allocated safety requirement.	no	Other RCS	N/A
263	C15	Clogging or unsuitable design of natural / forced ventilation	EN IEC 62282-3-100	4.6, 4.13.4, 5.15.2.3	IEC 62282-3-100 requires explosion protection measures and an analysis acc. to IEC 60079-10-1 in clause 4.6. It requires ventilation openings to be designed in such a way that they cannot be blocked from environmental conditions in clause 4.13.4. It also defines a type test to demonstrate the system reaction under reduced or blocked fresh air supply.	Medium	Active protection measures (e.g., detection and control functions) need to undergo functional safety analysis based on the allocated safety requirement, when adopting IEC 62282-3-100 fuel cell systems.	no	Other RCS	N/A
264	C15	Clogging or unsuitable design of natural / forced ventilation	EN IEC 62282-4-101	4.10, 8.2	IEC 62282-3-100 requires explosion protection measures and an analysis acc. to IEC 60079-10-1 in clause 4.10. It also addresses maintenance of ventilation openings in clause 8.2.	Medium	Active protection measures (e.g., detection and control functions) need to undergo functional safety analysis based on the allocated safety requirement, when adopting IEC 62282-4-101 fuel cell systems.	no	Other RCS	N/A
265	C16	Over filling (CGH2) / charging (Batteries)	EC 79/2009	Annex IV to VI	EC 79/2009 applies for hydrogen road vehicles only. 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 cyclying and leakage tests, which prove the tanks integrity also under extreme conditions. The detailed requirements are described in EU 406/2010.	High	None	no	Other RCS	N/A
266	C16	Over filling (CGH2) / charging (Batteries)	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. 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 provide an adequate safety margin to the hazards caused by single accidential over filling scenarios up to 1.5 times NWP. The vehicle and or the filling station must protect the tanks from being over filled.	High	None	no	Other RCS	N/A
267	C16	Over filling (CGH2) / charging (Batteries)	UN ECE R 134	Clauses 5 to 7 and Annex 3 to 4	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. 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	no	Other RCS	N/A

			Mitigation				Evaluation			
No.	ID	Cause / Trigger	Allocated RCS	Applicable clauses	Assessment of suitability	Suitability	Identified gap	Railway application	Result	Priority
268	C16	Over filling (CGH2) / charging (Batteries)	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, 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 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 fulfill railway standards.	no	Other RCS	N/A
269	C16	Over filling (CGH2) / charging (Batteries)	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 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 prescriptive. 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 fulfill railway standards.	no	Other RCS	N/A
270	C16	Over filling (CGH2) / charging (Batteries)	SAE J2601	all	SAE J2601 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 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 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. Input from CNH2: The standard contains important limitations which require adaption 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.	no	Other RCS	N/A
271	C16	Over filling (CGH2) / charging (Batteries)	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 could 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.	no	Other RCS	N/A
272	C16	Over filling (CGH2) / charging (Batteries)	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. The IR-Emitter is not mechanically compatible with state of the art very high flow receptacles with a 12 to 14 mm bore.	no	Other RCS	N/A
273	C16	Over filling / charging	EU 1299/2014	---	TSI INF does not define any requirements on the function of the hydrogen filling station in the railway infrastructure.	None	TSI INF should define requirements for hydrogen filling stations, such as the filling station side protection functions and protocols to ensure a safe implementation of the vehicle into the rail system.	yes	Modification	High
274	C16	Over filling / charging	EU 1301/2014	---	TSI ENE does not define any requirements on charging of onboard energy storage systems (ESS) via catenary islands or electrants in the railway infrastructure.	None	TSI ENE should define requirements for catenary islands or electrants and the interface to the railway vehicle with an onboard energy storage system (ESS) to ensure a safe implementation of the vehicle into the rail system.	yes	Modification	High
275	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.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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.	yes	Modification	High
276	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	yes	No Modification	N/A
277	C16	Over filling / charging	EN IEC 62864-1	---	IEC 62864-1 does not specify any requirements on the vehicle interface to catenary islands or electrants in the railway infrastructure.	None	IEC 62864-1 does not adress or make reference to the electrical interface between the infrastructure and the onboard energy storage system (ESS). At least the vehicle side electrical compatibility and protection measures should be defined.	yes	Modification	Medium
278	C16	Over filling (CGH2) / charging (Batteries)	EN 12245	5.2.4, 5.2.5	The scope of EN 12245 has its focus on composite tanks for any compressed, liquified or dissolved gases in transportation of dangerous goods. It does not include the tank valve and was not made for fixed installations in propulsion systems, but the tanks are not excluded for such use. The standard does not define the test pressure, which is left open to the manufacturer and the individual use case. The minimum burst pressure is twice the test pressure, which is to be defined by the manufacturer.	Medium	Adopting EN 12245 requires an assessment of the interface with the refuelling station and the safety margins (pressure and temperature) and protection measures with regards to over filling.	no	Other RCS	N/A
279	C16	Over filling (CGH2) / charging (Batteries)	EN 17339	4, 6.2.4, 6.2.5	The scope of EN 17339 has its focus on composite tanks for CGH2 in transportation of dangerous goods. It does not include the tank valve and was not made for fixed installations in propulsion systems, but the tanks are not excluded for such use. The minimum burst pressure is twice the test pressure, which is 1,5 times the nominal working pressure, which is in line with the requirement from automotive application.	Medium	Adopting EN 17339 requires an assessment of the interface with the refuelling station and the safety margins (temperature) and protection measures with regards to over filling.	no	Other RCS	N/A
280	C16	Over filling (CGH2) / charging (Batteries)	ISO 19881	10.2, 11.4, 11.5, 17.5.2, 17.5.3, 17.5.4	ISO 19881 defines requirements of CHSS primarily for road vehicle application. It does not include the tank valve. The standard defines the maximum fueling pressure as 125% of the nominal working pressure. In order to cope failures of the fueling station, the tanks shall sustain several overfilling incidents of up to 150% of the nominal working pressure. The minimum burst pressure is 2,25 time the nominal working pressure.	High	None	no	Other RCS	N/A
281	C17	Filling / draining with 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, 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 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 fulfill railway standards.	no	Other RCS	N/A
282	C17	Filling / draining with excessive mass flow	EN 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 or SAE J2601-2. 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 or SAE J2601-2		Other RCS	
283	C17	Filling / draining with 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 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 prescriptive. 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 fulfill railway standards.	no	Other RCS	N/A
284	C17	Filling / draining with excessive mass flow	SAE J2601	all	SAE J2601 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 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 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. Input from CNH2: The standard contains important limitations which require adaption 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.	no	Other RCS	N/A
285	C17	Filling / draining with 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 could 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.	no	Other RCS	N/A
286	C17	Filling / draining with 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. The IR-Emitter is not mechanically compatible with state of the art very high flow receptacles with a 12 to 14 mm bore.	no	Other RCS	N/A
287	C17	Excessive mass flow	EU 1299/2014	---	TSI INF does not define any requirements on the function of the hydrogen filling station in the railway infrastructure.	None	TSI INF should define requirements for hydrogen filling stations, such as the filling station side protection functions and protocols to ensure a safe implementation of the vehicle into the rail system.	yes	Modification	High
288	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.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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.	yes	Modification	High
289	C18	Deep discharge / low residual pressure	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.	no	Other RCS	N/A
290	C18	Deep discharge / low residual pressure	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.	no	Other RCS	N/A
291	C18	Deep discharge / low residual pressure	SAE J2601	6.4.1 and 8.3.1	SAE J2601 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 (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 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.	no	Other RCS	N/A
292	C18	Deep discharge / low residual pressure	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.	no	Other RCS	N/A
293	C18	Deep discharge / low residual pressure	EU 1299/2014	---	TSI INF does not define any requirements on the function of the hydrogen filling station in the railway infrastructure.	None	TSI INF should define requirements for hydrogen filling stations, such as the filling station side protection functions and protocols to ensure a safe implementation of the vehicle into the rail system.	yes	Modification	High

			Mitigation				Evaluation			
No.	ID	Cause / Trigger	Allocated RCS	Applicable clauses	Assessment of suitability	Suitability	Identified gap	Railway application	Result	Priority
294	C18	Deep discharge / low residual pressure	EU 1302/2014	---	TSI LOC&PAS does not specify any requirements for hydrogen storage systems or traction battery systems to prevent deep discharge.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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.	yes	Modification	High
295	C18	Deep discharge / low residual pressure	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	yes	No Modification	N/A
296	C18	Deep discharge / low residual pressure	EN IEC 62864-1	Annex A.1.4	IEC 62864-1 defines the usable SOC range in clause A.1.4, which need to be aligned between manufacturer and integrator. The standard does not specify protective measures between energy storage systems (ESS) and primary power sources (PPS) and propulsion or auxiliary inverters to stop discharging at a certain SOC.	Low	IEC 62864-1 does not comprehensively address safety aspects in the electrical integration of ESS, PSS and traction or auxiliary inverters. The usable SOC range must be respected by the vehicle with adequate safety integrity, based on the overall risk analysis.	yes	Modification	Medium
297	C18	Deep discharge / low residual pressure	EN 12245	5.2.6, 5.2.11.1	EN 12245 requires cycling tests with a lower pressure limit of 10% of the nominal working pressure or 30 bar at maximum in clause 5.2.6. In addition the standard requires a vacuum load cycle conditioning test in clause 5.2.11, which requires to apply a 0.2 bar (absolute) on the tank for 1 min and apply load cycles afterwards without causing damages on the liner. The test is capable to prove hardware integrity against accidential low residual pressures in operation, however only for a short period of time and without specifying requirements on the rate at which the tank will be filled afterwards.	High	None	no	Other RCS	N/A
298	C18	Deep discharge / low residual pressure	EN 17339	6.2.6, 6.2.10.1	EN 17339 requires cycling tests with a lower pressure limit of 10% of the nominal working pressure or 30 bar at maximum in clause 6.2.6. In addition the standard requires a vacuum load cycle conditioning test in clause 6.2.10, which requires to apply a 0.2 bar (absolute) on the tank for 1 min and apply load cycles afterwards without causing damages on the liner. The test is capable to prove hardware integrity against accidential low residual pressures in operation, however only for a short period of time and without specifying requirements on the rate at which the tank will be filled afterwards.	High	None	no	Other RCS	N/A
299	C18	Deep discharge / low residual pressure	ISO 19881	17.3.2, 17.3.4	ISO 19881 requires ambient and extreme temperature cycling tests with a lower pressure of 2 Mpa (+/- 1 Mpa) of the nominal working pressure in clauses 17.3.2 and 17.3.4. The required test sequences are similar to R 134.	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.	no	Other RCS	N/A
300	C19	Falling Objects	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 suitability has already been assessed for similar causes C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)". EC79 / EU406 do not provide additional mitigation against falling objects.	Medium	see C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)" The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof.	no	Other RCS	N/A
301	C19	Falling Objects	EU 406/2010	Annex IV, Part 2, clauses 3 and 4, Part 3, clauses 3 and 4	The suitability has already been assessed for similar causes C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)". EC79 / EU406 do not provide additional mitigation against falling objects.	Medium	see C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)" The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof.	no	Other RCS	N/A
302	C19	Falling Objects	UN ECE R 134	Part 3, clause 7.2, Annex III, clause 3.2, Annex IV, clause 1.7	The suitability has already been assessed for similar causes C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)". R 134 does not provide additional mitigation against falling objects.	Medium	see C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)" The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof.	no	Other RCS	N/A
303	C19	Falling Objects	ISO 19881	17.3.7, 17.3.10	The suitability has already been assessed for similar causes C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)". ISO 19881 does not provide additional mitigation against falling objects.	Medium	see C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)" The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof.	no	Other RCS	N/A
304	C19	Falling Objects	ISO 19882	7.9, Annex B.8	The suitability has already been assessed for similar causes C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)". ISO 19882 does not provide additional mitigation against falling objects.	Medium	see C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)" The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof.	no	Other RCS	N/A
305	C19	Falling Objects	EN 12245	5.2.9	The suitability has already been assessed for similar causes C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)". EN 12245 does not provide additional mitigation against falling objects.	Medium	see C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)" The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof.	no	Other RCS	N/A
306	C19	Falling Objects	EN 17339	6.2.8	The suitability has already been assessed for similar causes C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)". EN 17339 does not provide additional mitigation against falling objects.	Low	see C4 "Operational shock & vibration", C10, "Unsuitable mechanical design" as well as C12 "Crash / derailment / mechanical impact (caused by vehicle movement)" The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof.	no	Other RCS	N/A
307	C19	Falling Objects	EU 1299/2014	---	TSI INF does not specify any requirements for clearing tracks from vegetation, growth and tree branches, which may cause collisions, especially under bad weather conditions.	None	TSI INF should define requirements for clearing track side vegetation to reduce the probability of collisions with objects.	yes	Modification	Medium
308	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.	None	TSI LOC&PAS should define requirements for alternative propulsion systems e.g., by adding generic requirements for falling objects on sensitive components.	yes	Modification	High
309	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.	yes	Modification	Medium
310	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	yes	No Modification	N/A
311	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	yes	No Modification	N/A
312	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.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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.	yes	Modification	Medium
313	C20	Vandalism / Terrorism	EN IEC 62443-series	all	IEC 62442-series defines requirements for cyber security, which may also be applied on train control and management systems as well as on hydrogen filling station control and communication systems. The safety related software functions must be protected from critical manipulation.	High	None	no	Other RCS	N/A
314	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	no	Other RCS	N/A
315	C21	Residual voltage	1999/92/EC	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	no	Other RCS	N/A
316	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	no	Other RCS	N/A
317	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	yes	No Modification	N/A
318	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	yes	No Modification	N/A
319	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 should define requirements for alternative propulsion systems 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.	yes	Modification	Medium
320	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	yes	No Modification	N/A
321	C22	Wear / improper maintenance	1999/92/EC	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	no	Other RCS	N/A
322	C22	Wear / 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.	None	TSI LOC&PAS should define requirements for alternative propulsion systems 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.	yes	Modification	Medium

IV List of Railway RCS without need for modification

No.	RCS	Title	Suitable to prevent / mitigate	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 Unsuitable mechanical design C12 Crash / derailment / mechanical impact	High High High
2	EN 15085-series	Railway applications - Welding of railway vehicles and components - series	C10 Unsuitable mechanical design	High
3	EN 16404	Railway applications - Re-railing and recovery requirements for railway vehicles	C10 Unsuitable mechanical design	High
4	EN 45545-4	Railway applications - Fire protection on railway vehicles - Part 4: Fire safety requirements for rolling stock design;	C1 External fire / internal ignition source	Medium
5	EN 50121-3-1	Railway applications - Electromagnetic compatibility - Part 3-1: Rolling stock - Train and complete vehicle	C5 Electromagnetic emission / interference C11 Unsuitable electrical design	High High
6	EN 50121-3-2	Railway applications - Electromagnetic compatibility - Part 3-2: Rolling stock - Apparatus (analogue to IEC 62236-3-2)	C5 Electromagnetic emission / interference C11 Unsuitable electrical design	High
7	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
8	EN 50124-1	Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment	C11 Unsuitable electrical design C13 External short circuit / arcing	High High
9	EN 50124-2	Railway applications - Insulation coordination – Part 2: Overvoltages and related protection	C13 External short circuit / arcing	High
10	EN 50125-1	Railway applications - Environmental conditions for equipment - Part 1: Rolling stock and on-board equipment	C1 External fire / internal ignition source C2 Thermal impact / over temperature C3 Cold impact / under temperature C8 Corrosion C11 Unsuitable electrical design C13 External short circuit / arcing	High High High High High High
11	EN 50126-2	Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 2: Systems Approach to Safety	C24 Unsuitable functional hardware integrity	High
12	EN 50128	Railway applications - Communication, signalling and processing systems - Software for railway control and protection systems	C25 Unsuitable functional software integrity	High
13	EN 50129	Railway applications - Communication, signalling and processing systems - Safety related electronic systems for signalling	C24 Unsuitable functional hardware integrity	High
14	EN 50153	Railway applications - Rolling stock - Protective provisions relating to electrical hazards	C11 Unsuitable electrical design C13 External short circuit / arcing C21 Residual voltage	High High High
15	EN 50343	Railway applications - Rolling stock - Rules for installation of cabling	C11 Unsuitable electrical design C13 External short circuit / arcing	High High
16	EN 50657	Railways Applications - Rolling stock applications - Software on Board Rolling Stock	C25 Unsuitable functional software integrity	High

V List of Railway Application RCS with need for modification

No.	RCS	Title	Causes where gaps have been identified	Identified gaps / deficits	Priority
1	EN 15227	Railway applications - Crashworthiness requirements for rail vehicles	C12 Crash / derailment / impact	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 External fire / internal ignition src.	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 External fire / internal ignition src.	No specific requirement set for typical combustible materials of an alternative propulsion system, such as CFRP 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 External fire / internal ignition src.	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 External fire / internal ignition src.	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 fulfill 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 External fire / internal ignition src.	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 External fire / internal ignition src. C12 Crash / derailment / impact	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	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	C26 Manufacturing / quality defect	EN 50215 addresses 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 External fire / internal ignition src.	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	EN 61373	Railway applications - Rolling stock equipment - Shock and vibration tests	C1 External fire / internal ignition src. C4 Operational shock & vibration C10 Unsuitable mechanical design	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 EN 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 EN 61373. The future standards for hydrogen application in railway, such as IEC 63341-1 and IEC 63341-2, shall adopt EN 61373 and EN 50155 and define additional requirements.	High

No.	RCS	Title	Causes where gaps have been identified	Identified gaps / deficits	Priority
12	EN IEC 62864-1	Railway applications - Rolling stock - Power supply with onboard energy storage system - Part 1: Series hybrid system	C10 Unsuitable mechanical design C11 Unsuitable electrical design C12 Crash / derailment / impact C14 Excessive charging / discharging C16 Over filling / charging C18 Deep discharge / low pressure C22 Wear / improper maintenance C26 Manufacturing / quality defect	IEC 62864-1 does not adequately address the mechanical integration of energy storage systems (ESS) and primary power sources (PPS). The integration of ESS and PPS requires vaidation of its housing and the car body connection acc. to the loads defined by EN 12663-1. IEC 62864-1 does not comprehensively address safety aspects in the electrical integration of ESS, PSS and traction or auxiliary inverters. The voltage and current limitations are a basic electrical interface to be aligned between manufacturer and integrator and must be ensured with adequate safety integrity, based on the overall risk analysis. In addition, the usable SOC range must be respected by the vehicle with adequate safety integrity, based on the overall risk analysis. IEC 62864-1 does not address or make reference to the electrical interface between the infrastructure and the onboard energy storage system (ESS). At least the vehicle side electrical compatibility and protection measures should be defined. IEC 62864-1 should address the need for inspection and maintenance documentation by the manufacturer and the integrator. IEC 62864-1 should require additional safety related routine tests with regards to the functional interfaces between vehicle and energy storage system (ESS) / primary power source (PPS).	Medium
13	EN IEC 62928	Railway applications - Rolling stock - Onboard lithium-ion traction batteries	C1 External fire / internal ignition src. C2 Thermal impact / over temperature C4 Operational shock & vibration C9 Human error C12 Crash / derailment / impact C19 Falling objects	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 the referenced standards EN 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
14	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	C6 Hydrogen purity / particle ingress C14 Excessive charging / discharging C16 Over filling / charging C17 Excessive mass flow C18 Deep discharge / low pressure C19 Falling Objects	TSI INF should define requirements for hydrogen filling stations, such as the required purity of supplied hydrogen and filling station side protection functions and protocols to ensure a safe implementation of the vehicle into the rail system. TSI INF should also define requirements for clearing track side vegetation to reduce the probability of collisions with objects.	High
15	EU 1302/2014	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	C14 Excessive charging / discharging C16 Over filling / charging	TSI ENE should define requirements for catenary islands or electrants and the interface to the railway vehicle with an onboard energy storage system (ESS) to ensure a safe implementation of the vehicle into the rail system.	High
16	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 External fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C5 Electromagnetic emission / interf. C6 Hydrogen purity / particle ingress C7 Hydrogen incompatibility C8 Corrosion C9 Human error C10 Unsuitable mechanical design C11 Unsuitable electrical design C12 Crash / derailment / impact C13 External short circuit / arcing C14 Excessive charging / discharging C15 Clogging / unsuitable ventilation C20 Vandalism / Terrorism C21 Residual voltage C22 Wear / improper maintenance C26 Manufacturing / quality defect	TSI LOC&PAS should define generic requirements for alternative propulsion with traction batteries and/or hydrogen systems 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.	High

VI List of applicable RCS from other industries

No.	RCS	Title	Suitable to prevent / mitigate	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 C10 Unsuitable mechanical design C13 External short circuit / arcing C15 Clogging / aerodynamic effects C21 Residual voltage C22 Wear / improper maintenance	Low Medium Low Low Low 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 External fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock / vibration C5 Electromagnetic emission / interf. C7 Hydrogen incompatibility C8 Corrosion C9 Human error C10 Unsuitable mechanical design C11 Unsuitable electrical design C21 Residual voltage	Low Low Low Low Low Low Low Low Low Low 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 Electromagnetic emission / interf.	Medium	2014/30/EU specifically describes principal requirements for electrical devices with regards to Electromagnetic 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 fulfilment 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 C10 Unsuitable mechanical design C11 Unsuitable electrical design C13 External short circuit / arcing	Low Medium Medium Low	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 fulfill 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 Unsuitable mechanical design C26 Manufacturing / quality defect	High 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. CE-certification is done by a notified body on single component or assembly level per individual acceptance based on documented routine tests. The certification scheme requires a continuous production monitoring. Besides many generic safety 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. 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 for 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 External Fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C7 Hydrogen incompatibility C8 Corrosion C10 Unsuitable mechanical design C11 Unsuitable electrical design C12 Crash / derailment / impact C13 External short circuit / arcing C16 Over filling / charging C19 Falling Objects C23 Excessive number of cycles C26 Manufacturing / quality defect	High High High Low High High High Low Medium Low High Medium High High	EC 79/2009 and its implementation directive EU 406/2010 for hydrogen road vehicles were withdrawn and are replaced by UN ECE R134. Tightness of tanks and components and their media compatibility under the defined operating conditions is sufficiently proven by EC 79 type approval. More details see implementation directive EU 406/2010.
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 External Fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C7 Hydrogen incompatibility C8 Corrosion C10 Unsuitable mechanical design C11 Unsuitable electrical design C12 Crash / derailment / impact C13 External short circuit / arcing C15 Clogging / aerodynamic effects C16 Over filling / charging C18 Deep discharge / low pressure C19 Falling Objects C23 Excessive number of cycles C26 Manufacturing / quality defect	High High High Low High High High Low Medium Low Medium High Low Medium High High	EC 79/2009 and its implementation directive EU 406/2010 for hydrogen road vehicles were withdrawn and are replaced by UN ECE R134. Tightness of tanks and components and their media compatibility under the defined 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 in combination with adequate tightness tests, - 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, as well as - environmental and electrical requirements acc. to EN 50155. 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 integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. 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. The filling protocol requires adequate margin for excessive gas temperatures >85 °C from fast filling with regards to plastic liners. 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.

No.	RCS	Title	Suitable to prevent / mitigate	Suitability for mitigation	Remarks
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 a gap after withdrawal of EC79, since R134 does not specify requirements for hydrogen compatibility.
9	EN 894-1	Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 1: General principles for human interactions with displays and control actuators	C9 Human error C22 Wear / improper maintenance	High High	EN 894-1 provides general principles for human interactions with displays and control actuators, which may reduce human failures by ensuring cognitive ergonomics for staff in all operation, inspection and maintenance activities.
10	EN 1127-1	Explosive atmospheres - Explosive prevention and protection - Part 1: Basic concepts and methodology	C10 Unsuitable 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 on railway vehicles. Adopting EN 1127-1 principles for railway vehicles requires consideration of railway specific boundary conditions and a solid evidence as well as adequate maintenance plans and instructions.
11	EN 1779	Non-destructive testing - Leak testing - Criteria for the method and technique selection	C9 Human error	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.
12	EN 10216-5	Seamless steel tubes for pressure purposes - Technical delivery conditions - Part 5: Stainless steel tubes	C8 Corrosion C10 Unsuitable mechanical design	High High	EN 10216-5 is a product standard for seamless stainless steel pipes. It provides lists of alloys with reference to their tested resistance to intercrystalline corrosion (tables 6 to 8) with temperature thresholds in tables 9 to 11. The mechanical properties of the alloys can be found in clause 8.3 and the referenced tables. Additional tests for material strength are defined in chapter 11.
13	EN 12245	Transportable gas cylinders - Fully wrapped composite cylinders	C1 External Fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C7 Hydrogen incompatibility C10 Unsuitable mechanical design C12 Crash / derailment / impact C16 Over filling / charging C18 Deep discharge / low pressure C19 Falling Objects C23 Excessive number of cycles C26 Manufacturing / quality defect	Medium Low High Medium High High Medium Medium High Medium High High	Adopting EN 12245 requires an assessment of the gaps with the boundary conditions from railway application and closing of those with additional tests and design rules from existing (e.g., EN 45545-x) and still to be developed railway standards, such as IEC 63341-2. EN 12245 is open with regards to TPRDs and would generally allow alternative methods. The validation method is similar to tests from automotive regulations. This requires an assessment of the residual risk for railway application under consideration of potential fire scenarios. The maximum temperature of 65 °C defined by EN 12245 is not compatible with the expected gas temperature during (fast) refuelling of fixed installed tanks for propulsion in mobile applications, which is generally defined with 85 °C. The minimum temperature of -40 °C is compatible with the expected gas temperature during defuelling or refuelling with precooled hydrogen in mobile applications. Adopting tanks acc. to EN 12245 may require additional shock & vibration tests in assembled condition acc. to EN 61373 and/or a validation of the fixations in assembled condition acc. to EN 12663-1. The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. It also requires an assessment of the interface with the refuelling station and the safety margins (pressure and temperature) and protection measures with regards to over filling. The standard foresees a vacuum load cycle conditioning test, which demonstrates liner integrity under low pressure condition, which may serve as mitigation for low residual pressures with Type 4 tanks.
14	EN 13480-2	Metallic industrial piping - Part 2: Materials	C7 Hydrogen incompatibility C8 Corrosion	Medium Medium	EN 13480-2 is a product standard for stainless steel pipes, which may be compatible with hydrogen. The standard only implicitly refers to the correct material choice with regards to hydrogen embrittlement and corrosion in clause 4.2.1.1, but does not provide a white list of alloys to use.
15	EN 13480-3	Metallic industrial piping - Part 3: Design and calculation	C10 Unsuitable mechanical design	High	EN 13480-series is a product standard for stainless steel pipes. The requirements for materails of pressure bearing pipes can be found in chapter 4 and further tables and material tests can be found in annexes A and B.
16	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.
17	EN 17127	Outdoor hydrogen refuelling points dispensing gaseous hydrogen and incorporating filling protocols	C16 Over filling / charging C17 Excessive mass flow	Medium Low	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 (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. The refuelling protocols acc. to SAE J2601 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 fulfill railway standards.

No.	RCS	Title	Suitable to prevent / mitigate	Suitability for mitigation	Remarks
18	EN 17339	Transportable gas cylinders - Fully wrapped carbon composite cylinders and tubes for hydrogen	C1 External Fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C7 Hydrogen incompatibility C10 Unsuitable mechanical design C12 Crash / derailment / impact C16 Over filling / charging C18 Deep discharge / low pressure C19 Falling Objects C23 Excessive number of cycles C26 Manufacturing / quality defect	Medium Low High Low High High Low Medium High Low High High	Adopting EN 17339 requires an assessment of the gaps with the boundary conditions from railway application and closing of those with additional tests and design rules from existing (e.g., EN 45545-x) and still to be developed railway standards, such as IEC 63341-2. EN 17339 is open with regards to TPRDs and would generally allow alternative methods. The validation method is similar to tests from automotive regulations. This requires an assessment of the residual risk for railway application under consideration of potential fire scenarios. The maximum temperature of 65 °C defined by EN 17339 is not compatible with the expected gas temperature during (fast) refuelling of fixed installed tanks for propulsion in mobile applications, which is generally defined with 85 °C. The minimum temperature of -40 °C is compatible with the expected gas temperature during defuelling or refuelling with precooled hydrogen in mobile applications. Adopting tanks acc. to EN 17339 may require additional shock & vibration tests in assembled condition acc. to EN 61373 and/or a validation of the fixations in assembled condition acc. to EN 12663-1. The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. It also requires an assessment of the interface with the refuelling station and the safety margins (pressure and temperature) and protection measures with regards to over filling. The standard foresees a vacuum load cycle conditioning test, which demonstrates liner integrity under low pressure condition, which may serve as mitigation for low residual pressures with Type 4 tanks.
19	EN 60529	Degrees of protection provided by enclosures (IP Code)	C8 Corrosion	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.
20	EN 61508-series	Functional safety of electrical/electronic/programmable electronic safety-related systems - series	C24 Unsuitable funct. hardware integrity C25 Unsuitable funct. software integrity	High High	EN 61508-series defines the rules for development and assessment of eletric/electronic/programmable electronic functions (E/E/PE-functions) that are used to implement safety functions with a dedicated safety integrity level (SIL) in any product or system. EN 61508-series is references by EN 50126-2, EN 50128 and EN 50129.
21	EN IEC 60068-2-11	Environmental testing - Part 2: Tests; test Ka: Salt mist	C8 Corrosion	High	EN IEC 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).
22	EN IEC 60079-10-1	Explosive atmospheres - Part 10-1: Classification of areas - Explosive gas atmospheres - Edition 3.0	C10 Unsuitable mechanical design C15 Clogging / aerodynamic effects	High High	EN 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. 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.
23	EN IEC 62282-2-100	Fuel cell technologies - Part 2-100: Fuel cell modules - Safety	C1 External Fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C7 Hydrogen incompatibility C9 Human error C10 Unsuitable mechanical design C11 Unsuitable electrical design C12 Crash / derailment / impact C13 External short circuit / arcing C15 Clogging / unsuitable ventilation C22 Wear / improper maintenance C26 Manufacturing / quality defect	High Low Low Low Low Medium Medium Medium Low Medium Medium Low High	Adopting IEC 62282-2-100 requires an assessment of the gaps with the boundary conditions from railway application and closing these with additional tests and design rules from existing (e.g., EN 45545-x or EN 50155) and still to be developed railway standards, such as IEC 63341-1. This also applies for min./max. ambient temperatures and gas inlet temperatures. It also requires shock & vibration test acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11 for the assembly or functional parts of the fuel cell module - especially the fluidic part. It may also require additional validation of housing and fixations in assembled condition acc. to EN 12663-1. Compliance with IEC 62282-2-100 may require additional evidence for hydrogen compatibility for the fluidic part as those are not required by the standard. Potential failure modes that may lead to improper ventilation or critical hydrogen concentrations inside and outside of the fuel cell housing shall be determined by individual risk analysis. Active protection measures (e.g., detection and control functions) need to undergo functional safety analysis based on the allocated safety requirement. The manufacturer of IEC 62282-2-100 compliant fuel cells must propose adequate preventive maintenance intervals and may also provide instruction for corrective maintenance. The maintenance documentation must contain safety related application conditions and warnings for maintenance staff.
24	EN IEC 62282-3-100	Fuel cell technologies - Part 3-100: Stationary fuel cell power systems - Safety	C1 External Fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C5 Electromagnetic emission / interf. C7 Hydrogen incompatibility C8 Corrosion C9 Human error C10 Unsuitable mechanical design C11 Unsuitable electrical design C12 Crash / derailment / impact C13 External short circuit / arcing C15 Clogging / unsuitable ventilation C22 Wear / improper maintenance C26 Manufacturing / quality defect	High Medium Low Low High Medium Medium Medium Medium Low Low Low Medium Medium High	Adopting IEC 62282-3-100 requires an assessment of the gaps with the boundary conditions from railway application and closing these with additional tests and design rules from existing (e.g., EN 45545-x, EN 50155) and still to be developed railway standards, such as IEC 63341-1. This also applies for min./max. ambient temperatures and gas inlet temperatures. It also requires shock & vibration test acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11 for the assembly or functional parts of the fuel cell system - especially the fluidic part. It may also require additional validation of housing and fixations in assembled condition acc. to EN 12663-1. IEC 62282-3-100 compliant fuel cells may fulfill EMC-requirements of EN 50121-3-2, which must be confirmed by conformity assessmen or additional test. Compliance with IEC 62282-3-100 may require additional evidence for hydrogen compatibility for the fluidic part as those are not required by the standard. Active protection measures (e.g., detection and control functions) need to undergo functional safety analysis based on the allocated safety requirement, when adopting IEC 62282-3-100 fuel cell systems. The manufacturer of IEC 62282-3-100 compliant fuel cells must propose adequate preventive maintenance intervals and may also provide instruction for corrective maintenance. The maintenance documentation must contain safety related application conditions and warnings for maintenance staff.

No.	RCS	Title	Suitable to prevent / mitigate	Suitability for mitigation	Remarks
25	EN IEC 62282-4-101	Fuel cell technologies - Part 4-101: Fuel cell power systems for electrically powered industrial trucks - Safety	C1 External Fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C5 Electromagnetic emission / interf. C6 Hydrogen purity / particle ingress C7 Hydrogen incompatibility C8 Corrosion C9 Human error C10 Unsuitable mechanical design C11 Unsuitable electrical design C12 Crash / derailment / impact C13 External short circuit / arcing C15 Clogging / unsuitable ventilation C22 Wear / improper maintenance C26 Manufacturing / quality defect	High Low Low High Low Medium Medium Medium Medium Medium Medium Medium Low Medium Medium High	Adopting IEC 62282-4-101 requires an assessment of the gaps with the boundary conditions from railway application and closing these with additional tests and design rules from existing (e.g., EN 45545-x, EN 50155) and still to be developed railway standards, such as IEC 63341-1. This also applies for min./max. ambient temperatures and gas inlet temperatures. It also requires shock & vibration test acc. to EN 61373 including function tests acc. to EN 50155, 13.4.11 for the assembly or functional parts of the fuel cell module - especially the fluidic part. It may also require additional validation of housing and fixations in assembled condition acc. to EN 12663-1. Adopting IEC 62282-4-101 compliant fuel cells requires EMC test according to EN 50121-3-2. The standard generally defines the use of filters without defining the required mesh size or purity. This must be defined by the manufacturer. Active protection measures (e.g., detection and control functions) need to undergo functional safety analysis based on the allocated safety requirement, when adopting IEC 62282-4-101 fuel cell systems. The manufacturer of the fuel cell may need to define additional warnings for maintenance staff in maintenance documentation or on the fuel cell itself.
26	EN IEC 62443-series	Security for industrial automation and control systems - series	C20 Vandalism / Terrorism C25 Unsuitable funct. software integrity	High High	IEC 62442-series defines requirements for cyber security, which may also be applied on train control and management systems as well as on hydrogen filling station control and communication systems. The safety related software functions must be protected from critical manipulation.
27	EN ISO 4126-1	Safety devices for protection against excessive pressure - Part 1: Safety valves	C10 Unsuitable mechanical design	High	ISO 4126-1 provides general rules for the mechanical design of safety valves in chapter 5. The standard is harmonized with 2014/68/EU.
28	EN ISO 9223	Corrosion of metals and alloys - Corrosivity of atmospheres - Classification, determination and estimation	C8 Corrosion	High	ISO 9223 defines corrosivtiy categories for metals and atmospheres and makes specifications for material choice.
29	EN ISO 9227	Corrosion tests in artificial atmospheres - Salt spray tests	C8 Corrosion	High	ISO 9227 defines a salt spray test as validation method for corrosion resistance which is referenced by several standards and may be chosen as alternative test method to IEC 60068-2-11.
30	EN 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.
31	EN 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.
32	EN 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.
33	EN 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.
34	EN ISO 11623	Gas cylinders - Composite construction - Periodic inspection and testing	C22 Wear / improper maintenance	High	ISO 11623 provides a comprehensive guideline for periodic inspection, inspection methods and evaluation criteria of composite gas cylinders of all types and up to 3000 l. The application of this standard supports maintenance entities in proper inspection of CHSS and can be an adequate supplement to the maintenance documentation of the manufacturer.
35	EN ISO 13849-2	Safety of machinery - Safety-related parts of control systems - Part 2: Validation	C24 Unsuitable funct. hardware integrity	High	ISO 13849-2 is standard which is harmonized with machinery directive 2006/42/EC and provides a validation method for safety related parts of controls. It may be applied for functions, which have been realized using electric, electronic, electromechanic or mechanic components.
36	EN ISO 17268	Gaseous hydrogen land vehicle refuelling connection devices	C6 Hydrogen purity / particle ingress C7 Hydrogen incompatibility C8 Corrosion C9 Human error C17 Excessive mass flow	High Medium High High 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 or SAE J 2601-2. Application of ISO 17268 does not provide adequate protection from particle ingress, since the filter mesh size is not defined and must be agreed with the refuelling receptacle manufacturer. It may also require additional evidence for hydrogen compatibility of the applied metals, as the standard is not prescriptive in the choice of hydrogen compatible metals.
37	EN ISO 24431	Gas cylinders - Seamless, welded and composite cylinders for compressed and liquefied gases (excluding acetylene) - Inspection at time of filling	C22 Wear / improper maintenance	High	ISO 24431 provides a guideline for inspection, inspection methods and evaluation criteria of composite gas cylinders of all types up to 150 l and for single vessels exceptionally up to 450 l. It refers to ISO 11623 with regards to the inspection of the visual inspection and evaluation of damage patterns. The application of this standard supports maintenance entities in proper inspection of CHSS and can be an adequate supplement to the maintenance documentation of the manufacturer.
38	GB/T 26779	Hydrogen fuel cell electric vehicle refueling receptacle	C7 Hydrogen incompatibility C8 Corrosion	Medium High	GB/T 26779 does not clearly require the materials of the receptacle to be compatible with hydrogen. To demonstrate that non-metallic gaskets and materials are compatible with hydrogen, a dedicated test is defined in clause 6.9. In addition sealing materials shall undergo oxygen ageing and ozone ageing tests acc. to tests as defined in clauses 6.7 and 6.8. Compliance with GB/T 26779 may require additional evidence for hydrogen compatibility of the applied metals.

No.	RCS	Title	Suitable to prevent / mitigate	Suitability for mitigation	Remarks
39	ISO 12619-series	Road vehicles - Compressed gaseous hydrogen (CGH2) and hydrogen/natural gas blend fuel system components - series	C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C6 Hydrogen purity / particle ingress C7 Hydrogen incompatibility C8 Corrosion C10 Unsuitable mechanical design C11 Unsuitable electrical design C12 Crash / derailment / impact C13 External short circuit / arcing C23 Excessive number of cycles	High High High High High High High High Medium Medium High	ISO 12619-series defines a wide range of type test requirements for CGH2-components in mobile applications (except for tanks, TPRDs and receptacles). Part 1 defines the general boundary conditions, such as an operating temperature between +85 °C / +120 °C to -20 °C / -40 °C. Part 2 defines all generic type tests, while parts 3 to 16 address the respective fluidic component. Clause 9.2.3 of part 2 defines an maximum operating temperature cycling test. With regards to the maximum / minimum operating temperatures of +85 °C / +120 °C to -20 °C / -40 °C, the typical maximum operating temperatures for electrical or electro-mechanical railway components acc. to EN 50155 are fulfilled and excessive gas temperatures are covered with an adequate margin. The shock & vibration test defined by ISO 12619-2 provides a basic integrity against operational shock & vibration influences. Adopting ISO 12619-components on railway vehicles may require additional tests acc. to EN 61373, since the accelerations and test durations are lower. It may also require additional validation of the fixations in assembled condition acc. to EN 12663-1. ISO 12619-15 provides a comprehensive set of requirements for safe and reliable design of CGH2 filters. The actual mesh size must be chosen by the system integrator to ensure protection of functional components and fuel cells.
40	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).
41	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.
42	ISO 19880-1	Gaseous hydrogen - Fuelling stations - Part 1: General requirements	C12 Crash / derailment / impact C16 Over filling / charging C17 Excessive mass flow	Medium Medium Low	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 (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. The refuelling protocols acc. to SAE J2601-2, which apply for railway vehicles, are not prescriptive. 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 fulfill railway standards. Input from CNH2: One of the future objectives of ISO 19880-1 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 (e.g., by determination of protection from impact: Guard posts or other approved means, bumpers, buffers, protection structure, etc.) and the safety distances could be recalculated using a quantitative analysis.
43	ISO 19880-5	Gaseous hydrogen - Fuelling stations - Part 5: Dispenser hoses and hose assemblies	C10 Unsuitable mechanical design	Medium	ISO 19880-5 refers to 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. Input from CNH2: - 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.
44	ISO 19880-8	Gaseous hydrogen - Fuelling stations - Part 8: Fuel quality control	C6 Hydrogen purity / particle ingress	Medium	ISO 19880-8 defines methods to control the hydrogen quality which is supplied from hydrogen filling stations. It may be applied by the filling station operator to ensure the required hydrogen quality, which is to be filled in railway vehicles with hydrogen systems.

No.	RCS	Title	Suitable to prevent / mitigate	Suitability for mitigation	Remarks
45	ISO 19881	Gaseous hydrogen - Land vehicle fuel containers	C1 External Fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C7 Hydrogen incompatibility C8 Corrosion C10 Unsuitable mechanical design C12 Crash / derailment / impact C16 Over filling / charging C18 Deep discharge / low pressure C19 Falling Objects C23 Excessive number cycles C26 Manufacturing / quality defect	High High High Medium High High High Medium High Low Medium High High	ISO 19881 was primarily made for CHSS in road vehicle application with strong analogies to R134. Adopting this standard 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 45545-x) and still to be developed railway standards, such as IEC 63341-2. Adopting TPRDs from automotive standards 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. ISO 19881 defines operating temperatures of to 85 °C to -40 °C. However, it requires an adequate margin for excessive gas temperatures >85 °C from false filling operation with regards to plastic liners. ISO 19881 does not define any requirements for liner softening temperatures. The standard defines a margin for colder temperatures up to -50 °C (e.g., caused by rapid defuelling). Adopting tanks acc. to ISO 19881 may require additional shock & vibration tests in assembled condition acc. to EN 61373. It may also require additional validation of the fixations in assembled condition acc. to EN 12663-1. The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. It may require additional evidence for hydrogen compatibility as the standard is not prescriptive in the choice of hydrogen compatible materials. 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.
46	ISO 19882	Gaseous hydrogen - Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers	C1 External Fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C7 Hydrogen incompatibility C8 Corrosion C10 Unsuitable mechanical design C12 Crash / derailment / impact C19 Falling Objects C23 Excessive number of cycles C26 Manufacturing / quality defect	High High High High High High High Medium Medium High High	ISO 19882 was primarily made for TPRDs road vehicle application. Adopting this standard 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 standards 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. The drop and vibration test defined by ISO 19882 provides a basic integrity against operational shock & vibration influences. Adopting TPRDs acc. to ISO 19882 on railway vehicles may require additional tests acc. to EN 61373, since the accelerations and test durations are not the same. It may also require additional validation of the fixations in assembled condition acc. to EN 12663-1. The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. Compliance with ISO 19882 may require additional evidence for hydrogen compatibility as the standard is not prescriptive in the choice of hydrogen compatible materials.
47	ISO 20485	Non-destructive testing - Leak testing - Tracer gas method	C9 Human error	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.
48	ISO/TR 15916	Basic considerations for the safety of hydrogen systems	C1 External Fire / internal ignition src. C2 Thermal impact / over temperature C6 Hydrogen purity / particle ingress C7 Hydrogen incompatibility C8 Corrosion C9 Human error C10 Unsuitable mechanical design C11 Unsuitable electrical design C13 External short circuit / arcing C15 Clogging or unsuitable ventilation C21 Residual voltage	Medium Low High Medium Medium High High Low Low Low Low	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.).
49	ISO/TS 19016	Gas cylinders - Cylinders and tubes of composite construction - Modal acoustic emission (MAE) testing for periodic inspection and testing	C22 Wear / improper maintenance	High	ISO/TS 19016 may propose an innovative method for periodic non-destructive inspection of composite tank condition. It may require further research and development and application experience to confirm the validity of the inspection results.
50	SAE J2579	Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles	C7 Hydrogen incompatibility	High	SAE J2579 provides a white list of hydrogen compatible metals in annex B.
51	SAE J2600	Compressed Hydrogen Surface Vehicle Fueling Connection Devices	C9 Human error	High	SAE J2600 requires proper interchangeability to avoid nozzles dedicated to higher pressure levels being couples with receptacles of lower pressure levels by the mechanical shape.
52	SAE J2601	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 pressure	Low Low Low 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. Input from CNH2: The standard contains important limitations which require adaption 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.
53	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 pressure	Low Low Low 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.

No.	RCS	Title	Suitable to prevent / mitigate	Suitability for mitigation	Remarks
54	SAE J2799	Hydrogen Surface Vehicle to Station Communications Hardware and Software	C16 Over filling / charging C17 Excessive mass flow	Low 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. The IR-Emitter is not mechanically compatible with state of the art very high flow receptacles with a 12 to 14 mm bore.
55	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 Electromagnetic emission / interf.	Medium	The ECE R 10 describes tests in order to prove the electromagnetic compatibility of vehicles and components used in vehicles. It is possible to assess fulfilment 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.
56	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 External Fire / internal ignition src. C2 Thermal impact / over temperature C3 Cold impact / under temperature C4 Operational shock & vibration C8 Corrosion C10 Unsuitable mechanical design C11 Unsuitable electrical design C12 Crash / derailment / impact C13 External short circuit / arcing C16 Over filling / charging C18 Deep discharge / low pressure C19 Falling Objects C23 Excessive number of cycles C26 Manufacturing / quality defect	High High High Medium High High Medium High Medium High Low Medium High High	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. The tests defined by R 134 consider sequences where the test sample must undergo several different stresses to reflect a characteristic conservative load profile in road application. 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, as well as - environmental and electrical requirements acc. to EN 50155. The integrator must foresee adequate protection measures, such as protection covers or frames in case the CHSS is placed on the vehicle roof. 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. The filling protocol requires adequate margin for excessive gas temperatures >85 °C from fast filling with regards to plastic liners. Type 4 tanks are more sensitive to over temperatures (max. 85°C), while both, Type 3 and Type 4 tanks maximum temperatures are limited by the given triggering temperature of the TPRDs.

VII List of Hazards where no applicable RCS exists

No.	Cause	Description of technical issue
1	C1 External fire / internal ignition source	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	C1 External fire / internal ignition source	There is no RCS that describes a suitable alternative validation method for burst protection of CHSS systems installed on railway vehicles under with regards to possible heat and fire impact scenarios and under consideration of the existing barriers from railway design.
3	C2 Thermal impact / over temperature	There is no RCS that defines adequate measures to prevent hydrogen tanks from excessive sun radiation or heat dissipation.
4	C6 Hydrogen purity / particle ingress	There is no RCS that proposes adequate mesh sizes of filters for protection of valves and fuel cells under consideration of mass flow and pressure drop.
5	C9 Human error (manufacturing, operation, maintenance)	There is no RCS that requires leak test after any maintenance activity of the fluidic part and with reference to an adequate leak test method and pass/fail criteria.
6	C10 Unsuitable mechanical design	There is no RCS that requires vent upward facing vent lines (e.g. from TPRDs or PRVs) to be placed in such a way they neither damage an overhead wire above the vehicle nor reach any building or structures in the vicinity of the railway track.
7	C11 Unsuitable electrical design	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.
8	C15 Clogging or unsuitable design of natural / forced 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.
9	C15 Clogging or unsuitable design of natural / forced ventilation	There is no RCS that prevents ingress or clogging of vent lines from TPRDs or pressure relieve valves.
10	C16 Over filling (CGH2) / charging (Batteries)	There is no RCS with applicable filling protocols that adequately prevents heavy-duty tank systems from over filling (cold case --> filling stops too late or gas is colder than expected).
11	C17 Filling / draining with excessive mass flow	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.
12	C17 Filling / draining with excessive mass flow	There is no RCS that adequately prevents fast refuelling of Type 4 tanks from critical temperatures during fast refuelling at ambient gas temperatures of heavy-duty tanks as the temperature development is more critical at lower starting pressures.
13	C17 Filling / draining with excessive mass flow	There is no RCS that adequately warns the user from deep discharge and at the same time critical low temperatures during flushing procedures (risk of liner damage).
14	C17 Filling / draining with excessive mass flow	There is no RCS that requires hydrogen filling station for railway vehicles to provide non-discriminatory access for any railway vehicles.
15	C18 Deep discharge	There is no RCS that adequately prevents fast refuelling of Type 4 tanks with an SOC of less than 10 to 20 bar. This may lead to liner damage and consequently leakage if not detected.
16	C19 Falling Objects	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).
17	C20 Vandalism / Terrorism	There is no RCS that adequately prevents vandalism or terrorism to hydrogen systems. It requires a security assessment due to potential catastrophic consequence.
18	C22 Wear / improper maintenance	There is no RCS that provides adequate guidance to define maintenance intervals of hydrogen tanks and components that are compatible with typical railway maintenance intervals.

ANNEX_B – CNH2 Report FCH2RAIL_CGA

Co-funded by the European Union

Centro Nacional del Hidrógeno

Complementary gaps in analysis framework

Work Package 7

NATIONAL CENTER OF EXPERIMENTATION OF HYDROGEN TECHNOLOGIES AND FUEL CELLS

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GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
Unión Europea Fondo Europeo de Desarrollo Regional "Una manera de hacer Europa"
Castilla-La Mancha

	Edition	Date	Description	Executed	Checked	Approved
	00	30/11/2023	FIRST EDITION ANALYSIS	EJRM	BNC	BNC
PROJECT						
FCH2RAIL. WP 7						
D7.4. 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.

Complementary to the identification of Gaps in the Regulatory Framework, have been integrated new gaps found which are been assessed based on the experience obtained with the demonstrator train on field.

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.

Besides, new legislative gaps or technical issues derived from the experience with the demonstrator train have been found and analyzed for the correct implementation of the HRS in the railway sector.

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)
- F14 Delays to get Installation certification/Start up

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
- C23 Unknowledge

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

No.	RCS	Deliberable	DATE	TITLE	GAPS
1	ISO 19880-1	D7.1	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 favor 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.
		D7.4			As the HRS has been initially configured, in the 350 bar stage, the original refueling nozzle, that is, the TK-17, from the manufacturer WEH, with a supply flow of up to 3.6 Kg/min, counts with a single-channel (supply) configuration in which the venting process as well as the entire supply hose must be carried out from the dispenser itself. Due to the initial flow requirements to be dispensed, a nozzle was chosen, the TK-25, from the same manufacturer, which would allow a greater flow rate, that is, 7.2 Kg/min. The peculiarity of this device is that it is designed to be able to vent the interior volume that comprises its own body from the device itself, using a rotating drive lever, in addition to supplying the target vehicle with hydrogen (bi-channel configuration, supply and venting). Gap. ***Maximum amount of air entering the train storage*** . The standard does not contemplate the maximum percentage of air or maximum amount of air per kilogram of hydrogen dispensed that is admissible for the final use device, that is, the fuel cell. There are two possible cases associated with this gap: 1.) The volume that comprises the supply hose internally can be feeded with hydrogen, after the inerting process, as occurs with the rest of the process lines, positioning the nozzle in its closed position, acting as a shut-off valve, until it reaches a minimum positive pressure, higher than the ambient pressure, which allows no air to enter inside. However, this carries inherent dangers, such as: • At the moment of disconnecting the nozzle from the dispenser until the final coupling with the vehicle receptacle, the operator must carry out the process carrying the hose assembly with pressurized hydrogen. • If the remaining pressure is high enough, coupling with the receptacle may present some difficulty or may not occur at all. Furthermore, the higher the pressure contained in the hose, the more inflexible the assembly becomes, making the coupling operation difficult. 2.) Otherwise, and from a safety point of view, the dispensing process contemplates the coupling of the nozzle to the vehicle receptacle with the hose without hydrogen, but, given the configuration of the HRS, the hose would not be feeded with H2 in at no time before each dispensing, that is, refueling would begin by blowing air into the storage, as much as the remaining interior volume that comprises the vehicle's supply hose assembly, at atmospheric pressure. Gap. ***Maximum allowable pressure loss of the assembly.*** The standard does not establish an internal diameter/maximum length ratio that must be considered to minimize pressure losses in dispensing process, depending on the pressure range upstream to the regulation valve, responsible for regulating the dispensing supply flow. Especially noteworthy is quantifying the influence that the refueling hose has on the pressure losses in the dispensing stage. The pressure loss depends directly on the length of the conduit and inversely with its diameter, in addition to increasing quadratically with the flow. The pressure ramps established in the refueling matrix, from which the supply flow rates are derived, are greater the lower the ambient temperature, that is, at low temperatures the refueling times are shorter because the flow rates handled by the dispenser are larger. There is a possibility that the pressure loss is so high that it causes: • Malfunction of the regulating valve or other control elements. • Flow restriction to be able to efficiently use the hydrogen accumulation capacity of the HRS, especially at low ambient temperatures. • Unforeseen interruptions in the refueling process, especially as the pressure in the train storage tanks increases (Back pressure).
2	ISO 19880-5	D7.1	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 fueling 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	D7.1	2020	**Fueling Protocol for Light Duty Gaseous Hydrogen Surface Vehicles** **SAE J2601 establishes the protocol and process limits for hydrogen fueling 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 fueling 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 fueling 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 fueling with communications, this standard is to be used in conjunction with SAE J2799. An important factor in the performance of hydrogen fueling 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 fueling 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, fueling 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 fueling 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 refueling railway vehicles. The document takes into account safety limits during refueling 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 refueling the gas at temperatures close to ambient temperature. It presents important limitations in the adaptation to the train refueling process due to: - The mass of hydrogen transferred to the on-board storage of the train. - The setpoint temperature established in the refueling process. - Maximum admissible flow during refueling. - Characteristic curves for the refueling process.
		D7.4			***Initial pulse to determine the initial pressure of the storages based on their hydraulic volume.*** Given the size of the storages on which it is dispensed, a recurring error has been verified in the dispenser during the maneuver in which a pulse of hydrogen is launched, of a quantity determined according to this regulation, in order to quantify the initial pressure of the train storages, when these are typically below 1 MPa. This pulse is carried out to overcome the NRV's arranged between storage and dispenser, so that it allows, for a certain time, both devices to communicate, and obtain a pressure value. The problem, predictably, arises due to the hydraulic volume over which it is dispensed, much higher than the maximum contemplated in SAE 2601, in which a pulsed mass of hydrogen is established to obtain the initial pressure value of the storages. ***Interpolation between APPR values belonging to the refueling matrix, when storages are not categorized.*** SAE 2601-1 allows APPR values to be linearly interpolated when the storage categorization is known. This categorization is dependent on the nominal pressure of the storages to be dispensed (H35, H70), as well as the amount of total hydrogen stored by them when SOC = 100%. This can also be translated into the hydraulic capacity that they have. HRS must dispense modules with a capacity of 80 kg for a nominal pressure of 350 bars (H35), so it is not possible to categorize them according to this classification. It is expected that for greater volume to be dispensed, under same refueling conditions, lower HPPR values are used. It is therefore necessary, in order to optimize the refueling maneuver, to be able to interpolate.
4	SAE J2601-2	D7.1	2014	**Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles** **The purpose of this document is to provide performance requirements for hydrogen dispensing systems used for fueling 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 fueling, such as safety limits and performance requirements for gaseous hydrogen fuel dispensers used to fuel hydrogen transit buses. For fueling light-duty vehicles SAE J2601 should be used. SAE J2601-2 is a performance based protocol document that also provides guidance to fueling system builders, manufacturers of gaseous hydrogen powered heavy duty transit buses, and operators of the hydrogen powered vehicle fleet(s). This fueling 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 "Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles" and should be used separately. The fueling limits shown in this document are harmonized with the fueling 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	D7.1	2019	**Hydrogen Surface Vehicle to Station Communications Hardware and Software** **This standard specifies the communications hardware and software requirements for fueling 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	D7.1	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	D7.1	2006	**Gaseous Hydrogen Stations**	This document introduces guidelines to be taken into account related to gaseous hydrogen stations. It contemplates and defines the parts and processes carried out in a hydrogen refueling 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.
4	C23 Unknowledge	F 14 Delays to get Installation certification/Start up	There are specific application regulations to be followed by tertiary companies that act as certifiers in relation to gas installations, pressure equipment and low voltage. The issue lies in the refusal of these companies to draw up these certificates, for not assuming the risks of an installation without a consolidated foundation, either due to the complexity of the facility or lack of knowledge of the technology.

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, however, 4 new gaps, found based on the experience with the train demonstrator on field, has been found within the RCS analyzed.
- 4 technical issues have been found where currently there is no RCS that specifies how to mitigate the effects that may generate a hazard, a new one found based on the experience with the train demonstrator on field.

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_CGA

Co-funded by the European Union

/// STD3005REV01
Identification of Gaps in regulatory framework regarding the pantograph

Task 7.1

Project FCH2RAIL
Stemmann-Technik reference no. 566073

Document type : Analysis
Document no. : STD3005REV00
ECO : ---
Created : NNH
Checked : WGH
Approved : WGH

Date: 15/12/2023 - Edition: A00

BSN-ENG-2021-01

Table of changes						
Edition	**Date**	**Description**	**ECO**	**created**	**checked**	**approved**
00	13/05/2022	First edition	---	WGH	MUN	MUN
A00	15/12/2023	Modified and reworded chapters 1 to 5 Added the following new points: 7.1 FMECA of Pantograph, 7.2 List of Generic Hazards, Faults, and Causes, 7.3 Analysis for Application RCS Suitability and 7.4 List of Input RCS. Modified and updated as per EN 50367:2020+A1:2022 EN 50215 replaced by EN IEC 61133/2021 EU 1302/2014, EU 1301/2014, EU 1304/2014, EU 321/2013, and EU 1299/2014, modified and updated as per EU 1694/2023. EU 1303/2014, modified and updated as per EU 2019/776. Added the following new LGA of RCS: EN50124-1&2; EN12663-1; EN50388, EU1304; EN 45545-1,2,3,4&5. EN 50126-1 replaced by FMECA of pantograph	R	NNH	WGH	WGH

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/// 1. Abbreviations

Abbreviation	Definition
CAF	Construcciones Y Auxiliar De Ferrocarriles
CEN	European committee for standardization
CENELEC	European committee for electrotechnical standardization
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ENE	Energy
ERA	European Railway Agency
FCH2RAIL	European funding project Fuel Cell Hybrid Power Pack for Rail Applications
FCHPP	Fuel Cell Hybrid Power Pack
FMECA	Failure Mode, Effects, and Criticality Analysis
H2	Hydrogen
IRIS	International Railway Industry Standard
INF	Infrastructure
LGA	Legislative Gap Analysis
LOC&PAS	Locomotive and Passenger Rolling stock
NSAs	National Safety Authority
OCL	Overhead contact line
RCS	Regulations, Codes and Standards
STT	Stemmann-Technik (A Wabtec Company)
TSI	Technical Specification for Interoperability
WP	Work package

Table 1 – Abbreviations

/// 2. Introduction

2.1 Purpose

The purpose of this LGA report is to assess the compliance of a pantograph with relevant European standards and regulations within the European funding project FCH2RAIL, where the consortium is developing and testing a new hybrid (H2 and electrically actuated by a pantograph) train prototype. This new power system has been integrated in an existing electrical vehicle, marking a major step towards sustainable and environmentally friendly transportation solutions. The LGA of the pantograph is part of WP7 of this project.

The aim of WP7 is to list the gaps in the existing normative framework for the use of hydrogen technology in different kinds of railway applications across Europe and to transfer it to the relevant authorities (for example working groups for developing standards).

WP7 is divided into three specific tasks:

- Task 7.1: Identification of Gaps in the Regulatory Framework (TSI and EN)
- Task 7.2: Propose Modifications to the Normative Framework
- Task 7.3: Maximize the impact of the proposal by liaising with relevant bodies (ERA, CEN, NSAs, and CENELEC) and their stakeholders.

The pantograph gap analysis aims to identify gaps and mitigation measures between European standards, the TSI framework, and FCH2RAIL requirements, which correspond to task WP 7.1.

2.2 Scope

The scope of the LGA of the pantograph is to assess the existing legislative and regulatory framework for the safe use of hydrogen technology in different kinds of railway applications across Europe, including directives, regulations, standards, and guidelines. This would involve examining documents such as EU regulations, safety standards from organizations like the European Union Agency for Railways (ERA), CEN, and national regulations. It examines the European railway network within the scope of the interoperability directive EU 2016/797 and the underlying regulations for vehicles, operations, and infrastructure, such as the TSI for locomotives and passenger rolling stock (TSI LOCO and PAS), for the energy of the rail system (TSI ENE), EU 1301/2014, etc. and the relevant EN standards.

The LGA pantograph should focus on electric vehicles with integrated FCHPP in railway applications. It is essential to consider the external vehicle interface and the impact of this technology on operations and infrastructure such as tracks, stations, power transmission, refueling points, maintenance intervals, etc.

The LGA shall deliver the following potential results:

- Provide a baseline conformity matrix for the standards that are applicable.
- The analysis will evaluate potential risks associated with the identified gaps and provide recommendations for mitigating these risks.
- To provide a comprehensive assessment of compliance and highlight areas that require attention.
- It provides an outline of a plan for implementing the recommended action and provides regulatory framework updates.

2.3 Planned Issue

The LGA of the pantograph is performed alongside the project in compliance with European norms and regulations. The execution of Pantograph's gap analysis based on railway standards and regulations has been performed by STT's own experience and knowledge concerning the electric vehicle and the integration of hydrogen propulsion systems, as stated in two issues by CAF before it is delivered in its final form. According to CAF, as mentioned in the second issue, the gap analysis has to identify risks and their mitigation following European standards and regulations concerning the electrical vehicle and the integration of hydrogen systems.

The LGA will be performed according to the three distinct issues outlined by CAF:

- First Issue: Defines approach and 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, an update of the System & Train HL, and the Manufacturing Process Review. LGA is 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.

2.4 Support of Other Parties

The assessment of legislative gap analysis was executed under support of the company STT and stakeholders of FCH2RAIL. The quality system of Stemmann-Technik is certified according to IRIS and ISO 9001.

2.5 List of references

The following documents were used as 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

Table 2 – List of references

2.6 Classification RCS-List

The RCS, which have been identified so far as potentially applicable can be found in chapter 7.4 .
Up to the current stage, a total of 18 RCS are listed, which were identified by SST in an internal investigation relating to the pantograph. The list provides the code, the full title and current release date. In the LGA are considered the following types of RCS:

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

The LGA was done in chapter 7.3 and lists of the generic hazards and reason for the mitigation in chapter 7.2.

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 be extended in the planned second and third issues of the LGA.

Table 3 – Regulations, Codes and Standards

Standard	Date	Title
EN 50206-1	2010	Railway applications – Rolling stock – Pantographs: Characteristics and tests – Part 1: Pantographs for main line vehicles.
EN 50367:2020+A1:2022	2022	Railway applications – Fixed installations and rolling stock – Criteria to achieve technical compatibility between pantographs and overhead contact line.
EN 50405	2015	Railway applications – Current collection systems – Pantographs, testing methods for contact strips.
EN IEC 61133	2021	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	2018	Railway applications - Insulation coordination - Part 2 : over voltages and related protection.
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 50388	2012	Railway Applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability.
EU 2023/1694	2023	COMMISSION IMPLEMENTING REGULATION (EU) 2023/1694 of 10 August 2023 amending Regulations (EU) No 321/2013, (EU) No 1299/2014, (EU) No 1300/2014, (EU) No 1301/2014, (EU) No 1302/2014, (EU) No 1304/2014 and Implementing Regulation (EU) 2019/777
EU 1302/2014+EU 2023/1694	2014/2023	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.
EU 1301/2014+ EU 2023/1694	2014/2023	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.
EU 2019/776	2019	COMMISSION IMPLEMENTING REGULATION (EU) 2019/776 of 16 May 2019 amending Commission Regulations (EU) No 321/2013, (EU) No 1299/2014, (EU) No 1301/2014, (EU) No 1302/2014, (EU) No 1303/2014 and (EU) 2016/919 and Commission Implementing Decision 2011/665/EU as regards the alignment with Directive (EU) 2016/797 of the European Parliament and of the Council and the implementation of specific objectives set out in Commission Delegated Decision (EU) 2017/1474
EU 1303/2014+ EU 2019/776	2014/2019	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.
EU 1304/2014+ EU 2023/1694	2014/2023	COMMISSION REGULATION (EU) No 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem ‘rolling stock — noise’ amending Decision 2008/232/EC and repealing Decision 2011/229/EU.
EU 321/2014+ EU 2023/1694	2013/2023	COMMISSION REGULATION (EU) No 321/2013 of 13 March 2013 concerning the technical specification for interoperability relating to the subsystem ‘rolling

		stock — freight wagons' of the rail system in the European Union and repealing Decision 2006/861/EC.
EN 45545-1	**2013**	Railway applications — Fire protection railway vehicles — Part 1: General
EN 45545-2+A1	2023	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+A1	2016	EN 45545-5+A1:2016; 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 levitation vehicles

/// 3. Objective

The objective of the LGA is the identification of existing railway RCS that apply to hybrid vehicles that are electrically actuated by a pantograph and powered by H2 and their integration into the railway environment to analyze the gaps in the current applicable regulatory and voluntary framework (TSI and EN).

The analysis aims to identify and assess the stability of existing standards and regulations in mitigating specific hazards associated with electrically actuated pantographs to ensure compliance and safety with hydrogen propulsion. The specific hazards that the identification of the LGA of the pantograph may focus on are safe handling and storage of hydrogen, electrical safety, compatibility and interoperability, and environmental consideration.

STT has expertise in development, design, manufacturing pantographs and associated equipment for trams up to high-speed railway vehicles. STT executes the LGA of the pantograph with their experience to identify any regulatory or standard gaps and propose modification for compliance to enhance the operation, maintenance, and safety of hybrid trains with the pantograph.

/// 4. Methodology

The methodology for conducting a LGA is based on the following points, as described below:

1. Define the scope and objective of the execution of LGA for pantographs with the integration of hydrogen technology based on European standards and regulations.

2. Identify and review the standards and regulations that are applicable to the Pantograph system, such as the safety provisions and technical specifications outlined in these documents.

3. Determine the generic hazards, failure mood , and causes of the pantographs and associated equipment with hydrogen technology.

4. Analyze identified gaps in the legislative framework:
    a. Assess the potential risks or hazards associated with each identified gap and mitigate them.
    b. Limit adequately the severity or probability of occurrence and assess their suitability.

5. Finalize the report and provide lists of RCS that are suitable to prevent the causes or limit the consequences:
    a. From railway industry, where no modification is required.
    b. From railway industry, where modification is required including a description of the identified gap.

/// 5. Findings

5.1 FMECA

In this chapter, the objective of report is to conduct FMECA of pantograph and associated equipment. The efficient and reliable operation of pantographs is crucial for safe and flawless functioning of the overhead electrified rail. FMECA is systematic assess the criticality of potential failure mode and their causes to help in finding the legislative gap analysis and prioritize necessary actions for ensuring the safe and reliable operation of bi-mode hydrogen-electric train.

Executing FMECA according to EN50126 for pantograph and associated equipment involves a systematic process to identify potential failure modes, assess their effects , and determine their criticality.

EN 50126 is standards that provide guidance for the specification and demonstration of reliability ,availability, maintainability, and safety (RAMS) for that railway application.

The details of the FMECA analysis of the pantograph and associated equipment are provided in chapter 7.1

5.2 Generic Hazards, Faults and Causes

The identified Hazard, Faults and Causes, are listed in the LGA in chapter 7.2. They represent the current project stage and may be amended during the planned following issues of the LGA or an execution of an analysis according EN 50126, EN 60812 or similar.
The assessment of severity and occurrence in the LGA has to be done by CAF in the before mentioned analysis.

/// 6. Conclusion

From the LGA 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.

/// 7. Appendix

7.1 FMECA of Pantograph and Associated Equipment

7.2 List of Generic Hazards, Faults and Causes

7.3 Analysis for suitability of application RCS

7.4 List of input Regulation, Codes and Standards

7.1 FMECA of Pantograph and Associated Equipment

FAILURE INFORMATION						RISK O-occurrence S-Severity			FAILURE DETECTION	ADDITIONAL RISK CONTROL	REMARK
NO	Item Name	Function	Failure Mode	Failure Cause	Failure Effect	O	S	RISK			
1	BASE FRAME	To support, stabilize, and provide a mechanical connection for other pantograph connections.	Weld or joint failure	1. Aging 2. Inadequate material choices 3. Ineffective welding methods	An increase in vibration and possible damage to structural integrity.	E	2	Tolerable	-Visual inspection -Function check	**Existing Design Safeguard-** -Operational use of pantographs in long-distance traffic for more than 10 years (Proven Design) "Type test based on the EN50206-1" -Design of pantograph according to customer specification.	
			Material fatigue or cracking	1. Overloading 2. Inadequate material choices 3. Aging	Possible structural integrity loss and an increase in failure risk	E	3	Negligible			
			Corrosion or rusting	1. Lack of protective coating 2. External influence (ex. moisture)	Reduction in the base frame's lifespan and decreasing structural integrity	E	3	Negligible			
			Misalignment or poor assembly	1. Ineffective manufacturing or poor-quality control	Reduce the efficiency of the current collection system and increase the wear and tear of pantograph components.	E	4	Negligible			
2	AIR RAISING ACTUATOR	To raise or lower the pantograph smoothly and reliably.	Inability to raise the pantograph	1. Insufficient air pressure 2. leakage due to aging or material failure	Disruption of the electric power supply, causing the train to lose power.	E	4	Negligible		**Operational & Maintenance Control -** 1. Visual inspection 2. Function check 3. Overhaul pantograph after 10years	
			Inability to lower the pantograph	1. Jamming due to material failure or aging 2. Lack of lubrication	Pantographs may get damaged or cause damage to power supply infrastructure.	E	2	Tolerable			
			Partial raising or lowering of the pantograph	1. Insufficient air pressure 2. Contamination or blockage in air pressure line	leading to power fluctuations or sparking	D	4	Negligible			
			Inconsistent contact with the power supply	1. Insufficient air pressure 2. leakage due to aging or material failure	Increased wear on the carbon contact strip or possible damage to the overhead contact line due to arcing or strong sparking	D	4	Negligible			
			Loss of contact with the power supply	1. Complete air pressure loss 2. Jamming due to material failure or aging	Complete loss of power supply, the train comes to halt.	E	2	Tolerable			

3	LOWER ARM	To provide stable connection and movement of the pantograph along the OCL and to ensure reliable power transfer.	Deformation or bending of the lower arm	1. Jamming due to material failure or aging 2. Inadequate maintenance 3. Excessive force or overloading	Increased friction and wear, loss of electrical contact, misalignment with other components, or damage to the pantograph.	E	3	Negligible			
			cracks or fractures in the lower arm	1. Material fatigue 2. Excessive force or overloading 3. Manufacturing error	complete failure of the lower arm, potential damage to other components, interruption in the power supply, or loss of electrical contact with the overhead line.	E	2	Tolerable			
			Inability to raise the pantograph	1. Jamming due to material failure or aging	Disruption of the electric power supply, causing the train to lose power.	E	4	Negligible			
			Inability to lower the pantograph	1. Jamming due to material failure or aging	Pantograph may get damaged or cause damage to power supply infrastructure, increase sparking, or cause a short-time interruption of energy supply.	E	2	Tolerable			
			Corrosion / Excessive wear	1. Lack of protective coating 2. External influence (ex. moisture) 3. lack of lubrication 4. Misalignment of lower arm	Increased friction or wear on the contact surface and potential loss of current collection or transfer.	F	4	Negligible			
4	UPPER ARM	To provide stable connection and movement of the pantograph's collecting shoes along the OCL and to ensure reliable power transfer.	Disengagement of the upper arm from the connecting mechanism	1. rusted or loosened fasteners or joints 2. Insufficient clamping force	Potential damage to other components, interruption in the power supply, or loss of electrical contact with the overhead line.	E	3	Negligible			
			Deformation or bending of the upper arm	1. Jamming due to material failure or aging 2. Inadequate maintenance 3. Excessive force or overloading	Increase friction and wear, loss of electrical contact, misalignment with other components, or damage to the pantograph.	E	3	Negligible			
			cracks or fractures in the upper arm	1. Material fatigue 2. Excessive force or overloading 3. Manufacturing error	complete failure of the upper arm, potential damage to other components, interruption in power supply, or loss of electrical contact with the overhead line.	E	2	Tolerable			
			Inability to lower the pantograph	1. Jamming due to material failure or aging	Pantograph may get damaged or cause damage to power supply infrastructure, increase sparking, or cause a short-time	E	2	Tolerable			

					interruption of energy supply.						
			Corrosion or Excessive wear	1. Lack of protective coating 2. External influence (ex. moisture) 3. lack of lubrication 4. Misalignment of lower arm	Increased friction or wear on the contact surface and potential loss of current collection or transfer.	F	4	Negligible			
5	Collect-or head	To collect electrical power from the OCL and transfer it to trains electrical systems.	Insufficient spring force in the collector head	1 Deformation due to external influence or aging 2. Spring fatigue or degradation over time 3. Excessive wear or contamination	High-frequency oscillations cannot be compensated/increased wear of the contact pieces due to sparking or poor current collection.	D	4	Negligible			
			Contamination or foreign object interference	1. Dust or particles on overhead power lines 2. Lack of maintenance 3. External particles or objects	Risk of arcing, damage to the pantograph system, or poor current collection.	D	4	Negligible			
			Broken or damaged collector strip	1. excessive mechanical stress or overloading 2. Fatigue due to repeated flexing 3. Poor manufacturing quality or assembly faults	Partial or complete loss of electrical contact with the OCL, interruptions in power supply, or risk of arcing or sparks	E	1	Tolerable			
			wear of the collector strip or creation of grooves and cracks due to the OCL	1. continuous contact with the OCL 2. External influence (ex. Moisture, dust) 3. Lack of maintenance	Overheating of collector strips, interruptions in power supply, risk of arcing, or potential damage to the pantograph system	D	4	Negligible			
6	ADD (Automatic Dropping Device)	To automatically lower the pantograph when needed to avoid collisions with overhead structures (ex. tunnels).	ADD system activates unexpectedly (Automatic dropping Device)	1. Insufficient air pressure 2. leakage due to aging or material failure	Potentially damage the collector strip, no current supply or cause sparks and electrical arcing.	E	2	Negligible			
			No lowering after pressure loss between contact pieces and the membrane valve	1. Membrane valve does not blow-off 2. Malfunctioning or faulty ADD control unit	Increased up to strong sparking, short-time interruption of energy supply, or possible damage to the OCL due to arcing.	E	3	Negligible			
			ADD system activation delay or error	1. Insufficient air pressure 2. leakage due to aging or material failure 3. Contamination or blockage in the air pressure line	Increased up to strong sparking, short-time interruption of energy supply, or possible damage to the OCL due to arcing.	E	3	Negligible			

7	DAMPER	to assure a continuous stable contact while keeping the contact force to the overhead contact wire	Damper fatigue or loosen	1. excessive mechanical stress or overloading 2. Material failure	Increased pantograph vibration, damage to the collector head, or loss of damping functionality	D	4	Negligible			
			Damping leakage	1. Insufficient sealing 2. leakage due to aging or material failure	Reduce damping functionality, wear, and tear of other pantograph components, or arcing or sparking due to improper current transfer.	D	4	Negligible			
			Damper mounting failure	1. improper installation of the damper 2. Misalignment or poor attachment	Reduce damping functionality, wear, and tear of other pantograph components due to excessive vibration.	D	4	Negligible			
8	BRIDGING STRAN-DS	To provide support and stability to the pantograph system and current transfer	loss of the bolted fastenings	1. Improper installation or maintenance 2. loss of the nut lock	uneven contact with the OCL, resulting in poor current collection and damage to the pantograph structure.	E	2	Tolerable			
			Breakage of bridging strands	1. Excessive mechanical stress or tension 2. Aging or material fatigue	Increased electrical resistance, loss of mechanical stability, and weakening the structure	E	2	Tolerable			
9	GUIDE ROD	To provide support and stability to the pantograph system	Deformation or bending of the guiding rod	1. Jamming due to material failure or aging 2. Inadequate maintenance 3. Excessive force or overloading	Increased friction and wear on the collector strip, loss of electrical contact, or damage to the pantograph or the OCL	E	3	Negligible			
			cracks or fracture of the guiding rod	1. Material fatigue 2. Excessive force or overloading 3. Manufacturing error	Potential damage to other pantograph components, interruption in the power supply, or loss of electrical contact with the overhead line	F	2	Negligible			
			The guiding rod (bearings) gets stuck or jammed	1. Misalignment or wear of bearing 2. lack of lubrication 3. External influence (ex. Dirt, debris)	Electrical arcing due to inconsistent contact with the OCL and damage to the pantograph	E	3	Negligible			
10	25 kV INSULA-TOR	To protect car body from overhead voltage	Insulator detachment	1. Improper installation or maintenance	loss of power collection /Potential damage to the pantograph and other electrical component	E	1	Tolerable			
			Insulator breaking or cracking	1. Excessive mechanical stress or vibration 2. Aging or material failure	Potential damage to the pantograph and other electrical components / loss of electrical isolation between the pantograph and the OCL	E	1	Tolerable			

			Insulator contamination	1. Dust, dirt, and moisture	Potential damage to the pantograph and other electrical components / loss of electrical isolation between the pantograph and the OCL/ increased risk of electrical arcing or flashover	E	3	Negligible			
11	VALVE BOX	To control the movement and positioning of the pantograph	Valve blockages	1. Contamination or blockage in the air pressure line	Pantograph failure to raise or lower properly and inability to contact the OCL due to complete loss of air pressure	E	3	Negligible			
			valve leakage	1.leakage due to aging or material failure	Continuous contact with the overhead contact line is not secured, insufficient current collection or loss of air pressure.	E	3	Negligible			
			valve misalignment	1. Improper installation or maintenance	Increased wear on pantograph parts, insufficient current collection, or loss of air pressure.	E	4	Negligible			

7.2 List of Generic Hazards, Faults and Causes

HAZARDS:

- H1 Electrical hazards (e.g. overvoltage or insulation failure)
- H2 Mechanical hazards (e.g. contact strip wear or damage)
- H3 Operational hazards (e.g. improper operation or lack of maintenance)
- H4 Material hazards (e.g. defective components or aging)
- H5 Environmental hazards (e.g. weather condition or corrosion)
- H6 Pressure related hazards (e.g. air pressure level or leaks)

CAUSES:

- C1 Overvoltage or overcurrent (due to incompatibility between pantograph and the OCL)
- C2 Short circuits or arcing (external influence or aging of insulation material)
- C3 Fire, or Ignition source (contamination or damage to the contact strip or H2 Gas)
- C4 Electromagnetic interference or emission (nearby electrical equipment or poor shielding)
- C5 Improper electrical design
- C6 Excessive vibration or shock (Pantograph's own movements or track irregularities)
- C7 Improper mechanical design (dimension, mass, tightness, or strength of components etc.)
- C8 Corrosion (dusts, chemicals, moisture, or other foreign particles)
- C9 Thermal impact or high temperature
- C10 Cold impact or low temperature
- C11 Aerodynamic effect (due to cross wind or high-speed operation)
- C12 Inadequate maintenance / wear
- C13 Derailment of pantograph or lift-off
- C14 Human error (manufacturing, operation, or maintenance)
- C15 Overloading or excessive force
- C16 leakage due to aging or material failure
- C17 Faulty or worn-out air pressure regulators or control unit
- C18 Insufficient air pressure
- C19 Vandalism or Terrorism (any kind of intentional damage)
- C20 Pollution
- C21 Hydrogen embrittlement (leads to reducing the mechanical strength of components of the pantograph)
- C22 Hydrogen Leakage (Leads to fire or explosion due to electrically actuated pantograph)

7.3 Analysis for suitability of application RCS

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

Sr No	Causes		Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Overvoltage/ overcurrent	C1	EN 50206-1:2010	4.3	EN 50206-1 defines the values and duration of supply voltage for operating pantographs and housed pantographs according to EN 50163, or customer specification.	High	None	No modification
				6.13	EN 502026-1 provides the current collection test, considering the dynamic interaction between the pantograph and the OCL for both standing and moving vehicles. The temperature and current of the OCL shouldn't exceed the limits specified in 6.12 and 6.13.	High	None	No modification
3	Excessive vibration / shocks	C6	EN 50206-1:2010	6.4.3.3	The pantograph's robustness to shock and vibration under a specific load during train operation is crucial for the pantograph and the OCL to interact. EN 50206-1 provides the transverse vibration test for the pantograph on the test table, producing sinusoidal vibration amplitude. The frequency of the table shall be 10% lower than the transverse natural frequency of oscillation.	Medium	None	No modification
				6.4.3.4	EN 50206-1 provides vertical vibration tests for pantographs under the system, producing sinusoidal vibration in the vertical direction. The frequency and amplitude of the system shall be recorded, considering contact force variations.	High	None	No modification
				6.5	EN 50206-1 specifies a test for the resistance of the pantograph to shock when 300N force is applied longitudinally to the collector head and then abruptly disconnected. It is a supplementary type of test.	High	None	No modification
4	Improper mechanical design	C7	EN 50206-1:2010	4.8	The design of the pantograph and the OCL shall ensure continuous contact and allow minimum wear for both subsystems. Clause 4.8 states that the A.D.D. system shall be designed to ensure minor damage to the contact strips, considering reaction time and reliability.	High	None	No modification
				6.2.3	EN 50206-1 provides a general test for pantographs, including all electrical and mechanical components, as stated in clause 6.2. Clause 6.2.3 states that the pantograph's dimensions (including tolerances) must be verified using the proper measuring tools as specified on the design drawing.	High	None	No modification

				6.4	EN 50206-1 specifies in the endurance test for a pantograph with a collector head that the raising and lowering consecutive operation range shall be within the design working range without abnormal wear or fracture. The pantograph shall meet the requirements of 6.3.1 and 6.3.2.	High	None	No modification
				9.1	Clause 9.1 specifies that the design life of the pantograph structure (frame, base frame, collector head) has a design life of 12 x 10^6 km or 30 years, whichever comes first or according to customer specification.	High	None	No modification
5	Corrosion	C8	EN 50206-1:2010	4.10	In Annex C, a detailed explanation must be provided along with the specifications regarding the application requirements and type of corrosion protection.	Medium	None	Modification
6	Thermal impact / high temperature	C9	EN 50206-1:2010	6.3.3	EN 50206-1 provides a climate test (+40 °C to -25 °C) for pantographs that states that the operation of the pantograph must be satisfactorily operable at extremely high temperatures and humidity levels, as specified by the customer, or at +40 °C.	Medium	None	No modification
				6.7.3	Cluses 6.7.3 describe air tightness for (tank) air bellow, which has to be carried out at the extreme temperature specified in the customer specification, or (+40 °C to -25 °C).	Medium	None	No modification
				6.13	In clauses 6.13.1 and 6.13.2, the heating tests are specified for the pantograph structure when the vehicle is at a standstill or running. During the test, temperature and current against time shall not exceed as per customer specification or permissible values.	High	None	No modification
7	Low temperature / cold impact	C10	EN 50206-1:2010	6.3.3	EN 50206-1 provides a climate test (+40 °C to -25 °C) for pantographs that states that the operation of the pantograph must be satisfactorily operable at extremely low temperatures and humidity levels, as specified by the customer, or at -25 °C.	Medium	None	No modification
8	Insufficient air pressure	C11	EN 50206-1:2010	6.7.2	EN 502026-1 provides the air tightness test for the operating device cylinder (or air bellows) at ambient temperature for the function of the ADD system and pantograph operation, as stated in 6.7.2. The pressure in the tank shall not decrease by more than 5% of the initial pressure after 10 minutes.	High	None	No modification
				6.7.3	Cluses 6.7.3 describe air tightness for (tank) air below, which has to be carried out at the extremes temperature specified in the customer specification, or (+40 °C to -25 °C).	High	None	No modification
9	Inadequate maintenance /wear	C12	EN 50206-1:2010	6.2	Pantographs can be visually inspected as part of a routine test according to EN 50206-1. According to clause 6.2.1, the pantograph must be fully assembled and visually inspected.	High	None	No modification
				7	Clause 7 defines that the inspection plan should be in accordance with EN 29001 or EN 29002, whichever is specified in the customer specifications.	High	None	No modification

				8.2	EN 50206-1 specifies categories of failure in three sections, and the expected conditions of operation and expected operating life for the pantograph. The reliability specification is important from a maintenance viewpoint.	High	None	No modification
				9.3	According to EN 50206-1, the maintenance documentation, along with the RAMS documents and other framework conditions, must be defined in the customer specifications as parts of the pantograph system that are easily repairable, testable, repairable, and accessible. Otherwise, the system could damage parts of the pantograph, vehicle, OCL, and additional parts of infrastructure.	High	None	No modification
10	Overloading / excessive force	C15	EN 50206-1:2010	4.4	EN 50206 specifies a force requirement for the safe operation of pantographs. In compliance with clause 4.4, the Specific Static Contact Forces measured during raising and lowering must not exceed the boundaries specified in Annex A. Operating requirements for static contact force, total mean uplift force, and total contact force shall follow the requirements in EN 50367 if not specified in the customer specification.	High	None	No modification
				4.9	In accordance with clause 4.9, the supplier must supply the mass of the pantograph with and without insulators as well as the maximum force at each location to determine the force acting on the vehicle's roof.	High	None	No modification
				6.6	EN 502026-1 provides a transverse rigidity test for pantograph systems. The displacement must be less than or equal to 30 mm on each side, and there is no permanent deformation when a force of 300 N is applied successively on each side of the frame of the collector head.	High	None	No modification
				6.9	EN 50206-1 specifies the measurement of housing force by using an instrument fixed to the collector head pivot. The housing force shall prevent the pantograph from raising from the housed position at all speeds up to the maximum speed of the vehicle.	High	None	No modification
				6.10	EN 50206-1 provides a combined test for the total mean uplift force for the pantograph system. The value of the total uplift force shall be in accordance with clause 4.4 at a specified range of operating heights for a given maximum speed and in both directions of travel. Values shall not be validated under bad weather conditions: heavy rain, wind speed above 8 m/s.	High	None	No modification

				6.11	EN 50206-1 provides a combined test for the total contact force for the pantograph system. The value of the total contact force shall be in accordance with clause 4.4 at a specified range of operating heights for a given maximum speed and in both directions of travel. The total contact force shall be measured by a measurement system according to EN 50317.	High	None	No modification
11	Leakage (due to an attack or material failure)	C16	EN 50206-1:2010	6.7.2	EN 502026-1 provides the air tightness test on the operating device cylinder(or air bellows) for the function of the ADD system and pantograph operation as stated in 6.7.2. The test should be carried out at ambient temperature and check the sealing of the operating device cylinder. The pressure in the tank shall not decrease by more than 5 % of the initial pressure after 10 min.	High	None	No modification
12	Insufficient air pressure	C18	EN 50206-1:2010	6.7.2	EN 502026-1 provides the air tightness test on the operating device cylinder(or air bellows) for the function of the ADD system and pantograph operation as stated in 6.7.2. The test should be carried out at ambient temperature and check the sealing of the operating device cylinder. The pressure in the tank shall not decrease by more than 5 % of the initial pressure after 10 min.	High	None	No modification
				6.7.3	EN 50206-1 provide air tightness climate test that should be carried out the maximum and minimum temperature specified in the customer specifications or extreme temperature -25 °C and at +40 °C.	Medium	None	No modification

Gap analysis EN 50367:2020/A1:2022; Railway applications – Fixed installations and rolling stock – Criteria to achieve technical compatibility between pantographs and overhead contact line

Sr No	Causes		Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Overvoltage / overcurrent	C1	EN 50367/2020+A 1:2022	6	EN 50367 specifies that the permissible current at the contact point depends significantly on the materials of the contact wire and contact strips and the wear on both. Furthermore, the characteristics of the contact wire and contact strips shall be in accordance with 6.2 and 6.3.	High	None	No modification
				7.2	EN 50367 provides that the properties of the pantograph and contact wire shall be such that overheating does not occur. The current demand of the train, as set out in EN 50388:2012, shall comply with the working limits of the overhead contact line. The overhead contact line shall be designed to accept, as a minimum, the value of current at standstill per pantograph stated in Table 5.	High	None	No modification
2	Improper electric design	C5	EN 50367/2020+A 1:2022	5.2.2	In compliance with EN 50367, the infrastructure gauge for a pantograph's clear passage is based on the electrical clearance defined in EN 50119:2020, 5.1.3. The pantograph head's live parts must be electrically isolated from any neighboring earthed structures.	High	None	No modification
				7.3	According to EN 50367, the requirements for the dynamic behavior of the OCL must be verified by assessing the total mean uplift force and the percentage of arcing NQ by arcing, as per EN 50317:2012.	High	None	No modification
3	Improper mechanical design	C7	EN 50367/2020+A 1:2022	5.2	EN 50367 provides values for nominal contact wire height in Table 1. The maximum contact wire height shall not exceed 6.50 meters. Contact wire height shall be within the limits calculated in accordance with EN 50119:2020, 5.10. .	High	None	No modification
				5.2.7	EN 50367 defines that the trains shall be able to move from one section to an adjacent one (which is fed from a different phase or system) without bridging the neutral section. The neutral section shall be designed in such a way that trains have multiple pantographs arranged in accordance with A.1.	High	None	No modification
				5.2.8	EN 50367 defines the change in area between pantograph profiles where one pantograph type shall be lowered, and the other type shall be raised. A changeover area must be provided where two distinct OCL types that are intended for different pantograph profiles intersect.	High	None	No modification
				8.2.2	EN 50367 defines that the overhead contact line shall be designed for a minimum of two pantographs operating adjacently. The design distance of the two adjacent pantograph heads, measured center line to center line, shall be equal to the values set out in one overhead contact line type 'A', 'B', or 'C' selected from Table 9 for the relevant power supply system.	High	None	No modification

4	Thermal impact / high temperature	C9	EN 50367/2020+A 1:2022	7.2	EN 50367 defines the maximum temperature rise in the conductors due to load or short-circuit currents shall be limited in accordance with EN 50119:2020, 5.12.	High	None	No modification
5	Derailment of pantograph or lift-off	C13	EN 50367/2020+A 1:2022	5.2.2	EN 50367 defines the design of the overhead contact line shall allow the operation of vehicles compliant with the appropriate vehicle gauge for the route. This gauge shall be calculated in accordance with EN 15273-1:2013+A1:2016. EN 15273-2:2013+A1:2016 and EN 15273-3:2013+A1:2016. The gauge for free and unrestricted passage of pantographs shall be calculated based on the kinematic gauge for pantographs in accordance with EN 15273-3:2013+A1:2016, Clause 11. Electrical clearances requirements shall be as set out in EN 50119:2020, 5.1.3	High	None	No modification
				5.2.4	EN 50367 provides values for contact wire gradient and change of gradient in Table 1. The contact wire gradient specified in Table 1 may be exceeded on an exceptional basis, where a series of restrictions on the contact wire height, such as level crossings, bridges, tunnels, etc., prevents compliance.	High	None	No modification
				5.2.5	The working zone of the pantograph for serviceability and the limit of dewirement as specified in 5.2.5.2 and 5.2.5.3 are used to calculate the permissible lateral deviation of the contact wire from the track center line.	High	None	No modification
				5.2.6	EN 50367 provides that the permissible contact wire uplift at supports shall be in accordance with EN 50119:2020, 5.10.2. Exceeding the permissible limits of the system could damage OCL, vehicles, and additional parts of the infrastructure.	High	None	No modification
6	Overloading or excessive force	C15	EN 50367/2020+A 1:2022	5.2.5.2	EN 50367 defines that the horizontal movement of the contact wire shall be calculated for the application of the maximum mean contact forces. Stability is achieved when the contact wire position on the pantograph head lies between the pantograph head center line and the point of dewirement.	High	None	No modification
				7.2	A static contact force is exerted by the pantograph on the contact wire. The overhead contact line shall be designed for a range of static contact forces as specified in Table 4. Conformity assessment for static contact force shall be carried out by design review and measurements in accordance with EN 50206-1:2010.	High	None	No modification
				7.3	EN 50367 specifies that the overhead contact line shall be designed to accept as a minimum the value of mean force (Fm,max) in Tables 6 and for small tunnels in Table 7.	High	None	No modification

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

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Overvoltage or overcurrent	C1	EN 50405:2015	7.1	EN 50405 defines the test for the contact strip design to achieve energy dissipation under specified current limits so that the maximum design temperature limit is not exceeded. It demonstrates that the strip design achieves dissipation of energy under current loading so that the maximum design temperature limit is not exceeded when thermal equilibrium is reached.	High	None	No modification
2	Improper electric design	C5	EN 50405:2015	7.7	EN 50405 provides a test to determine the electrical resistance of the contact surface of the contract strip supporting structure. Resistance measurements shall be within the manufacturer's declared resistance limits for the contact strip.	High	None	No modification
3	Improper mechanical design	C7	EN 50405:2015	5.1	EN 50405 specifies the essential characteristics of contact strip material that shall be provided in the data sheet and design drawing as stated in clause 5.	High	None	No modification
				7.3	EN 50405 describes the flexural test of contact strips that must maintain the elastic limit when a minimum force of 350 N is applied. If the linear part of the deformation curve is not reached, the force will be increased until the linear characteristic is shown.	High	None	No modification
				7.4	EN 50405 specifies that the test for the contact strip's share strength must be at its minimum at ambient temperature (clause 6.5). The shear strength is defined as: Ts = Fs / A (N/mm2).	High	None	No modification
				7.6	EN 50405 describes the test values and acceptance criteria for the mechanical fatigue resistance of the contact strip in Table 4. This test is based upon the forces and frequency of application that a pantograph could experience in service	High	None	No modification
4	Thermal impact or high temperature	C9	EN 50405:2015	7.1	EN 50405 defines the test for the contact strip design achieves energy dissipation under a defined current, ensuring that the maximum design temperature limit is not exceeded. It demonstrates that the strip design achieves dissipation of energy under current loading so that the maximum design temperature limit is not exceeded when thermal equilibrium is reached.	High	None	No modification
				7.2.2	EN 50405 provides tests for vertical deflection, and changes in the length of the conductor strip assembly must be performed in accordance with clause 7.2.2 under the influence of extremely high temperatures.			
5	Cold impact or low temperature	C10	EN 50405:2015	7.2.3	EN 50405 proposes that tests for vertical deflection and changes in the length of the conductor strip assembly must be conducted under the influence of extremely low temperatures (-25 °C) or as specified by the customer. The minimum temperature of -25 °C is based on category T1 in EN 50125-1.	High	None	No modification

6	Inadequate maintenance / wear	C12	EN 50405:2015	7.9	EN 50405 provides the measurement of the coefficient of friction of the running surface of the contact strip according to IEC 60773:1983. The measurement shall be made immediately after the sample is lowered onto the test ring.	High	None	No modification
7	Overloading or excessive force	C15	EN 50405:2015	7.3	EN 50405 describes the flexural test of contact tips that must maintain the elastic limit when a minimum force of 350 n is applied. The force may be increased to the point of permanent deformation of the contact strip.	High	None	No modification
8	leakage due to aging or material failure	C16	EN 50405/2015	7.5.3	EN 50405 provides a sealing integrity test for the contact strip in extreme temperatures. The temperature of the contact strip must be lowered to -25 °C or a lower minimum temperature that the customer specifies according to EN 50125-1.	High	None	No modification
9	Insufficient air pressure	C18	EN 50405/2015	7.5.4	EN 50405 provides the test for the air flow continuity for the operation of the ADD system that has been subject to the sealing integrity test set out in 7.5.2. The supply shall be pressurized and maintained at the specified pressure and the minimum operating pressure of the Pantograph automatic dropping device as specified by the customer.	High	None	No modification

Gap analysis EN IEC 61133:2021; Railway applications – Rolling stock – Testing of rolling stock on completion of construction and before entry into service.

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Overvoltage or overcurrent	C1	EN IEC 61133/2021	8.7.2	The withstand test voltage shall be applied to all circuit parts of the pantograph and associated equipment according to EN 60077, as stated in clause 8.7.2. Failure of insulation could result in electrical arcing and damage to the OCL, pantographs, and other parts of infrastructure and vehicles.	High	None	No modification
				8.2.2.4	EN IEC 61133 provides that the current collector static test has to be satisfactory according to EN 50206, as specified in 8.2.2.4. Exceeding the permissible limits could result in electrical arcing and damage to the OCL, pantographs, and other parts of infrastructure and vehicles.			
2	Short circuits or arcing	C2	EN IEC 61133/2021	8.7.1	EN IEC 61133 specifies that the insulation integrity test shall be carried out on a completed vehicle, including pantographs and associated electrical components, as stated in clause 8.7.1.	High	None	No modification
3	Electromagnetic interference or emission	C4	EN IEC 61133/2021	9.15	EN IEC 61133 provides electromagnetic compatibility test for all equipment on the vehicle, including the pantograph and associated electronic equipment, to ensure there is no harmful electrical interference, as stated in 9.15.	High	None	No modification
4	Improper electric design	C5	EN IEC 61133/2021	9.13	The electrical performance of the current collector and associated electrical circuit or neutral section shall be checked before carrying out power supply compatibility tests according to EN 50388 as specified in clause 9.13.	High	None	No modification
5	Aerodynamic effect	C11	EN IEC 61133/2021	9.14	EN IEC 61133 specifies that the unauthorized raising of the lowered pantograph has to be checked and has no adverse influence on the proper execution of raising or lowering movements at speed due to aerodynamic effects, as stated in 9.13 and 9.14	High	None	No modification
6	Derailment of pantograph or lift-off	C13	EN IEC 61133/2021	9.11.1	EN IEC 61133 specifies the kinematic gauging test to check pantograph sway motion, as specified in 9.11.1. These tests may be combined with the ride comfort quality tests covered at 9.10.2 using data computed from the suspension displacements to check the motion of the vehicle body. The same data may be used to check the pantograph sway motion to check conformance with pantograph gauge limits.	High	None	No modification

				9.13	The requirements for testing the dynamic interaction between the pantograph and the overhead line are given in EN 50317 in 9.13, and it shall be verified by measurement that the calculated maximum pantograph sway is not exceeded, considering the worst dynamic movement of the vehicle (also see 9.10.2 and 9.11.1).			
7	Leakage due to aging or material failure	C16	EN IEC 61133/2021	8.9.2	EN IEC 61133, clause 8.9.2, provides the air tightness test for main reservoirs and other air equipment, including the ADD system of pantographs and associated equipment.	High	None	No modification
8	Faulty or worn-out air pressure regulators or control unit	C17	EN IEC 61133/2021	8.9.4	EN IEC 61133 specifies that the operation of compressed air equipment shall be checked on the complete train set, including the equipment of the ADD system of the pantograph, as stated in clause 8.9.4.	High	None	No modification
9	Insufficient air pressure	C18	EN IEC 61133/2021	8.9.2	EN IEC 61133, clause 8.9.2, provides the air tightness test for main reservoirs and other air equipment, including the ADD system of pantographs and associated equipment.	High	None	No modification

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

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Overvoltage or overcurrent	C1	EN 50124-1:2017	All	EN 50124-1 provides insulation coordination with regards to peak voltage and transient overvoltage as specified in 4.1.2. Overvoltage's in large and complex systems, such as the OCL, subjected to multiple and variable influences can be based on statistical and risk considerations. The overhead contact lines should comply with EN 50119. In clause 4.2, the required voltage and rated voltage are specified to avoid overvoltage concerning safety and reliability.	High	None	No modification
2	Short circuits / arcing	C2	EN 50124-1:2017	All	EN 50104-1 provide insulation coordination with the selection, dimensioning, and correlation of insulation both within and between items of equipment. This standard specifies general requirements for tests associated with insulation coordination. In addition, it is important to consider electrical stresses, dimensioning insulation, and environmental conditions.	High	None	No modification
3	Electromagnetic interference or emission	C4	EN 50124-1:2017	5.3	EN 50124-1 specifies clearance for functional insulation based on rated impulse voltage, which can be determined by electromagnetic compatibility test requirements such as those given in the EN 50121 series.	High	None	No modification
4	Improper electrical design	C5	EN 50124-1:2017	All	EN 50124-1 provides insulation coordination to avoid unnecessary over dimensioning of insulation. This standard specifies the requirements for clearances and creepage distances for equipment and general requirements for tests pertaining to insulation coordination.	High	None	No modification
5	Pollution	C20	EN 50124-1:2017	4.4, 4.1.3, 8.2.5	EN 50124-1 provides several pollution degrees (PD) , according to Table A4, for the purpose of evaluating creepage distance and clearance. The micro-environment determines the effect of pollution on the insulation. According to Table E.1, PD3 describes Correlation between pollution degrees and macro-environmental conditions regarding pantographs. Pollution caused by contaminated water, soot, metal or carbon dust is inherently conductive.	High	None	No modification

Gap analysis EN 50124-2:2018; Railway applications - Insulation coordination - Part 2 : over voltages and related protection.

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Overvoltage or overcurrent / Short circuits / arcing	C1 & C2	**EN 50124-2:2018**	All	EN 50124-2:2018 provides simulation and/or test requirements for protection against transient overvoltage of such equipment. In Annex A, provide the maximum value of voltage U according to duration. Failure of insulation could result in electrical arcing and damage to the OCL, pantographs, and other parts of infrastructure and vehicles.	High	None	No modification

7.3.7 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)

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Improper mechanical design	C7	**EN 12663-1:2015**	All	EN 12663-1:2015 provide Structural requirements of railway vehicle bodies. Railway vehicle bodies are designed to meet specific structural requirements to ensure safety, stability, and performance according to these standards. Exceeding the permissible limits could damage components of the pantograph, vehicles, the OCL, and other parts of the infrastructure.	High	None	No modification

Gap analysis EN 45545-1:2013; Railway applications — Fire protection on railway vehicles — Part 1: General

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Fire or Ignition source	C3	**EN 45545-1:2013**	All	Fire protection measures and requirements on railway vehicles are crucial to ensuring the safety of passengers, railway staff, and the infrastructure itself, according to these standards. Otherwise, it could cause potential damage to the pantograph, vehicle, OCL, and other parts of the infrastructure. The measures and requirements specified in EN 45545 are intended to protect passengers and staff in railway vehicles in the event of a fire on board.	High	None	No modification

7.3.9 Gap analysis EN 45545-2:2020+A1:2023; Railway applications –Fire protection on railway vehicles –Part 2: Requirements for fire behavior of materials and components.

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Fire or Ignition source	C3	**EN 45545-2:2020+A1:2023**	All	Fire protection measures and requirements on railway vehicles are crucial to ensuring the safety of passengers, railway staff, and the infrastructure itself, according to these standards. The operation and design categories defined in EN 45545-1 are used to establish hazard levels that are used as the basis of a classification system. For each hazard level, this part specifies the test methods, test conditions and reaction to fire performance requirements Otherwise, it could cause potential damage to the pantograph, vehicle, OCL, and other parts of the infrastructure.	High	None	No modification

Gap analysis EN 45545-3:2013; Railway applications — Fire protection on railway vehicles — Part 3: Fire resistance requirements for fire barriers

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Fire or Ignition source	C3	**EN 45545-3:2013**	All	EN 45545-3 specifies the fire resistance requirements and testing methods for fire barriers for railway vehicles. The objective of the measures and requirements specified in this part of EN 45545 is to protect passengers and staff in railway vehicles in the event of a developing fire on board. Otherwise, it could cause potential damage to the pantograph, vehicle, OCL, and other parts of the infrastructure.	High	None	No modification

7.3.11 Gap analysis EN 45545-4:2015; Railway applications — Fire protection on railway vehicles — Part 4: Fire safety requirements for rolling stock design

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Fire or Ignition source / Improper mechanical design	C3 & C7	**EN 45545-4:2015**	All	EN 45545-4 specifies fire safety requirements for railway vehicle design to cover the objectives defined in EN 45545-1. The measures and requirements specified in this part of EN 45545 aim to protect passengers and staff in railway vehicles in the event of a fire on board by minimizing the risk of a fire starting, delaying the fire development and controlling the spread of fire products through the railway vehicle, thus aiding evacuation. Otherwise, it could cause potential damage to the pantograph, vehicle, OCL, and other parts of the infrastructure.	High	None	No modification

Gap analysis EN 45545-5+A1:2016; 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 levitation vehicles

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Fire or Ignition source / Improper electrical design	C3 & C5	**EN 45545-4:2015**	All	EN 45545-3 specifies the fire safety requirements for electrical equipment on railway vehicles, including trolley buses, track-guided buses, and magnetic levitation vehicles, ensuring that electrical emergency equipment continues to be functional until evacuation is complete and lowering the risk of starting a fire both during operation and as a result of a technical defect and/or malfunction of the electrical equipment. Otherwise, it could cause potential damage to the pantograph, vehicle, OCL, and other parts of the infrastructure.	High	None	No modification

Gap analysis EN 50388:2012; Railway Applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability.

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Overvoltage/ overcurrent	C1	EN 50388:2012	8.2	EN 50388 provides the minimum values for mean voltages at the pantograph under normal operating conditions, as given in Table 3. The characteristics and values for supply voltages at the pantograph are specified in EN 50163.	High	None	No modification
				10.1	Electrical Harmonic values shall be limited below critical values to achieve electrical system compatibility under steady state and dynamic conditions; otherwise, it causes overvoltage in the system, as stated in 10.1. Overvoltage can lead to insulation breakdown, increase electrical stress, and potentially damage the pantograph, the OCL, and other electrical devices.	High	None	No modification
2	Short circuits or arcing	C2	EN 50388:2012	11.2	EN 50388 provides such protection against short-circuits that protective systems on traction units and at substations shall be compatible with electrification systems. The maximum contact line rail short circuit levels are specified in Table 6.	High	None	No modification
				11.3	In clause 11.3, it is stated that automatic reclosure of the line circuit breakers is used to reenergize the overhead contact line network and localize the affected line section to avoid short circuits.	High	None	No modification
5	Improper electrical design	C5	EN 50388:2012	8.5	EN 50388 provides that the electrical system design shall guarantee the ability of the power to achieve the specified performance in 8.3 and 8.4.	High	None	No modification
				10.1	Electrical Harmonic values shall be limited below critical values to achieve electrical system compatibility under steady state and dynamic conditions; otherwise, it causes overvoltage in the system, as stated in 10.1. Overvoltage can lead to insulation breakdown, increase electrical stress, and potentially damage the pantograph, the OCL, and other electrical devices.	High	None	No modification
7	Improper mechanical design	C7	EN 50388:2012	5	EN50388 specifies that the arrangement of the pantograph on the train and the rising or lowering of the pantograph must be done in a way that avoids bridging in different phases, as stated in clause 5. Please note comments on the LOC&PAS TSI (1302/2023/EC) clause 4.2.8.2.9.8	High	None	No modification

7.3.14

Sr No	Causes		Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Overvoltage/ overcurrent	C1	EU 1302/2014+A 1694/2023	4.2.8.2.7	TSI LOC&PAS specifies that an electric unit shall not cause unacceptable overvoltage or other phenomena described in the specification stated in EN 50388-1:2022. (Harmonics and dynamic effects for an AC system)	High	None	No modification
				4.2.8.2.2	The pantograph-related electric units have to operate within the voltage and frequency range specified in TSI Energy 4.2.3 in order to prevent overvoltage, according to TSI LOC&PAS.	High	None	No modification
				4.2.8.2.4	TSI LOC&PAS provide maximum power and current from the overhead contact line. Electric units shall be equipped with automatic regulation to maximum current or power against voltage according to EN 50388-1:2022. Pantographs shall be designed for the rated current to be transmitted to the Electric unit. (4.2.8.2.9.3a)	High	None	No modification
				4.2.8.2.5	TSI LOC&PAS provide the maximum current per pantograph for AC and DC systems when a train is at standstill, as stated in Table 5, according to EN 50367:2020+A1:2022. Pantographs shall be designed for the rated current to be transmitted to the Electric unit. (4.2.8.2.9.3a)	High	None	No modification
2	Short circuits / arcing	C2	EU 1302/2014+A 1694/2023	4.2.8.2.9.4.2	TSI LOC&PAS provides that the material for contact strips shall be mechanically and electrically compactible with point 4.2.14 of the ENE TSI in order to ensure proper current collection, avoid excessive abrasion, and minimize wear of both contact strips and the OCL.	High	None	No modification
				4.2.8.2.9.9	TSI LOC&PAS defines the pantographs as being assembled on an electric unit in a way that ensures the current path from the collector head for vehicle equipment is insulated. The insulation shall be adequate for all system voltages the unit is designed for.	High	None	No modification
3	Fire, or Ignition source	C3	EU 1302/2014+A 1694/2023	4.2.10.2.1	TSI LOC&PAS provide the material requirement, and the selection of materials and components (pantograph) shall take into account their fire behavior properties, such as flammability, smoke opacity, and toxicity, according to the operation category as specified in EN 45545-2:2020.	High	None	No modification
4	Improper electrical design	C5	EU 1302/2014+A 1694/2023	4.2.8.2.9.4.2	TSI LOC&PAS provides that the material for contact strips shall be mechanically and electrically compactible with point 4.2.14 of the ENE TSI in order to ensure proper current collection, avoid excessive abrasion, and minimize wear of both contact strips and the OCL.	High	None	No modification

				4.2.8.2.9.8	TSI LOC&PAS defines electrical units as being designed for several power supply systems, and the infrastructure register gives information on the permitted pantograph position: lowered or raised (with permitted pantograph arrangements) when running through system separation sections, and it automatically recognizes the voltage of the power supply system at the pantograph.	High	None	No modification
				4.2.8.2.10	The pantograph, main circuit breaker, and high voltage connection between them should be on the same vehicle to protect the onboard high voltage circuit or connection, according to EN 50388-1:2022. Otherwise, it could damage components of the pantograph, vehicles, and the OCL.	High	None	No modification
				4.2.8.4	TSI LOC&PAS provides protection against electrical hazards. Pantograph and its electrically live part shall be designed such that direct or indirect contact with train staff and passengers is prevented, and in cases of equipment failure, according to EN 50153:2014-05/A1:2017-08/A2:2020-01.	High	None	No modification
5	Improper mechanical design	C7	EU 1302/2014+A 1694/2023	4.2.8.2.9.1.2	TSI LOC&PAS specifies that the pantograph shall have a working range of at least 2000 mm. The characteristics of a pantograph should be verified according to the requirements of the specification referenced in Appendix J-1, index 23. (EN 50206-1:2010)	High	None	No modification
				4.2.8.2.9.2	TSI LOC&PAS specifies that the electrical unit designed to be operated on other track gauge systems (1520mm or 1600mm) should have pantograph head geometry according to clauses 4.2.8.2.9.2.1 and 2.	High	None	No modification
				4.2.8.2.9.4.2	TSI LOC&PAS provides that the material for contact strips shall be mechanically and electrically compactible with point 4.2.14 of the ENE TSI in order to ensure proper current collection, avoid excessive abrasion, and minimize wear of both contact strips and the OCL.	High	None	No modification
				4.2.8.2.9.1.1	TSI LOC&PAS provide the pantograph working range for the height of interaction with contact wires. The installation of a pantograph on the electrical unit shall allow mechanical contact with the OCL at a height between points 1 and 5, as described in this clause.	High	None	No modification
				4.2.8.2.9.7	TSI LOC&PAS defines the number of pantographs, and their spacing shall be designed according to the requirement of current collection performance as defined on point 4.2.8.2.9.6. It is permissible for more than one pantograph to be simultaneously in contact with the overhead contact line equipment.	High	None	No modification
				4.2.8.2.9.10	TSI LOC&PAS specifies the automatic dropping device (ADD) that lowers the pantograph in case of a collector failure. The requirement for the ADD system is fulfilled as specified in Appendix J-1, index 23: (EN 50206-1:2010)	High	None	No modification
6	Aerodynamic effect	C 11	EU 1302/2014+A 1694/2023	4.2.8.2.9.6 , Point 1	TSI LOC&PAS defines the mean contact force as the statistical mean value of the static contact force and aerodynamic components of the contact force with dynamic correction. Pantographs fitted on rolling stock are designed to exert a mean contact force on the OCL in the range specified in point 4.2.12 of the TSI Energy.	High	None	No modification

				4.2.8.2.9.2, point 6	The connection between OCL and pantograph head is permitted outside of contract strips and within the conducting range in unfavorable circumstances, such as strong winds, according to the pantograph head geometry type listed in Appendix J-1, index 24 of TSI LOC&PAS.	High	None	No modification
7	Inadequate maintenance / wear	C 12	EU 1302/2014+A 1694/2023	4.2.8.2.9.4	TSI LOC&PAS specifies that the contact strip shall be removable parts of the pantograph head, which are in direct contact with the OCL. Continuous interaction between the OCL and contact strip causes wear and friction. Replaceable contact strips will be easy for maintenance purposes.	High	None	No modification
8	Derailment of pantograph or lift -off	C 13	EU 1302/2014+A 1694/2023	4.2.3.1, Point 5	TSI LOC&PAS provides he pantograph gauge shall be verified by calculation according to EN 15273-2:2013+A1:2016 to ensure that the pantograph envelope complies with the mechanical kinematic pantograph gauge as stated in (EU) No. 1301/2014.	High	None	No modification
				4.2.8.2.9.1.1	TSI LOC&PAS provide the pantograph working range for the height of interaction with contact wires. The installation of a pantograph on the electrical unit shall allow mechanical contact with the OCL at a height between points 1 and 5, as described in this clause.	High	None	No modification
				4.2.8.2.9.2, point 5	According to TSI LOC&PAS, pantographs with contact strips along with independent suspension systems must adhere to Appendix J-1, index 24. (EN 50367:2020+A1:2022)	High	None	No modification
9	Overloading or excessive force	C 15	EU 1302/2014+A 1694/2023	4.2.8.2.9.5	TSI LOC&PAS define the static contact force as the vertical force exerted by the pantograph on the OCL. Static constant force shall be adjusted according to different power supply systems, as stated in point 2.	High	None	No modification
				4.2.8.2.9.6	TSI LOC&PAS defines the mean contact force as the statistical mean value of the static contact force and aerodynamic components of the contact force with dynamic correction. Pantographs fitted on rolling stock are designed to exert a mean contact force on the OCL in the range specified in point 4.2.12 of the TSI Energy.	High	None	No modification

7.3.15

Sr No	Causes		Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Overvoltage/ overcurrent	C1	EU 1301/2014+A 1694/2023	2.1.2, point 1	TSI ENE defines the interaction between the overhead contact line and the pantograph as an important aspect of interoperability. The objective is to ensure reliable and continuous power transfer from the traction power supply system to the rolling stock.	High	None	No modification
				4.2.3	TSI ENE provides the nominal voltage and frequency of the traction power supply system. The power supply system shall be one of the four systems: AC 25 kV, 50 Hz; AC 15 kV, 16.7 Hz; DC 3 kV; and DC 1,5 kV.	High	None	No modification
				4.2.5	TSI ENE defines the OCL shall be designed to sustain at least the values of current at standstill per pantograph, in accordance with EN 50367:2020+A1:2022.	High	None	No modification
5	Improper electrical design	C5	EU 1301/2014+A 1694/2023	4.2.7	TSI ENE provides the electrical protection coordination design of the energy subsystem, which shall comply with the requirements of EN 50388-1:2022.Exceeding the permissible limits could damage components of the pantograph, vehicles, the OCL, and additional parts of the infrastructure.	High	None	No modification
				4.2.8	According to TSI ENE, there may be electrical instability in the system as a result of the rolling stock and traction power supply interact. EN 50388-1:2022 specifies that harmonic overvoltage must be kept below critical values to prevent instability and ensure electrical system compatibility.	High	None	No modification
				4.2.16.1	TSI ENE defines the design of system separation sections to ensure that trains can move from one traction power supply system to an adjacent different traction power supply system without bridging the two systems. The overall length D of neutral sections is defined in EN 50367:2020+A1:2022.	High	None	No modification

7	Improper mechanical design	C7	EU 1301/2014+A1694/2023	4.2.9	The overhead contact lines shall be designed for pantographs with the head geometry for efficient current transfer, according to LOC & PAS TSI. Otherwise, it can result in electrical arcing and damage the OCL, pantographs, and other parts of infrastructure and vehicles. The contact wire height and the lateral deviation of the contact wire under the action of a crosswind are factors that govern the interoperability of the rail network.	High	None	No modification
				4.2.9.1	TSI ENE defines the relation between the contact wire heights and pantograph working heights according to EN 50119:2020 and EN 50122-1:2022. The wire height shall not be greater than 6.5 m. Otherwise, it can result in electrical arcing and damage to the OCL, pantographs, and other parts of infrastructure and vehicles.	High	None	No modification
				4.2.13	The overhead contact line shall be designed for trains with two pantographs operating simultaneously. The design spacing of the two pantograph heads, center line to center line, shall be equal to or lower than the values set out in EN 50367:2020+A1:2022.	High	None	No modification
				4.2.15.1	TSI ENE defines the design of phase separation sections to ensure that trains can move from one section to an adjacent one without bridging the two phases. The overall length D of neutral sections is defined in EN 50367:2020+A1:2022.	High	None	No modification
12	Inadequate maintenance / wear	C12	EU 1301/2014+A1694/2023	4.2.14	TSI ENE provides a combination of contact wire material and contact strip material that has a strong impact on the wear of contact strips and contact wire. Permissible contact strip materials are defined in point 4.2.8.2.9.4.2 of LOC&PAS TSI. The permissible material of copper or copper alloy for contact wire shall comply with EN 50149:2012. Exceeding the permissible limits could damage components of the pantograph, vehicles, the OCL, and other parts of the infrastructure.	High	None	No modification
13	Derailment of pantograph or lift-off	C13	EU 1301/2014+A1694/2023	4.2.9.2	TSI ENE provides that the maximum lateral deviation of the contact wire in relation to the track center line under the action of crosswind shall be in accordance with EN 50367:2020+A1:2022. When it comes to multi-rail tracks, each pair of rails (which are meant to be evaluated separately and evaluated against TSI) must meet the lateral deviation requirement, as mentioned in point 2.	High	None	No modification

				4.2.10, point 1	TSI ENE defines the mechanical kinematic pantograph gauge, which shall be specified using the method specified in EN 50367: 2020+A1:2022 to this TSI and the pantograph profiles defined in LOC&PAS TSI, clauses 4.2.8.2.9.2.1 and 4.2.8.2.9.2.2.	High	None	No modification
				4.2.12, point 2	TSI ENE defines the simulated space for steady arm uplift, or measured uplift of the contact wire at a steady arm, with a minimum of two pantographs operating simultaneously with the upper limit of mean contact force at the OCL design speed. The uplift of the steady arm is physically limited due to the overhead contact line design, according to EN 50119:2020.	High	None	No modification
14	Human error	C14	EU 1301/2014+A1694/2023	4.6	To prevent human error, TSI ENE specifies the professional qualifications of staff required for the energy subsystem's maintenance and operation. The procedures mentioned are not outlined in this TSI; instead, they are covered in the infrastructure manager safety management system.	High	None	No modification
15	Overloading or excessive force	C15	EU 1301/2014+A1694/2023	4.2.11	TSI ENE provides the range of the mean contact force for the OCL. The overhead contact lines shall be designed to be capable of sustaining the upper design limit of mean contact force according to EN 50367:2020+A1:2022.	High	None	No modification
				4.2.12, point 3	TSI ENE defines the maximum force (Fmax) as usually within the range of Fm plus three standard deviations (σmax S), or higher values may occur at particular locations and are given in EN 50119:2020. For rigid components such as section insulators in overhead contact line systems, the contact force can increase up to a maximum of 350 N.	High	None	No modification

7.3.16 **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 + COMMISSION IMPLEMENTING REGULATION (EU) 2019/776 of 16 May 2019 amending Commission Regulations (EU) No 321/2013, (EU) No 1299/2014, (EU) No 1301/2014, (EU) No 1302/2014, (EU) No 1303/2014 and (EU) 2016/919 and Commission Implementing Decision 2011/665/EU as regards the alignment with Directive (EU) 2016/797 of the European Parliament and of the Council and the implementation of specific objectives set out in Commission Delegated Decision (EU) 2017/1474.**

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Short circuits or arcing	C2	EU 1303/2014+A776/2019	4.2.2.2, (a)	TSI SRT states that an earthing device shall be provided at tunnel access points if they are longer than 1 km to maintain electrical safety and system integrity. Otherwise, it can result in electrical arcing and damage the OCL, pantographs, and other parts of infrastructure and vehicles.	High	None	No modification
2	Fire, or Ignition source	C3	EU 1303/2014+A776/2019	4.2.1.2	TSI SRT defines the main structure of the tunnel must withstand the temperature of the fire for a period of time that is sufficient to permit the self-rescue and evacuation of passengers and staff. Otherwise, it could damage parts of the pantograph, vehicle, OCL, and other parts of the infrastructure.	High	None	No modification
				4.2.3.1	TSI SRT states that measures to prevent fire shall be applicable for all categories of rolling stock, according to 4.2.3.1.	High	None	No modification
				4.2.3.1.2	Please note comments on the LOC&PAS TSI clause 4.2.10.2.2.	Medium	None	No modification
				4.2.3.2.2	Please note comments on the LOC&PAS TSI clause 4.2.10.3.2.	High	None	No modification
3	Improper electrical design	C5	EU 1303/2014+A776/2019	4.2.2.1	The traction power supply system in tunnels should be divided into sections if it is longer than 1km to prevent electrical faults and ensure safe operation. Otherwise, it can result in electrical arcing and damage to the OCL, pantographs, and other parts of infrastructure and vehicles.	High	None	No modification
4	Improper mechanical design	C7	EU 1303/2014+A776/2019	4.2.3.1	Please note comments on the LOC&PAS TSI clause 4.2.10.2.1. These requirements shall also apply to the on-board CCS equipment.	High	None	No modification
				4.2.3.3.4	Please note comments on the LOC&PAS TSI clause 4.2.10.4.4.	High	None	No modification
				7.1.2	Please note comments on the LOC&PAS TSI clause 7.1.1.	High	None	No modification
				7.2.1	Please note comments on the LOC&PAS TSI clause 7.1.2.	High	None	No modification
				7.3.2.2	Please note comments on the LOC&PAS TSI clause 7.3.2.21.	High	None	No modification

Gap analysis 1304/2014/EC; COMMISSION REGULATION (EU) No 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem 'rolling stock — noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU + COMMISSION IMPLEMENTING REGULATION (EU) 2023/1694 of 10 August 2023 amending Regulations (EU) No 321/2013, (EU) No 1299/2014, (EU) No 1300/2014, (EU) No 1301/2014, (EU) No 1302/2014, (EU) No 1304/2014 and Implementing Regulation (EU) 2019/777.

7.3.17

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Pollution	C20	EU 1304/2014+A1694/2023	4.2.3	TSI NOS states that it is essential to limit noise emissions produced by vehicles with pantographs during operating conditions according to this TSI, EN 16205, and EN ISO 3095. Exceeding the permissible limits of noise level could have an impact on the environment and surrounding communities.	High	None	No modification

7.3.18

Sr No	Causes	ID	Applicable RCS	Applicable clauses	Assessment of suitability	Suitability for mitigation	Identified gap	Result
1	Fire, or Ignition source	C3	EU 1304\2014	4.2.6.1.2.2	Please note comments on the LOC&PAS TSI clause 4.2.10.2.1. These requirements shall also apply to the on-board CCS equipment.	High	None	No modification
				4.2.6.1.2.3	The characteristics of electrical cables should have low flammability, low fire spread, and low smoke density, according to EN 50355, EN 13501-1, and EN 50343. Otherwise, it can result in electrical arcing and damage to the OCL, pantographs, and other parts of infrastructure and vehicles.	High	None	No modification
				4.2.6.1.2.4	Please note comments on the fire safety requirements for flammable liquid and flammable gas installations in EN 45545-7.	High	None	No modification
2	Improper electrical design	C5	EU 321/2013+A1694/20223	4.2.6.2.2	The electrical unit of the pantograph shall be designed so that direct contact is prevented. For electrical installation and insulation of the unit, please note comments on EN 50153:2002, clause 5.	High	None	No modification

7.4 List of input Regulation, Codes and Standards

T -**Test standard**
D -**Design standard**
P -**Process / Quality standard**
L -**Legislation**

NO.	Standards	Date	Title	Topic	Category (T/D/P/L)	Railway application	Analyzed
1	EN 50206-1	2010	Railway applications – Rolling stock – Pantographs: Characteristics and tests – Part 1: Pantographs for main line vehicles	Pantograph	T	Yes	Yes
2	EN 50367+A1	2022	Railway applications –Fixed installations and rolling stock –Criteria to achieve technical compatibility between pantographs and overhead contact line	Pantograph, The OCL	D	Yes	Yes
3	EN 50405	2015	Railway applications –Current collection systems Pantographs, testing methods for contact strips.	Pantograph, Contact Strips	T	Yes	Yes
4	EN IEC 61133	2021	Railway applications – Rolling stock – Testing of rolling stock on completion of construction and before entry into service.	Rail System	T	Yes	Yes
5	EN 50124-1	2017	Railway applications –Insulation coordination –Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment.	Electrical Safety	D	Yes	Yes
6	EN 50124-2	2018	Railway applications - Insulation coordination - Part 2 : over voltages and related protection.	Electrical Safety	T	Yes	Yes
7	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)	Structural requirements	D	Yes	Yes
8	EN 45545-1	2013	Railway applications — Fire protection railway vehicles — Part 1: General	Fire Safety	D	Yes	Yes
9	EN 45545-2+A1	2023	Railway applications –Fire protection on railway vehicles –Part 2: Requirements for fire behavior of materials and components.	Fire Safety	D	Yes	Yes
10	EN 45545-3	2013	Railway applications — Fire protection on railway vehicles — Part 3: Fire resistance requirements for fire barriers	Fire Safety	D	Yes	Yes
11	EN 45545-4	2015	Railway applications — Fire protection on railway vehicles — Part 4: Fire safety requirements for rolling stock design	Fire Safety	D	Yes	Yes
12	EN 45545-5	2016	EN 45545-5+A1:2016; 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 levitation vehicles	Fire Safety	D	Yes	Yes
13	EN 50388	2012	Railway Applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability.	Power supply-Subsystem	T	Yes	Yes
14	EU 1302+A1694	2014/2023	COMMISSION REGULATION (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the 'rolling	Rail System	L	Yes	yes

			stock —locomotives and passenger rolling stock' subsystem of the rail system in the European Union.				
15	EU 1301+A1694	2014/2023	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.	Rail System-Energy	L	Yes	Yes
16	EU 1303+776	2014/2019	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.	Rail System-Tunnels	L	Yes	Yes
17	EU 1304+A1694	2014/2023	COMMISSION REGULATION (EU) No 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem 'rolling stock — noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU.	Rail System-Noise	L	Yes	Yes
18	EU 321+1694	2013/2019	COMMISSION REGULATION (EU) No 321/2013 of 13 March 2013 concerning the technical specification for interoperability relating to the subsystem 'rolling stock — freight wagons' of the rail system in the European Union and repealing Decision 2006/861/EC.	Freight wagons	L	Yes	Yes

ANNEX_D – DLR Report FCH2RAIL_CGA

Co-funded by the European Union

FCH2Rail
Deliverable 7.4
Annex D - TSI Analysis DLR

Document Properties

Title	FCH2Rail Deliverable 7.4 Annex D - TSI Analysis DLR
Author	Michael Mönsters
Reviewed by	Stefanie Schöne
Date	06.10.2023
Version	1.0

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

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis	Reference
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.	Does hydrogen train operation have a negative impact on the environment?	Analysis/Tests if the train operation causes unusual environmental impact. Would leaking small amounts of hydrogen be harmful to the environment?	"Leaking hydrogen will rise and diffuse quickly in air because its low density results in high buoyancy (14 times less dense than air). Hydrogen mixes readily with air, creating an ignitable mixture (3x greater diffusivity than nitrogen in air). This hazard is especially important where hydrogen can accumulate in a confined area." https://h2tools.org/bestpractices/hydrogen-leaks "hydrogen is a climate-heating gas, with a 100-year global warming potential that is about 11 times greater than carbon dioxide" https://www.theguardian.com/environment/2022/jun/17/pollutionwatch-hydrogen-power-climate-leaks
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.	EMC is an important issue, especially for hydrogen trains, as flying sparks or static charge must be avoided due to the high ignitability and explosion hazard with hydrogen, with particular attention paid to the refueling process	Analysis/Tests if the train operation causes unusual eletromagnetic effects. Includes Hydrogen refueling stations. In General: Do hydrogen trains have a higher susceptibility to EMC or do they have a greater effect in terms of EMC?	

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis	Reference
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.	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 in this project because of max speed 120 km/h	
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.	Is that sufficiently the case for the additional installations on the roof?	Analysis/Tests if extended measures necessary regarding the insulation here due to	

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis	Reference
		The insulation shall be adequate for all system voltages the unit is designed for.		the hydrogen operation?	
4.2.8.3	Diesel and other thermal traction systems	Diesel engines are to comply with the Union legislation concerning exhaust (composition, limit values).	Do hydrogen trains fall into this category even though they emit only water vapor? Or can Hydrogen propulsion be classified as thermal propulsion because hot water vapor is emitted?	Hydrogen powered will likely 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)		In hydrogen applications, preventing leakage is even more important than with conventional fuels because of the much higher flammability and the fact that hydrogen fires cannot usually be extinguished. https://www.fwvbw.de/fileadmin/Downloads/Einsatz_Wasserstoffleitfaden.pdf
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. If the coolant in the air conditioning system is flammable, separate measures are required to reduce the risk of ignition and thus also reduce the risk related to the presence of hydrogen	

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis	Reference
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	Extinguishing hydrogen fires is much more difficult than conventional fires	There are no portable fire extinguishers for hydrogen fires. New firefighting systems are required	When hydrogen burns in the air, the flame is hardly visible in daylight; despite low heat radiation, the flame can reach 2000 °C; this makes it dangerous to approach the flame, as one can quickly get into the flame jet; extinguishing the flame is made much more difficult due to the lack of visibility; extinguishing the hydrogen flame is not recommended, certainly not with fire extinguishers; in this respect, fighting with portable fire extinguishers is not possible (presumably this is why no portable fire extinguishers exist specifically for hydrogen fires); instead, controlled burning under observation should take place https://www.fwvbw.de/fileadmin/Downloads/Einsatz_Wasserstoffleitfaden.pdf
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	Extinguishing hydrogen fires is much more difficult than conventional fires and thus new firefighting measures are needed (see comment on 4.2.10.3.1)	Detection of hydrogen fires is likely to be much more difficult than for conventional fuels, since the flame is barely visible in daylight when burning in air and has little heat radiation. https://www.fwvbw.de/fileadmin/Downloads/Einsatz_Wasserstoffleitfaden.pdf

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis	Reference
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).	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. In a hydrogen train, a hydrogen explosion must be avoided at all costs. The central objective is to secure and make the hydrogen tanks resistant in the event of a fire on board the train.	Detection of hydrogen fires is likely to be much more difficult than for conventional fuels, since the flame is barely visible in daylight when burning in air and has little heat radiation. https://www.fwvbw.de/fileadmin/Downloads/Einsatz_Wasserstoffleitfaden.pdf

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis	Reference
		— 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.			
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	Further Analysis on how hydrogen related ventilation is influencing smoke control emergency situations. however, there is an increased risk that dangerous concentrations of hydrogen can then form in the interior air of the train if there is a	

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis	Reference
			than "traditional" smoke?	leak in the hydrogen system.	
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	When hydrogen burns in the air, the flame is hardly visible in daylight; despite low heat radiation, the flame can reach 2000 °C; this makes it dangerous to approach the flame, as one can quickly get into the flame jet; extinguishing the flame is made much more difficult due to the lack of visibility; extinguishing the hydrogen flame is not recommended, instead, controlled burning under observation should take place https://www.fwvbw.de/fileadmin/Downloads/Einsatz_Wasserstoffleitfaden.pdf

Chapter	Chapter Name	TSI Requirement	Assessment	Action for further analysis	Reference
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 or monitoring systems?	This is no gap in the regulation	
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.	Care must be taken to ensure that the additional roof structures for the hydrogen drive do not protrude into the pantograph clearance. 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. However, if the existing categories are to be used, since a hydrogen train with a fuel cell can be said to be thermally driven (e.g. reactions in the fuel cell, emission of water vapor), hydrogen trains could be adequately covered by the existing definition.
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	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. When a hydrogen train is stationary, there is a small amount of steam and noise coming from the fuel cell area. Fan noise may also be audible. However, all of these noises are below those of a combustion train at idle speed. When the hydrogen train accelerates, the startup noise of the electric drive is added.

		of both thermal and electric power at the same time the less restrictive limit value applies.		Here it is necessary to investigate which noises dominate.
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	Reference
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, because in the case of hydrogen trains, there is an increased risk that dangerous concentrations of hydrogen can then form in the interior air of the train if there is a leak in the hydrogen system.	Maybe it could be safer to also apply the category B requirements to (otherwise) category A trains when hydrogen is involved. How are hydrogen fires fought? How does the firefighting differ from other fires? Does this lead to conclusions about extended capabilities of the hydrogen train to have to reach a specific firefighting location?	When hydrogen burns in the air, the flame is hardly visible in daylight; despite low heat radiation, the flame can reach 2000 °C; this makes it dangerous to approach the flame, as one can quickly get into the flame jet; extinguishing the flame is made much more difficult due to the lack of visibility; extinguishing the hydrogen flame is not recommended, certainly not with fire extinguishers; in this respect, fighting with portable fire extinguishers is not possible (presumably this is why no portable fire extinguishers exist specifically for hydrogen fires); instead, controlled burning under observation should take place https://www.fwvbw.de/fileadmin/Downloads/Einsatz_Wasserstoffleitfaden.pdf
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	Due to the extremely low minimum ignition energy and the wide ignition range in air, hydrogen can ignite much faster than methane/natural gas, for example. In addition, hydrogen is approx. 14 times lighter than air; hydrogen therefore accumulates indoors in the upper area of the room. This can lead to dangerous air concentrations that quickly reach ignitable mixtures; even very slight sparking, such as the rubbing of textiles, is sufficient for ignition. https://www.fwvbw.de/fileadmin/Downloads/Einsatz_Wasserstoffleitfaden.pdf
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	Are the heat resisstance requirements suited for fires involving hydrogen?	The conditions under which hydrogen burns or explodes directly must be checked. In the case of a hydrogen fire, it must be clarified whether it develops more quickly and	When hydrogen burns in the air, the flame is hardly visible in daylight; despite low heat radiation, the flame can reach 2000 °C; this makes it dangerous to approach the flame, as one can quickly get into the flame jet; extinguishing the flame is made much more difficult due to the lack of visibility; due to the extremely low minimum ignition energy and the wide ignition range in air, a

	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.		unpredictably than conventional fires and what control is possible, especially in the tunnel. In the case of a hydrogen explosion in the tunnel, it must be investigated how this can be avoided under all circumstances, as the effects in the tunnel would be catastrophic.	hydrogen fire can spread much faster and more uncontrolled than conventional fires; this makes it difficult to fight; extinguishing the hydrogen flame is not recommended, instead controlled burning under observation should take place; leakage of large quantities of hydrogen without burning is unlikely due to the extremely low minimum ignition energy; in tunnels, particular care should be taken to ensure that no CO2 extinguishing systems are installed, as CO2 ignites hydrogen directly https://www.fwvbw.de/fileadmin/Downloads/Einsatz_Wasserstoffleitfaden.pdf

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

ANNEX_E – ADIF Report FCH2RAIL_CGA

REGULATORY GAPS IN THE APPLICATION OF HYDROGEN TECHNOLOGY IN ADIF INFRASTRUCTURES

WP 7–Normative Framework

Task 7.1–Identification of Gaps in regulatory framework

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Date	11.09.2023
Document ID	FCH2RAIL-823879026-296

Dissemination Level	
PU: Public	**X**
CO: Confidential, only for members of the consortium (including the Commission Services):	

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Co-funded by the European Union

Document Status History			
Status Description	**Date**	**Partner**	**Status Code in Filename**
Document of normative gaps	11.09.2023	Inés Vadillo, Santiago Santamaría, ADIF	Final Document

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No. 101006633. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

Executive Summary

This document is Deliverable D7.4: 'Complementary gaps in analysis framework, 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 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.

As Spain's rail infrastructure manager, ADIF plays a key role in the authorisation of the train demonstrator to run on ADIF lines, as well as the analysis of interfaces between the new train concept and the infrastructure, such as the hydrogen refuelling system and its location. For this reason, since the start of the project in January 2021, ADIF has been working on the location of the hydrogen refuelling points that will be used to locate the portable hydrogen tank supplied by CNH2 to the CIVIA prototype during the project tests.

Once the detailed study of the different locations that have been selected for the installation of the hydrogen generator (HRS) has been carried out and the requirements of the Portable Refuelling System have been studied, which have been included in deliverable D1.8 "Requirements for the HRS locations". One of these generic requirements is the need to have a lightning rod installation, either its own or to use an existing one in the vicinity of the selected location. This has led to it being treated as a regulatory gap for the reasons explained in the following points.

Define the regulatory GAPs related to the railway infrastructure, whether it is related to the refuelling infrastructure, the vehicle or the interaction of both with all the elements and agents in the railway operation.

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Contents

1. Background

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. 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 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
- 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 task.

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2. Analysis of Regulatory Gaps

2.1 Documentation for legalisation of a portable hydrogen system

A refuelling installation requires documentation prior to its authorisation in order to be installed on a railway infrastructure, although the authorisation procedures are not defined for hydrogen supply installations, as none have been installed to date, and there may be greater uncertainty, even if in the case of a portable installation that is only there for a few weeks.

Within the authorisation processes of the Infrastructure Administrator (Adif), there is no procedure applicable to hydrogen installations, which is why it is identified as a regulatory GAP as it is not possible to clearly define it with the current procedures.

To cover this GAP, similarity will be sought with other authorisation procedures, in this case diesel (PRN_TOD_O04 - procedure for the supply of diesel B to rail vehicles at ADIF fuel facilities). However, there are fields such as justification of ATEX zones or the effects of electrical installations that have been identified as critical and singular points in this type of installations that will be covered by specific projects and singular authorisations. A reference standard could be the UNE-ISO 19880-1.

2.2 Application of the Royal Decree of the European Union RUE 402/2013 to a railway refuelling installation

Any change or new element in the railway infrastructure must implement the common safety method defined by the RD 402/2013 transposing the ENFORCEMENT REGULATION (EU) No 402/2013 on the adoption of a common safety method for risk evaluation and assessment.

Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety will also be mandatory.

Article 6 on Common Safety Methods (CSM) describes.

1. CSMs shall describe the procedures for assessing safety levels, the achievement of safety targets and compliance with other safety requirements, including, where appropriate, through an independent assessment body, by developing and defining:

    a) The risk assessment and evaluation methods.

    b) Methods for assessing conformity with the requirements of safety certificates and safety authorisations issued in accordance with the provisions of Articles 10 and 12.

In the application of the common safety methods a regulatory GAP has been found where it is defined which type of ASBO or ISA safety certification is applicable, scope or suitability for the cases of an existing train incorporating new propulsion elements such as batteries and hydrogen cells, a hydrogen refuelling, storage and compression facility and the train, hydrogen plant and infrastructure interface.

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To clarify in this respect, an AsBo is an independent body (usually a private company) authorised to carry out risk analysis (assessment and evaluation) according to Implementing Regulation 402/2013 on the adoption of a common safety method and risk assessment and evaluation and Regulation 2015/1136 according to ISO 17020.

An ISA is an independent body (usually a private company) authorised to carry out the independent safety analysis (and secondly the reliability, availability and maintainability, RAMS) of a railway application or product in accordance with CENELEC standards: UNE-EN50126 and UNE-EN50129.

2.3 Lighting Arrester

A lightning rod is an instrument whose purpose is to attract an ionised lightning strike from the air in order to conduct the discharge to the ground in such a way that it does not cause damage to people and buildings.

There are no lightning conductors to protect people or buildings in logistics railway installations where containers are moved and fuels such as diesel are supplied. There are also no references to accidents or incidents caused by lightning discharges at such facilities.

It could be interpreted that a hydrogen refuelling installation where hydrogen is stored, compressed, and supplied at high pressure should be protected against lightning strikes, although it would not be appropriate to install it in the vicinity as it may attract lightning.

The lightning arrester by definition would not be appropriate to install in the refuelling installation itself, as it could attract lightning strikes, but it is appropriate to install this element in the vicinity of the hydrogen plant where lightning strikes do not pose a danger and provided that the total independence of the insulation systems connected to the earth is guaranteed.

Another factor to take into account is that the purpose of lightning conductors is to protect people or buildings, not open installations.

A regulatory GAP has been identified as the advisability or obligation of installing a lightning conductor in the vicinity of a hydrogen refuelling installation and, if so, the recommended distance from the installation.

It has also been identified as a GAP to define whether in a portable installation it would be essential or could be covered by complementary measures to protect personnel.

The reference standards are the CTE (Technical Building Code) and UNE 21186:2011.

The lightning conductor as a protection element and its installation is included in the Technical Building Code (CTE) in which it was initially taken as a reference since it states: "The Technical Building Code (CTE) applies to public and private buildings of a permanent nature whose projects or technical reports signed by a competent technician need to have the corresponding licence or legally required authorisation".

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According to the UNE 21186:2011 standard "Lightning protection: Lightning arresters with arrester", it would not be necessary to install a lightning arrester in an Adif infrastructure given the characteristics of the same.

This standard could be complemented with the UNE-ISO 19880-1 standard where in section 10.1.4 it is stated that "Lightning protection must be provided when required". According to the characteristics of this installation, this would not be necessary in a temporary hydrogen installation similar to the one in the project.

Therefore, a detailed analysis of the benefits and disadvantages of installing a lightning arrester as the only one installed in a specific railway area or the definition of mitigation measures such as the prohibition of the operation of the Refuelling System during climatic events that cause lightning strikes is still pending.

Another of the requirements to be defined in this normative gap is to be able to distinguish whether this installation is provisional/temporary or whether it is a definitive installation, since the characteristics that each of them may require may vary to such an extent that the installation of a lightning protection system may not be necessary.

Taking into account the UNE 21186:2011 and UNE-ISO 19880-1 standards, and the non-application of the CTE, a specific standard is necessary to define whether it is essential to have lightning protection elements in the installation or not.

2.4 Grounding points

A regulation is needed to determine the maximum resistivity of the ground that allows an unwanted shunt or discharge, caused for example by a lightning strike, to be directed at a sufficient depth so that it does not interact with the elements of the refuelling installation itself or with the control, command and signalling elements, as well as with those belonging to the track circuits that could interfere with normal operation.

In the case of the FCH2Rail project, the installation of the Portable Hydrogen Refuelling System requires the installation of earthing systems in a terrain where the resistivity prevents them from being installed on the surface and a deep trench must be dug to prevent undesired shunting between the track elements and the hydrogen generator.

2.5 Safety distances to railway elements

The hydrogen refuelling installation has safety systems, called venting systems, which come into operation when any kind of problem is detected in the pressurised systems. They work by releasing the pressurised hydrogen to the outside. This venting of the fuel gas can be modelled as an inverted cone from the refuelling system or a dome, where no ignition point should interfere with this volume.

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This so-called Explosive Atmospheres Zone (ATEX) is identified as a regulatory GAP, since there are no railway regulations that delimit the safety zones that can interfere between a Refuelling System and the Railway Safety Zone and therefore with the elements that can access this ATEX zone. It is necessary to define a regulation that sets out the necessary safety distances for a hydrogen installation within a railway environment and any system, whether it is a storage or refuelling system.

2.6 Passage through underground stations and tunnels

A regulatory GAP has been identified as the passage of hydrogen trains through tunnels, underground stations and bathtubs, these being urban routes without a natural gradient that allows the train to leave by releasing the brakes without any propulsion.

This GAP is identified because there is no specific regulation governing the traffic of this type of trains with hydrogen as propulsion fuel. Therefore, precautionary measures are taken during the tests to avoid the circulation of the hydrogen train through underground stations with a large number of passengers, especially those with bathtubs. These precautionary measures can be similar to the Dangerous Goods regulation (RD 412/2001, which regulates various aspects related to the transport of dangerous goods by rail), although this regulation is not directly applicable, as the transport of hydrogen in this case is not considered dangerous goods as it is self-consumption, or in other words, it is the fuel used for its propulsion. The RD 412/2001 regulation indicates, among other aspects, the areas and general rules for stopping or not stopping, the actions of the driver in the event of an emergency or of the competent authorities.

It is therefore necessary to have a specific regulatory framework for traffic in these areas with special characteristics.

2.7 Emergency Protocol

The GAP identified would consist of the non-existence of a standard in which it is necessary to establish a specific regulation for the implementation of an emergency protocol that can establish coordination between the hydrogen train operating company and the emergency and protection services and the infrastructure management company. In the case of the FCH2Rail project tests, in order to make up for this lack of regulations, a Self-Protection Protocol is drawn up that coordinates Renfe with the emergency services of the communities and provincial councils where the tests are carried out, among others.

2.8 Train - Hydrogen Refuelling Station Interface

As rail infrastructure manager, one of the main objectives of this project is to install a Hydrogen Refuelling System to supply fuel to trains powered by a fuel cell. This involves guaranteeing the security

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of supply, as well as a safe and efficient refuelling process. This process identifies a new regulatory GAP, as it is necessary to develop a protocol and regulations that guarantee a communications system that registers a minimum amount of data that makes it possible to view this data during refuelling and facilitates an increase in the safety and efficiency of the process.

To this end, this regulation should collect the data in an open-source format that promotes the development and international interoperability to encourage the use of this technology.

2.9 Train - Infrastructure Interface

This regulatory GAP is identified due to the absence of this traction technology in the current rolling stock, where the use of the pantograph and hydrogen can be interspersed with the use of batteries, there is an absence in the Control, Command and Signalling (CMS) that allows, from the communications of the different safety systems, to act on the train to order the raising or lowering of the pantograph.

This action shall be carried out at the moment when either the train reaches a track where the electrification of the line ends, or on the contrary, when the train returns to the electrified part of the line. This change in the catenary must be reflected both in the track signalling and recorded on the safety system beacons which, as explained above, must be the ones to warn and act on the pantograph.

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