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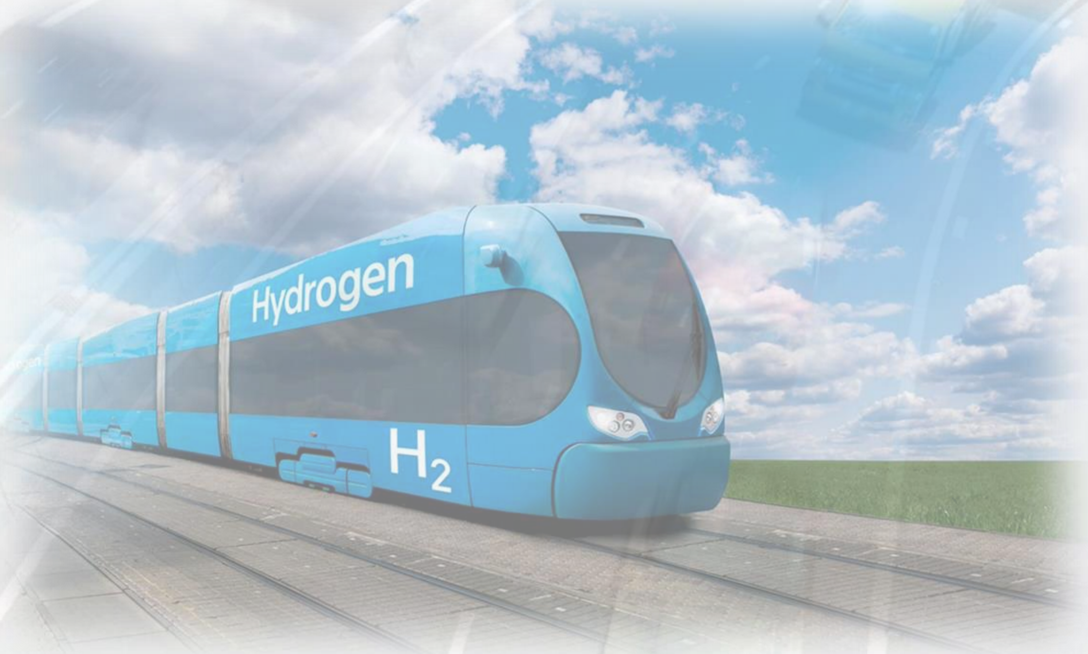

PROJECT REPORT RPN3016

Impact of Hydrogen Standards on the UK Transportation System (iHYLAST)

Deliverable D2

Workshop Findings

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Executive Summary

Hydrogen fuel has been identified by GB railways as a candidate technology to decarbonise the railway. Efforts in the UK are being mirrored globally, and there are current initiatives to progress the homologation of fuel cell, hydrogen, and line side equipment into the rail sector. These efforts are proceeding in parallel with engineering and manufacturing developments; despite not having global standards and regulations yet. There is a need to develop a framework and understanding to harmonise standards to enable the rapid, safe, and cost-effective demonstration of hydrogen trains and their refuelling infrastructure.

This project was commissioned to map relevant hydrogen standards and regulations and identify the key barriers for the safe demonstration of hydrogen trains in the UK. TRL worked with the University or Birmingham and Durham University to address the following research question:

1. What are the current barriers/challenges faced by the UK market relating to the safe trialling of hydrogen fuel cell trains?

Two approaches were used to address this research question. Firstly, the university of Birmingham carried out a literature review and review of evidence of hydrogen standards and regulations in rail.

Secondly TRL led on a stakeholder engagement workshop to validate some of the initial results of the University of Birmingham's research and investigating potential barriers for demonstration. Policy makers and relevant regulatory bodies could use the findings of this report to address safety issues and potential regulatory needs that will enable the demonstration of hydrogen trains in the UK.

Key findings from the workshop

The responses were analysed using thematic content analysis to produce insights that explain what the gaps in standards and barriers to deployment of hydrogen as a fuel source for trains.

The main themes identified in the workshop related to:

- The current gaps in the safety standards,
- The key safety showstoppers for the demonstration of hydrogen trains,
- The overlaps with other sectors deploying hydrogen fuelled vehicles,
- What the future of hydrogen in rail could look like, and
- People's attitudes regarding the location of the hydrogen fuel cell tanks within the rolling stock.

Conclusions

While there are still many unknowns surrounding the safe deployment of hydrogen trains in the UK due to the lack of global standards and regulations, there is an enthusiasm and desire from relevant stakeholders to pursue this pathway. Several recommendations were made to help expedite the rollout of hydrogen trains**,** including:

1. Ensure standards and regulations use clear and simple language

2. For timely consultations with appropriate bodies responsible for developing legislation to take place
3. The development of working groups or hydrogen safety rail task forces to better understand what is needed to develop the necessary standards
4. To review the approaches of alternative sectors in the UK have taken to expedite the processes needed to integrate hydrogen in the UK rail network, in particular to work with the Railway and Safety Standards Board in harmonising the efforts across the sector.
5. To review and explore the processes Germany have taken to become the leading country of the deployment of hydrogen trains

1 Background

There is considerable momentum within the rail industry to rapidly deploy hydrogen fuelled trains to achieve decarbonisation.

Hydrogen fuel has been identified by GB railways as a candidate technology to decarbonise the railway. Efforts in the UK are being mirrored globally, and there are current efforts to understand the homologation of fuel cell, hydrogen, and line side equipment into the rail sector. These efforts are proceeding in parallel with the engineering which is advancing at pace and delivering numerous mainline applications in the coming months and years. There is a need to develop a framework and understanding to harmonise the standards in the hydrogen sector with those in the rail sector to enable the rapid, safe, and cost-effective deployment in service applications.

Hydrogen can be produced from many different renewable and non-renewable feedstocks and technological pathways, with widely varying greenhouse gas emissions. For hydrogen to have a role in future low-carbon energy systems, it is necessary to demonstrate that it has sufficiently low carbon emissions but also, that its deployment in regular rail operations is safe.

Therefore, this project was commissioned to map relevant hydrogen standards and regulations that apply to the safe operation of hydrogen fuel cell trains and as well as discussing with relevant stakeholders how practical and implementable those safety measures are. TRL worked with the University or Birmingham and Durham University to address the following research questions:

1. What are the current barriers/challenges faced by the UK market relating to the safe trialling of hydrogen fuel cell trains?
2. What new standards and regulations are required or need updating to facilitate the deployment of hydrogen rail demonstrations?

1.1 Structure of the report

The report is structured as follows:

- Sections 1.2 and 1.3 set the context for the research,
- Section 2 details the method,
- Section 3 summarises the workshop findings,
- Section 4 presents the discussion, and
- Section 5 presents conclusions and recommendations that emerged from the workshop discussion.

1.2 Hydrogen in Rail

The UK government is planning to ban diesel-only trains by the year 2040 (Powley, 2018[1]). Similar intentions are echoed by several EU states (Briginshaw, 2019[2]). The case to phase out diesel trains is multipronged, including reasons such as meeting net-zero targets, fuel supply security (The Role of Hydrogen and Fuel Cells in Delivering Energy Security for the UK, 2017[3]). and concerns about air quality in the direct vicinity of diesel trains (Research into air quality in enclosed railway stations, 2019[4]; Brahmin Soua, 2021[5]).

From a technical perspective, running electric trains using overhead line electrification (OLE) is the preferred method to replace diesel trains. Electric trains are not only cheaper to run than diesel trains, but they are also quieter, locally cleaner (emissions) and quicker. Nonetheless, the OLE capital investment might be too high for routes with low traffic or prohibitively expensive for routes that require substantial infrastructure adaptation, e.g., increasing tunnel clearance. The aforementioned factors combined with a lack of sustained political will to electrify has led only 40% of the UK rail network to be electrified (Traction Decarbonisation Network Strategy: Interim Programme Business Case, 2020[6]).

Hydrogen trains are a promising alternative to electrification when the case for electrification cannot be justified. They can be a low-carbon option when the hydrogen fuel sourced was created using renewable energy. They also exhibit many of electrification's benefits, namely quietness and lack of local emissions. Unlike battery-only trains, hydrogen trains are capable of a longer travel range which makes it more likely to replace diesel on longer branch lines.

The most common variant of hydrogen traction is the fuel cell hybrid, shown in Figure 1. The fuel cell converts hydrogen fuel into electric power that drives the traction and auxiliary loads on-board. Water in both vapor and liquid forms are released as a by-product. A traction battery is present to support the fuel cell during peak acceleration periods. The battery doubles as an energy storage device for recovering kinetic energy during periods of regenerative braking. Recovering this kinetic energy is vital for the business case, as it can lead up to 30% fuel savings.

[1] Powley, T. (2018). Diesel-only trains in UK to be phased out by 2040. *Financial Times*. Retrieved from https://www.ft.com/content/026e3bc6-0f4e-11e8-940e-08320fc2a277

[2] Briginshaw, D. (2019). Europe leads the charge to replace diesel traction. *International Railway Journal.* Retrieved from https://www.railjournal.com/opinion/europe-leads-charge-replace-diesel-traction/

[3] The Role of Hydrogen and Fuel Cells in Delivering Energy Security for the UK. (2017) *H2FCSUPERGEN.*

[4] Research into air quality in enclosed railway stations. (2019). *RSSB*

[5] Brahim, S. (2021). Emission-free train solutions to deliver railway decarbonisation. Retrieved from Alstom: https://www.alstom.com/press-releases-news/2021/11/emission-free-train-solutions-deliver-railway-decarbonisation

[6] Traction Decarbonisation Network Strategy: Interim Programme Business Case. (2020). *Network Rail*.

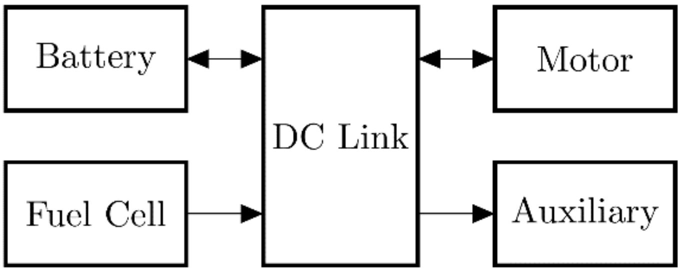

Figure 1: Fuel cell hybrid. Arrows depict flow of electric power.

Many rolling stock manufacturers have expressed interest in supplying hydrogen trains including names like Alstom, Siemens, CAF, Talgo and Stadler. Their progress in this regard is varied ranging from experimental attempts to already signing deals with transport companies. Delivery dates range between 2022-2024. Most publicised attempts focus on regional passenger trains running under 140 km/h. The strategy adopted is to convert the traction system of an existing train platform into hydrogen. This keeps costs down because much of the existing train platform remains unchanged.

Alstom was the first to run extensive public passenger testing in Europe (more than a year) using the Coradia iLint in Lower Saxony Germany. This has led to contracts being signed with transport companies in Lower Saxony and Frankfurt Germany as well as with the Italian region Lombardy.

Stadler is to supply some hydrogen trains to the San Bernardino County Transportation Authority (Green-Tech for the US: Stadler Signs First Ever Contract for Hydrogen-Powered Train, 2019[7]). Siemens will deliver hydrogen trains to various German regions in Bayern (Siemens Mobility develops hydrogen train for climate-neutral rail transport in Bavaria, 2021[8]), Baden (Deutsche Bahn and Siemens Mobility present new hydrogen train and hydrogen storage tank trailer, 2022[9]) and Berlin (First hydrogen-powered trains for the Berlin-Brandenburg metropolitan region, 2022[10]).

[7] Green-Tech for the US: Stadler Signs First Ever Contract for Hydrogen-Powered Train. (2019). Retrieved from Stadler: https://www.stadlerrail.com/en/media/article/green-tech-for-the-us-stadler-signs-first-ever-contractfor-hydrogen-powered-train/649/

[8] Siemens Mobility develops hydrogen train for climate-neutral rail transport in Bavaria. (2021). Retrieved from Siemens: https://press.siemens.com/global/en/feature/siemens-mobility-develops-hydrogen-train-climate-neutral-rail-transport-bavaria

[9] Deutsche Bahn and Siemens Mobility present new hydrogen train and hydrogen storage tank trailer. (2022). (Siemens) Retrieved from https://press.siemens.com/global/en/pressrelease/premiere-deutsche-bahn-and-siemens-mobility-present-new-hydrogen-train-and-hydrogen

[10] First hydrogen-powered trains for the Berlin-Brandenburg metropolitan region. (2022, June 27). (Siemens) Retrieved from https://press.siemens.com/global/en/pressrelease/first-hydrogen-powered-trains-berlin-brandenburg-metropolitan-region

CAF is currently co-developing its hydrogen traction offering within the FCH2Rail consortia (Europe Selects the consortium led by CAF for the development of a hydrogen train prototype, 2020[11]). Talgo is yet developing its solution using a prototype called H2P (Talgo's hydrogen train will be ready in 2023, 2020[12]).

The train leasing company Porterbrook successfully converted a retired Class 319 to fuel cell hybrid and tested it on the UK mainline, shown in Figure 2 (HydroFLEX offers zero-emission rail travel, 2020[13]). Also in the UK, Network Rail has identified at least 900 single-track-km as suitable to be served by hydrogen traction, this is shown in Figure 3 (Traction Decarbonisation Network Strategy: Interim Programme Business Case, 2020[14]).

Figure 2: The HydroFLEX train.

[11] Europe Selects the consortium led by CAF for the development of a hydrogen train prototype. (2020). *CAF.* Retrieved from https://www.caf.net/en/sala-prensa/nota-prensa-detalle.php?e=316

[12] Talgo's hydrogen train will be ready in 2023. (2020). *Talgo.* Retrieved from https://www.talgo.com/home-highlights

[13] HydroFLEX offers zero-emission rail travel. (2020). *Porterbrook.* Retrieved from https://www.porterbrook.co.uk/innovation/hydroflex-cop

[14] Traction Decarbonisation Network Strategy: Interim Programme Business Case. (2020). *Network Rail.*

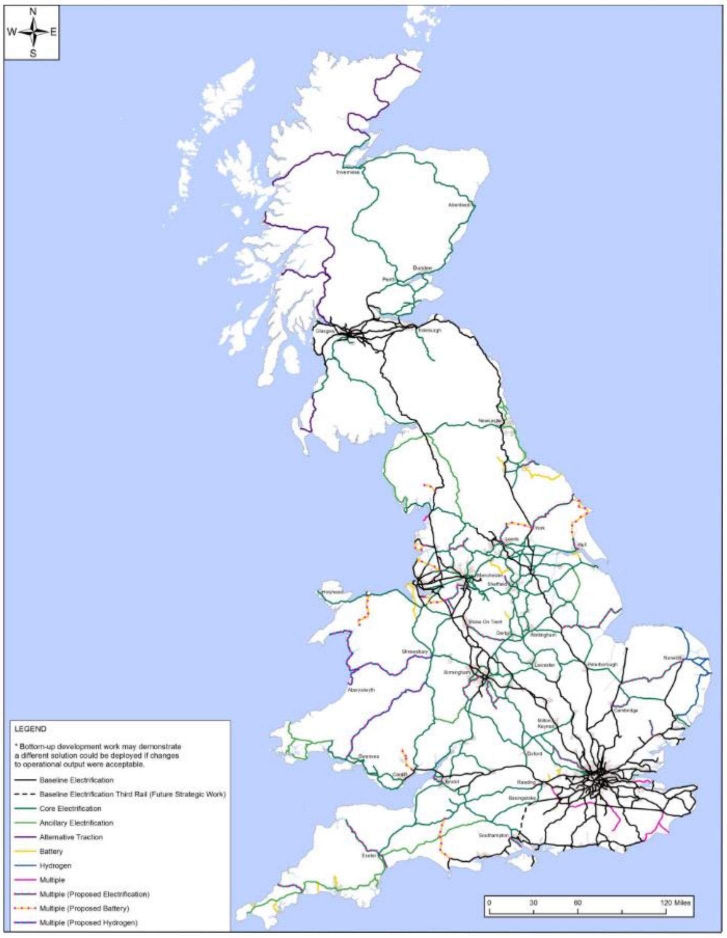

Figure 3: Recommended traction technology to decarbonise UK rail network. Adopted from (Traction Decarbonisation Network Strategy: Interim Programme Business Case, 2020)

Hydrogen was also chosen for the trams of the Chinese cities Tangshan (Fuel cell tram enters service in Tangshan, 2017[15]) and Foshan (World's First Fuel Cell Tram for Foshan China, n.d.[16]). The main motive behind hydrogen trams is to avoid installing catenary in city streets which might be deemed too disruptive or visually unappealing.

Hydrogen traction is likely also to play a role in rail freight. Activity for such is surfacing in North America where rail moves more freight than passengers (Canadian Pacific expands its

[15] Fuel cell tram enters service in Tangshan. (2017). Retrieved from https://www.railwaygazette.com/technology-data-and-business/fuel-cell-tram-enters-service-in-tangshan/45399.article

[16] World's First Fuel Cell Tram for Foshan China. (n.d.). *Ballard* Retrieved from https://www.ballard.com/docs/default-source/motive-modules-documents/case-study-foshan-gaming-tram-final-web.pdf?sfvrsn=935ddd80_4

Hydrogen Locomotive Programme, 2021[17]; Wabtec and GM to Develop Advanced Ultium Battery and HYDROTEC Hydrogen Fuel Cell Solutions for Rail Industry, 2021[18]).

1.3 Hazards and Safety Plan

Using hydrogen as a propulsion fuel is novel to the railways and would thus introduce new hazards. Railways EU-wide use the common safety method for risk evaluation and assessment (CSM-REA) to build the safety case for any technical, operational and organisational changes (Common Safety Method for Risk Evaluation and Assessment, 2018[19]). Figure 4 shows a flowchart for carrying out a CSM-REA. Hydrogen introduces technical changes due to new rolling stock and depots, for which operational changes are surely to follow suit.

The explosion hazard caused by a hydrogen leak is among the most concerning for the railways. A leak originating from the storage tanks on-board the train could be caused by faulty equipment, derailment or a train crash. Stationary storage tanks at depots and refuelling points could also pose this hazard. Risks are to be mitigated by adequate ventilation to the outdoors and judicious tank placement. However, the risk could remain high should a train leak hydrogen inside a tunnel, with longer tunnels posing a bigger hazard due to higher chances of gas accumulation. To this end, part of the HyTunnel project investigated emergency crew codes and practices for hydrogen fires (HyTunnel Deliverable 1.4, 2020). It was found that emergency crews can deal with hydrogen fires in the context of a chemical at industrial sites. However, a gap was identified for when hydrogen is used as a vehicle propulsion fuel inside a tunnel, e.g., the UK's National Technical Specification Notice (NTSN) and Safety in Railway Tunnels (SRT) (National Technical Specification Notice: Safety in Railway Tunnels, 2021) makes no mention of hydrogen fuel.

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[17] Canadian Pacific expands its Hydrogen Locomotive Programme. (2021). *Global Railway Review*. Retrieved from https://www.globalrailwayreview.com/news/129360/canadian-pacific-expands-hydrogen-locomotive-programme/

[18] Wabtec and GM to Develop Advanced Ultium Battery and HYDROTEC Hydrogen Fuel Cell Solutions for Rail Industry. (2021). *Wabtec Corporation.* Retrieved from https://www.wabteccorp.com/newsroom/press-releases/wabtec-and-gm-to-develop-advanced-ultium-battery-and-hydrotec-hydrogen-fuel-cell-solutions-for-rail

[19] Common Safety Method for Risk Evaluation and Assessment. (2018). *Office for Rail and Road*.

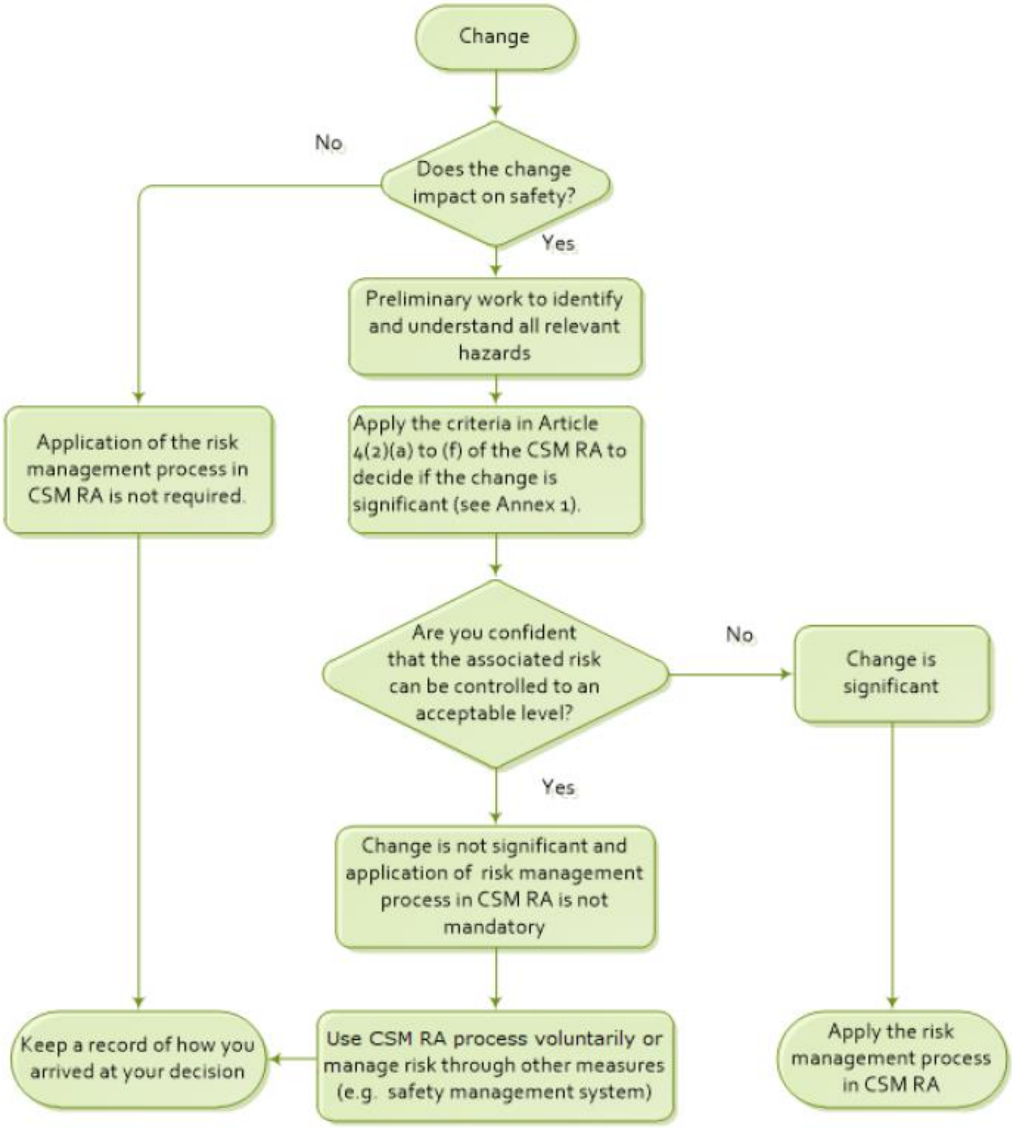

Figure 4: Flowchart for applying the CSM-REA. Adopted from (Common Safety Method for Risk Evaluation and Assessment, 2018).

1.3.1 Main Standards for Depot and Refuelling

ISO 19880 defines the minimum design, installation, commissioning, operation, inspection and maintenance requirements for the safety of fuelling stations dispensing gaseous hydrogen to light duty road vehicles.

ISO 17268 defines the design, safety and operation characteristics of gaseous hydrogen vehicle refuelling connectors.

ISO 26142 defines the performance requirements and test methods of hydrogen detection apparatus for monitoring hydrogen concentrations in stationary applications.

ISO 23273 specifies the requirements for protecting persons and environment inside and outside gaseous hydrogen vehicles.

J2601 fuelling protocols for gaseous hydrogen including pressure and flow rate limits at various ambient temperatures.

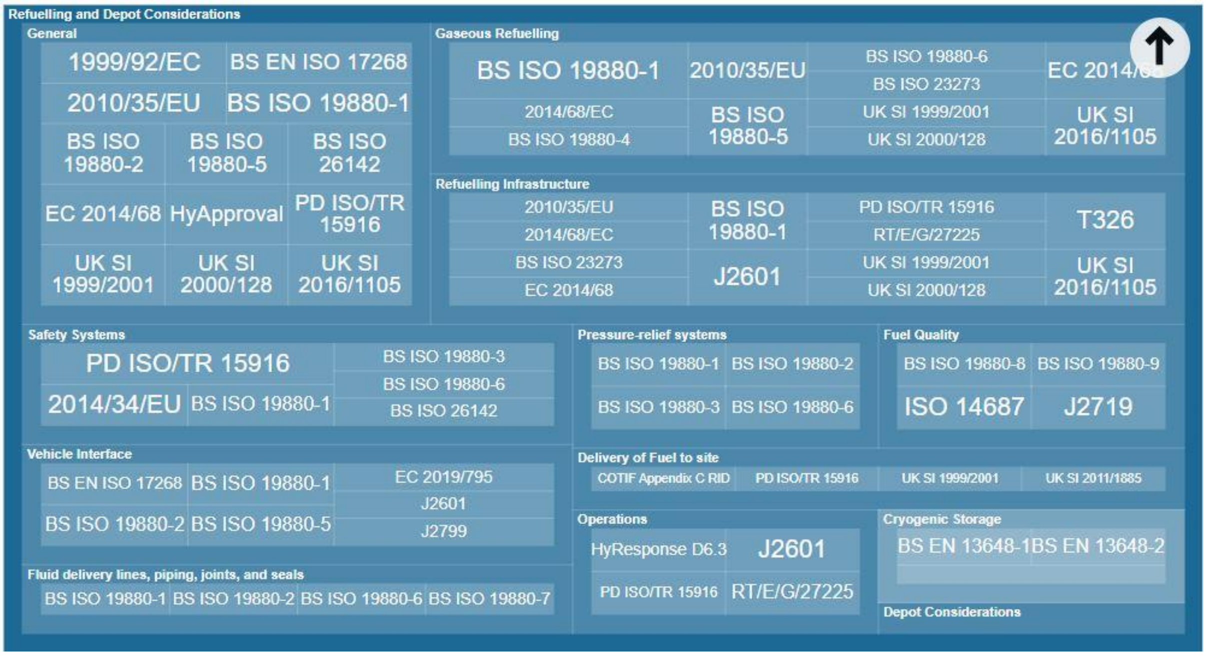

Figure 5 Relevant hydrogen refuelling standards in rail.

1.3.2 Main Standards for Hydrogen Train Itself

BS EN IEC 62928 specifies design, operation parameters, safety recommendations and testing for lithium-ion batteries for railway traction. Needed because most hydrogen trains are fuel cell hybrid.

ISO 14687 hydrogen fuel quality for vehicle applications.

IEC 63341-1 fuel cell power system performance and safety requirements for hydrogen railway vehicles.

IEC 63341-2 addresses gaseous hydrogen storage on-board train as well as interface with refuelling points.

IEC 62864-1 specifies performance characteristics and test methods for hybrid rail vehicles.

Figure 6 Relevant hydrogen rail systems standards.

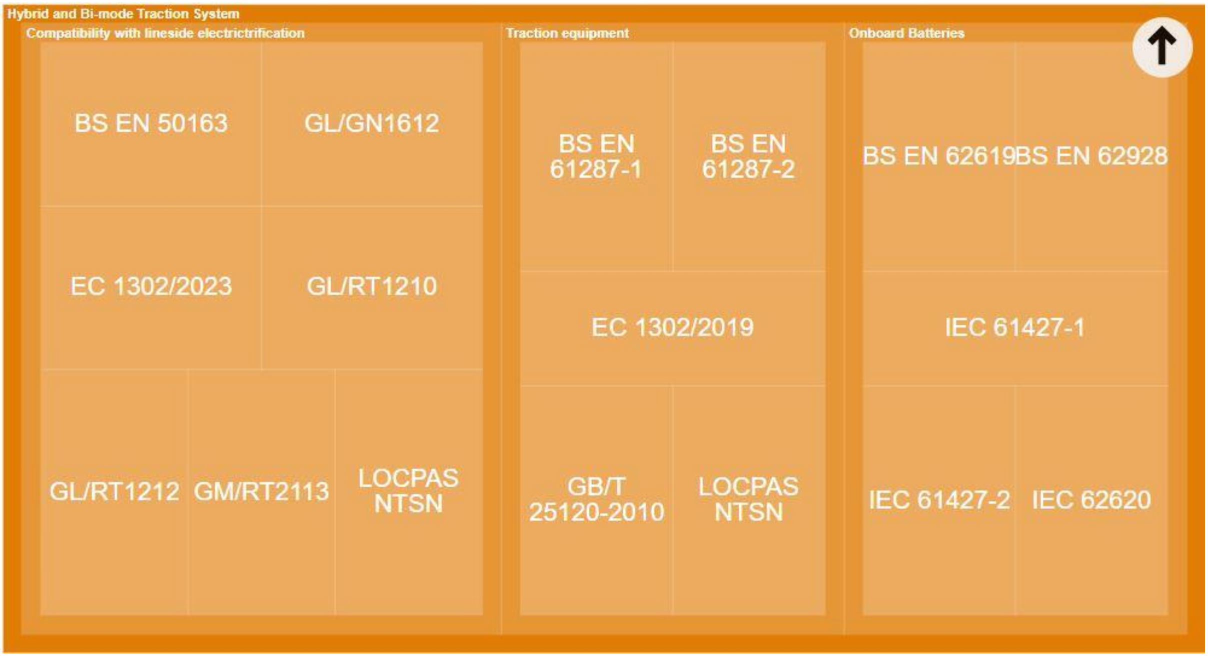

Figure 7 Relevant standards for hydrogen rail traction systems.

2 Workshop Method

2.1 Rationale

A workshop was deemed to be the most appropriate method to address the research questions, as these facilitate discussions, promote interactions between participants and allow elaboration on remarks. Conducting a workshop with experts enabled us to understand the viewpoints and insights from a range of rail industry backgrounds.

2.2 Recruitment

Stakeholders were identified by collating relevant contacts from publicly available repositories and our professional networks within the hydrogen and/or rail sector. An invitation to participate in the workshop was sent to 61 stakeholders via email (Appendix A) which included a link to an Eventbrite page (Appendix B) where stakeholders could register their interest. The registration form had mandatory fields for stakeholders' names, email addresses, organisation, and job title. When individual names could not be identified within an organisation, invitations to attend the workshop were sent to the companies via the standard contact method stated on their website. Attempts to contact key stakeholders within the rail and/or hydrogen industry were also made via LinkedIn when email addresses were not accessible. A database was created using Microsoft Excel to maintain and update stakeholder activity to ensure that invitations were tracked and confirm stakeholders' consent. To boost engagement, a Facebook post was created via the TRL Trials page and announcements posted in LinkedIn feeds. This elicited 22 stakeholders to proactively register for the event.

In the week prior to the workshop, confirmed stakeholders who were deemed appropriate to take part (i.e., representatives of organisations in the hydrogen rail supply chain and its agencies, or academic researchers) were sent a second email (Appendix C) with an information pack consisting of an information sheet (Appendix D) and a consent form (Appendix E). Once the consent form was completed and returned, they were sent a Microsoft Teams invitation with instructions to join the workshop. Those who did not return a completed consent form were not considered eligible to take part in the workshop and did not join the event.

2.3 Delivery

A virtual workshop was delivered using Microsoft Teams on the 16th of June 2022. The workshop was held virtually to maximise attendance and accessibility and minimise health risks and environmental impact. The research and workshop delivery team consisted of six individuals, four from TRL and two from the University of Birmingham, and was made up of two social researchers, an expert in safety, another in hydrogen systems and policy, and two in hydrogen in the rail sector.

Microsoft PowerPoint slides, Microsoft Teams chat and poll function, and a virtual interactive whiteboard[20] were used to administer the event and gather responses to key research questions. Notes were taken throughout the workshop, and the session was recorded with participants' consent and automatically transcribed.

The workshop covered the following topics:

- Safety standards of hydrogen in the rail sector
    - The maturity, clarity and number of hydrogen safety standards in rail
    - The gaps in the current safety standards
    - What needs to be considered when safety standards are updated
- Identification of the key safety showstoppers and how these could be mitigated
- Any crossovers with current standards surrounding hydrogen HGVs such as:
    - Carriage of Dangerous Goods (ADR) regulations
    - ATEX regulations
    - Type approval, certification and compliance requirements
    - Risk assessments
- The future of hydrogen standards and regulations in the rail sector
- Attitudes to the potential location of the hydrogen tanks and fuel cell.

2.4 Analysis

The workshop was video recorded via Microsoft Teams. An automatic tool was used to generate written transcripts. These were analysed using thematic content analysis, using NVivo[21], whereby the text was examined to identify recurring ideas and themes. A combination of deductive and inductive approaches was used, with some themes specified in advance. The main ideas and themes were identified through thematic content analysis to become the main 'codes. From the transcript, four codes were identified.

2.5 Participants

Nineteen participants took part in the workshop from the following sectors (see Figure 8):

- Academia
- Railway infrastructure
- Rail safety

[20] MURAL is a virtual whiteboard platform - https://www.mural.co/

[21] NVivo is a software program used for qualitative and mixed-methods research – https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

- Engineering
- Hydrogen research
- Logistics
- Sustainable infrastructure

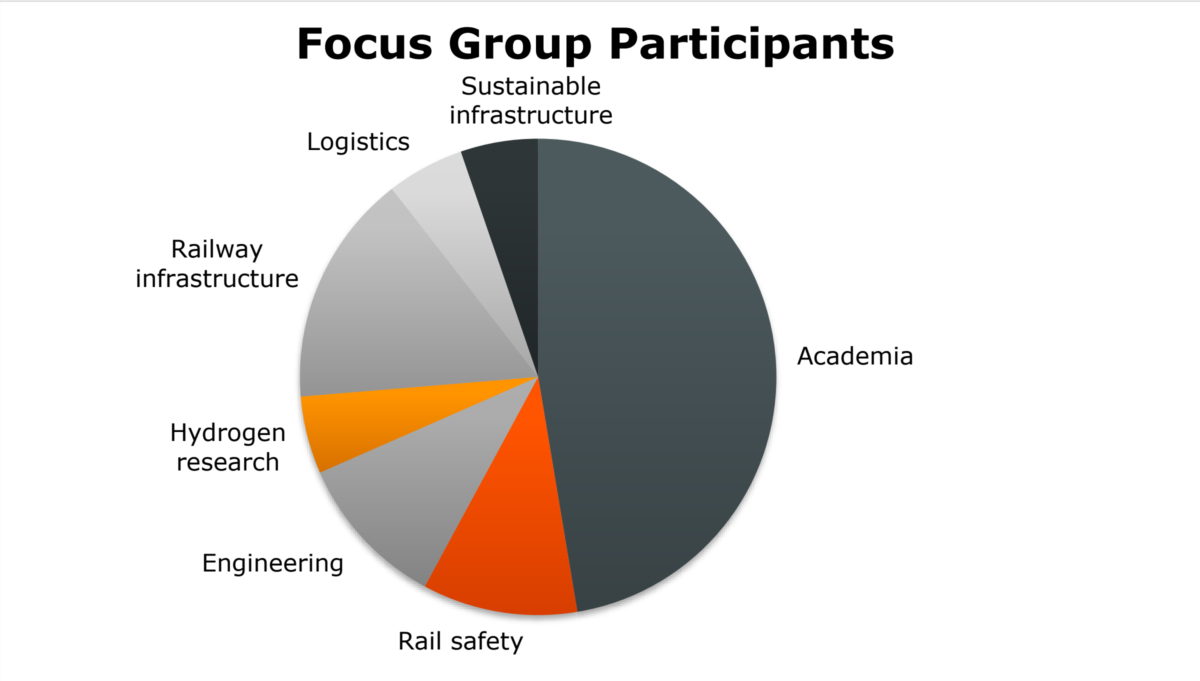

Figure 8 Representation of workshop attendees per type of organisation

3 Results

3.1 Self-Reported Knowledge Results

To understand the participants' self-reported knowledge in particular areas, they were asked three questions using the Teams Poll function, with the results from the questionnaire displayed in the pie charts below.

Figure 9 highlights that the most common level of expertise in hydrogen among the attendees was basic (53%). Figure 10 indicates that the levels of expertise in safety was rated similarly between basic, knowledgeable, and expert. This finding may be due to the current lack of safety standards and regulations for hydrogen trains. Figure 11 suggests that most attendees have a high level of awareness about hydrogen in the rail sector (41%).

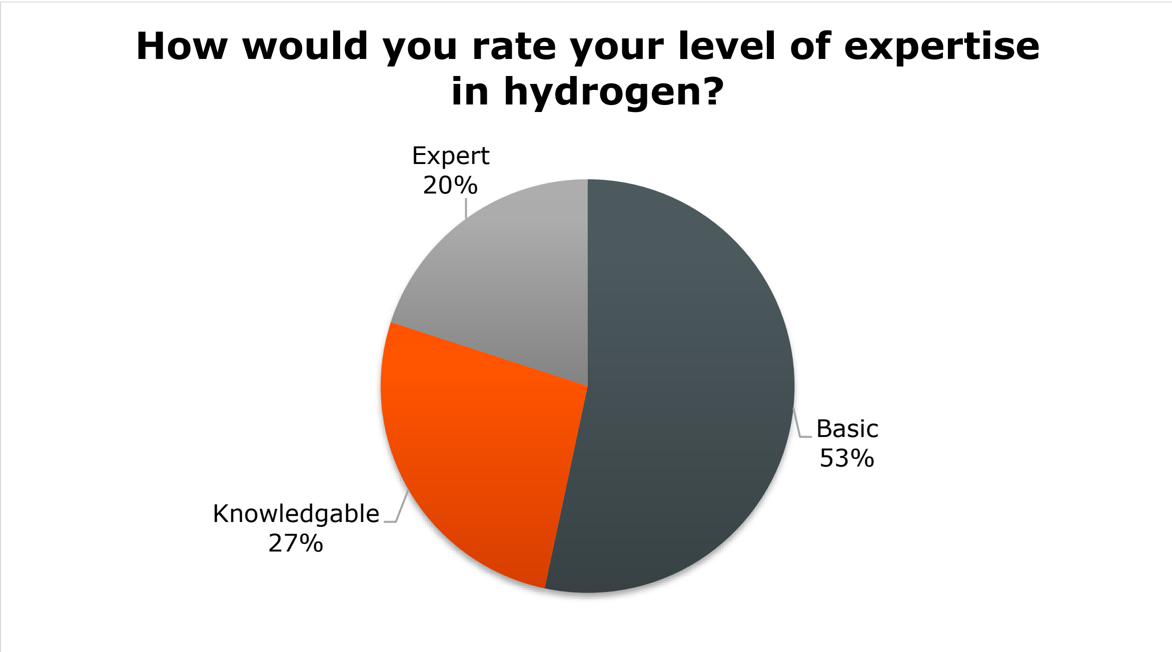

Figure 9 Representation of the results from the Microsoft Teams Poll assessing self-reported levels of expertise in hydrogen

Figure 10 Representation of the results from the Microsoft Teams Poll assessing self-reported levels of expertise in safety

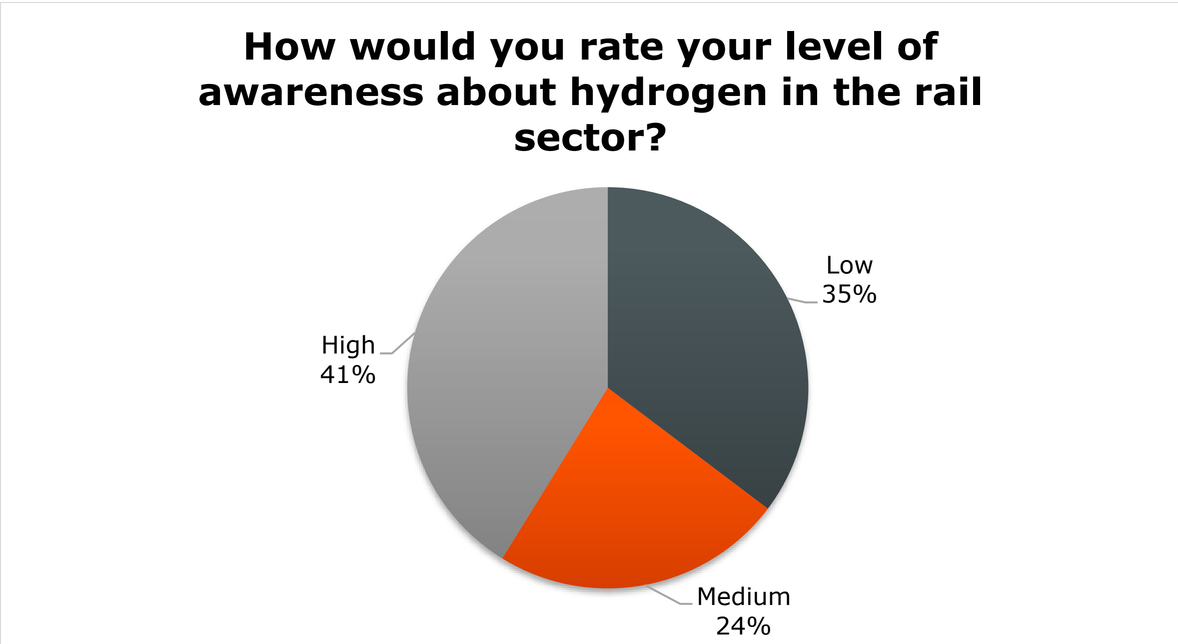

Figure 11 Representation of the results from the Microsoft Teams Poll assessing self-reported awareness levels of hydrogen in the rail sector

3.2 Key Findings

The main theme areas discussed throughout the workshop referred to:

- The current gaps in the safety standards,
- The key showstoppers for the demonstration of hydrogen trains,

- The overlaps with other sectors deploying hydrogen fuelled vehicles,
- What the future of hydrogen in rail looks like, and

These main discussion areas are shown in Figure 12, a visual representation of the flow of the topics discussed and the relationships between the themes. The visual representation highlights that the low maturity and clarity of standards, the lack of collaboration between stakeholders, and the potential "showstoppers" for the demonstration of hydrogen trains are key factors which explain the current lack of safety standards for hydrogen in the rail sector, which was a key finding during the workshop. All these factors will inevitably affect the future of hydrogen trains. A potential "showstopper" of the demonstration of hydrogen trains is the commercial imperative behind the decisions of how hydrogen trains are manufactured, which is influenced by the rolling stock of existing trains. This would then impact the future of hydrogen trains. Furthermore, the established safety standards for hydrogen buses and the state of the research on safety standards for hydrogen HGVs are factors which cause an overlap of standards between sectors, which also impacts the future of hydrogen trains.

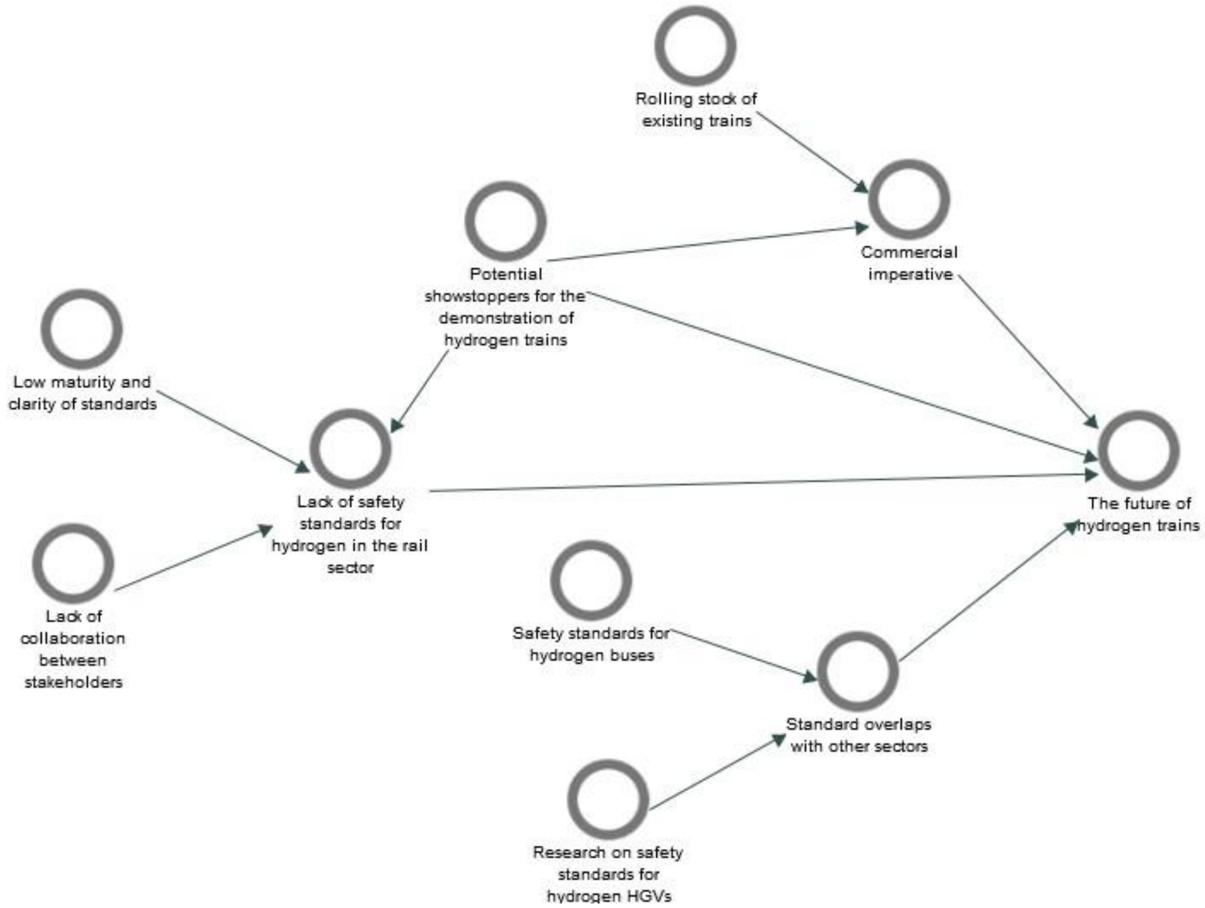

Figure 12 Key themes from the workshop and their connections

The frequency of the words mentioned in the discussion is shown in Figure 13 below, where the font size reflects the number of times a word was repeated during the workshop. It is indicative here that the most frequently used words during the workshop were “train”, “hydrogen”, “think”, “standards”, “need”, and “know”.

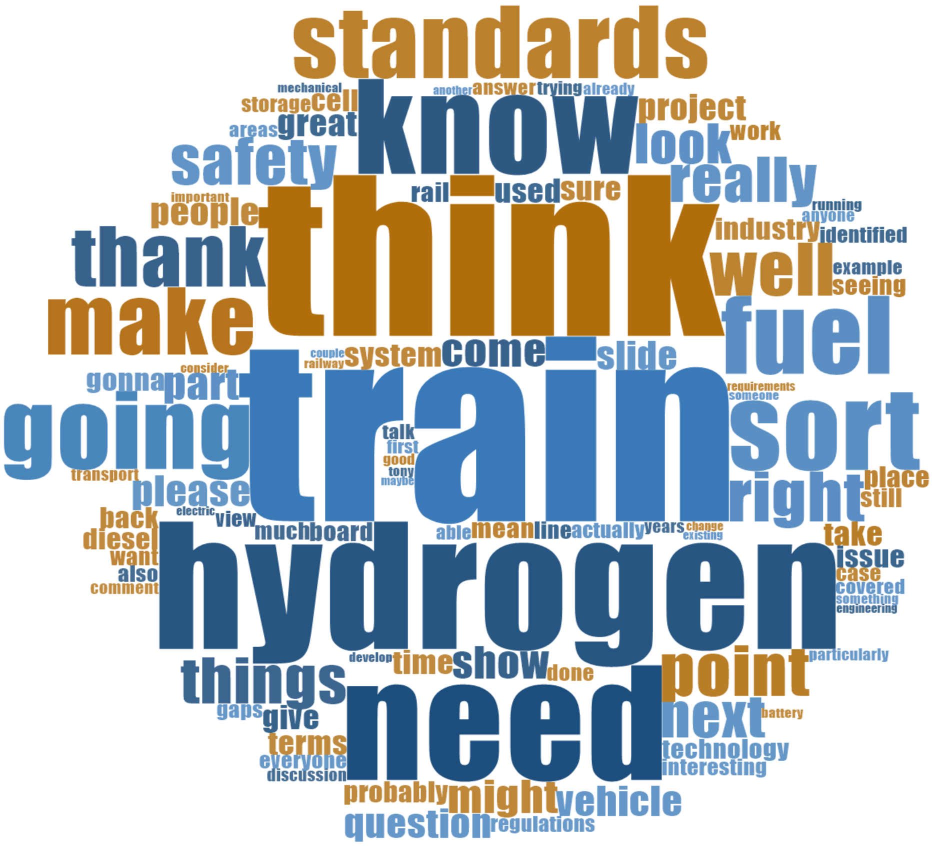

Figure 13 Frequency of words mentioned during the workshop

3.2.1 Safety Standards

To understand the attendees’ point of views on the current state of the safety standards and identification of any gaps, the research team used a Mural board to capture key points using the Post It Note function. A visual of the interactive activity can be seen in Appendix F. The points emerged from these discussions are outlined in the sections below.

3.2.1.1 Collaboration and coordination between stakeholders

During the workshop, it became apparent that **there are gaps in the safety standards of hydrogen in rail** which multiple organisations are attempting to fill in isolation. Responses from the attendees indicated that **collaboration and coordination between stakeholders could ultimately help accelerate the deployment of hydrogen trains**: ***“it’s essential that there’s a level of coordination between us to make sure that we come up with some consistent answers”***.

It was also highlighted that by **using learning from other sectors** such as the bus and HGV sector, the rail industry would be able to work more efficiently towards the goal of demonstrating hydrogen trains: ***“we must ensure that we learn and collaborate with other sectors and industries … we don’t have the time or funds to operate in a silo”***. There was acknowledgement that although the operation of rail, bus and HGVs have key operational differences, there are crossovers in the safety standards applied to all sectors and that these crossovers should be capitalised on where possible. Examples of overlaps between the safety standards for HGVs and rail are discussed further in Section 3.2.3.

3.2.1.2 Lack of current safety standards

Stakeholders reported that the **current state of safety standards for hydrogen trains are in early development**, with a lack of established standards for organisations in the rail sector to adhere to. There was recognition that the standards are at an ***"appropriate level of clarity and maturity at this stage of development"*** which reinforces the overriding response that the current state of standards is in alignment with the progress of the deployment of hydrogen trains. However, there was also the recognition that there is work to be done: ***"there is more to develop yet … regarding refuelling there are a lot of gaps"*** which highlights the volume of current gaps and lack of clear standards.

A specific gap with regards to the operational aspect of safe use of hydrogen in rail was identified during discussions: ***"there's a lot of work internationally, it discusses safety from a technical perspective, but I think there are gaps in safety from an operational perspective as well"***.

In terms of what needs to be considered when the safety standards for hydrogen trains are being developed, one attendee said that: ***"it's not just pure gaps where a standard doesn't exist … it's about the impact on other areas too and that needs to be considered"***. The other areas being referred to include the emergency services, national road networks, original equipment manufacturers, and members of the public.

3.2.2 Key "Showstoppers"

During the workshop, participants were asked to identify any showstoppers (factors or features) that would prevent the demonstration of hydrogen trains by writing text on virtual Post It Notes on the Mural board. The raw results can be seen in Appendix G. From the discussions, it was noted that there are things that need to be considered to understand how to mitigate potential showstoppers. The key potential showstopper, for both the long and short term, was deemed to be the **lack of a set of standards specific to hydrogen safety** which currently hinders the ability for organisations to demonstrate hydrogen trains: ***"not having the standards could potentially be a showstopper for a large demonstration, or it will be a showstopper later on if we don't have them soon enough"***. This quote highlights the knock-on effect of the lack of safety standards on the demonstration process of hydrogen trains.

Training was considered both a potential showstopper and a mitigator to a number of key points identified as barriers for the uptake of hydrogen trains. In terms of the role of emergency services, an attendee explained that the standards should ***"make sure that all of the relevant authorities are aware so that appropriate training can be carried out by those organisations"***. With regards to the culture and education of rail staff, a participant expressed that ***"depot and rail staff are not necessarily used to the level of awareness required"***. However, the view from many participants was that training is requirement for any role within the rail sector, therefore it should not be considered a barrier to the uptake of hydrogen trains based on the sole fact that the trains will be operated using an alternative fuel: ***"people have to be trained … I don't see that as a barrier, it should not be difficult to do this and it's a legislative requirement"***.

3.2.3 Overlaps with current standards from other sectors

TRL have recently undertaken work looking at functional safety, safety risk assessments, and the development of a safety roadmap for future trials of hydrogen fuel cell HGVs on the strategic road network.

The use of hydrogen to fuel HGVs is also in its very early stages, so it was considered useful in the workshop to examine regulations and standards that may apply to both forms of transport. While exactly the same regulations may not apply to both sectors, it is likely that there may be parallel or similar pieces of legislation or standards to those encountered in the research for Zero Emissions Road Freight Trial (ZERFT) that may pose similar barriers or obstacles to the deployment of hydrogen fuel cell trains.

A high-level overview of some of the areas identified where there may be similar issues faced across both modes were highlighted and discussed.

Attendees from the rail industry drew attention to a wide range of regulations that may potentially be applicable, and a number of these overlapped with findings from TRL's previous research in the HGV field. This included the applicability of Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) and Control of Major Accident Hazards (COMAH) regulations, and the Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations (CDG) and Regulations concerning the International Carriage of Dangerous Goods by Rail (RID) which are equivalent to the Carriage of Dangerous Goods (ADR) regulations in road transportation.

However, while areas of commonality and similarity were identified, no specific barriers were identified during the workshop. Rather, attention was drawn to the fact that the showstoppers identified in the HGV research may have parallels within rail standards and regulations, and these should be identified and investigated at the earliest opportunity.

3.2.3.1 Carriage of Dangerous Goods (ADR) Regulations

ADR regulations are highly prescriptive in relation to the transport of hydrogen through tunnels, with specific categorisations given for all major road tunnels as a result. Discussions with the University of Birmingham indicated that routes featuring tunnels were avoided for the HydroFLEX project. The ADR equivalent for railways may contain similar potential barriers. For example, it may include restrictions around the length of the tunnel, or the amount of hydrogen being transported. Feedback in the workshop suggested that tunnel length and bore may be a factor – one workshop participant asked: ***"would length of tunnel play a role in a safety case?"*** but no information was provided in terms of potential barriers.

ADR regulations also consider the transportation of hydrogen, and whether it can be carried by hydrogen fuel cell vehicles. The wording of the ADR regulations is open to interpretation as we found in a previous sectorial workshop. Its drafting preceded the deployment of hydrogen carrying vehicles, and it was not the intent of the authors to explicitly prevent the transportation of hydrogen loads by hydrogen fuelled vehicles. It may be prescient of the developers of hydrogen fuel cell trains to understand whether they will be allowed to be carry hydrogen as a cargo. Although hydrogen may not be a large element of the current rail freight cargo make-up, if hydrogen trains are to become established, getting hydrogen to the refuelling stations by hydrogen trains would seem logical, and any barriers to this may prove problematic in gaining traction for hydrogen freight trains. While one attendee stated ***"it is not clear to me why a hydrogen vehicle cannot carry hydrogen as cargo"*** it is this potential lack of clarity in the industry that should be addressed.

3.2.3.2 ATEX Workplace Directive (99/92/EC) and Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)

The ATEX Workplace Directive is a European directive concerning the control of explosive atmospheres. In the UK, it has largely been implemented through the DSEAR regulations. ATEX aims to manage the potential safety implications of working in explosive, or potentially explosive atmospheres. This would include workshops, garages and other enclosed or partially enclosed locations where hydrogen trains may be maintained or stored. ATEX and DSEAR provide guidance on creating zones for different types of explosive atmospheres and taking measures within these zones to prevent ignition of the explosive substance. Implementation of these regulations may require segregated or dedicated facilities for hydrogen trains, to ensure all aspects of the regulations can be effectively realised. While not an outright barrier, consideration at an early stage may need to be given to compliance with these regulations as in addition to developing appropriate safety guidance, physical changes, or layout changes to some aspects of the built environment associated with trains may be required and this may be a time-consuming process.

Furthermore, these regulations would also apply to any covered or underground stations, which may restrict the routes any demonstrations could occur on.

3.2.3.3 Certification and Compliance

There was some discussion and contribution to the Mural board around certification and compliance, and the requirement for any new train to comply with applicable directives, legislation and standard, but no barriers were explicitly identified during the course of the workshop discussion.

3.2.3.4 Risk Assessment

Risk assessment methods and routes to completing a compliant risk assessment were explored through discussion mainly thanks to the in-depth contributions from the rail industry stakeholders. However, again the general theme was that there were requirements that would need to be met, and evidence provided, but at this stage no obvious barriers to meeting required risk assessment obligations were identified.

3.2.4 The future of hydrogen trains

Participants were asked broad questions surrounding what the future of hydrogen in the rail sector would look like. With regards to whether manufacturers would build new and unique hydrogen trains or convert existing diesel trains, the overarching response was that the decisions are dependent on the commercial imperative or business case at the time:

"It depends on the business case for where you're going to operate"

"There's a lot of diesel trains out there that need to be converted one way or another by 2030, so that's probably your commercial imperative"

Moreover, the lifespan of the existing diesel trains was mentioned as a dependency to the uptake of hydrogen trains:

"It depends on the age of those [existing diesel] trains and where they're currently operating. I doubt anyone just wants to get rid of them and bring in new stock"

Regarding the lifespan of the existing diesel trains, stakeholders estimated that rolling stock life expectancy is more than 50 years, therefore operators may be reluctant to invest in the deployment of hydrogen trains until they can be certain that the vehicles are resilient and future proof. This aligns with the findings of the Decarbonising UK Freight project (Velazquez Abad, 2021[22]), were participants from the rail freight workshop stated that policy uncertainly hinders the investment in greener rolling stock.

In terms of the practicalities of converting or replacing the existing diesel trains, attendees expressed that it would be simpler and faster to retrofit an existing or old rail stock rather than procuring a new hydrogen train:

"Retrofitting a diesel locomotive with a hydrogen internal combustion engine would be easy"

"Hybridizing the electric setup would be much easier than the mechanical setup as you'd just hook the batteries on the electric side, much easier than the mechanical side".

3.2.5 Attitudes towards the location of the hydrogen tank and fuel cell on trains

Attendees were asked to rate, on a scale of one to five, how comfortable they would feel about four scenarios concerning the potential locations of the hydrogen tanks and fuel cell on a train. This was a quick, interactive activity for attendees to be able to highlight their personal views on where they think the hydrogen tank and fuel cell should be positioned on a train. Locations included:

- Underneath the passenger cabin,
- On the roof of the cabin,
- In place of passenger seating in the end cabin, and
- Within the cabin, either side of the aisle.

A visual from this interactive activity can be seen in Appendix K. Findings indicate that the most 'comfortable' location of the hydrogen tanks and fuel cell, from the stakeholders' perspectives, was on the roof of the cabin, as demonstrated by Siemens' Mireo Plus H

[22] Velazquez Abad, A. (2021). Understanding Drivers for Decarbonising UK Freight. TRL, Wokingham

(Figure 14) and Alstom's Coradia iLint (Figure 15). The second most 'comfortable' location was in place of passenger seating in the end cabin, as demonstrated by Porterbrook's HydroFLEX (Figure 16). The other two options (underneath the passenger cabin and within the cabin either side of the aisle) received mixed responses spread across the one to five scale with no clear finding.

The purpose of this discussion was to assess the attendees' initial thoughts surrounding the location of the hydrogen tank and fuel cell in a train. As there were no attendees with experience of the safety risks and mitigations of the various positions of the hydrogen tank and fuel cell present during the workshop, it was not discussed to be indicative of the design standards for manufacturers to adhere to regarding the location of the hydrogen tank and fuel cell. The following statement from one attendee highlights this: ***"I'm not sure any of us have done the work required to understand this and hence be able to provide an honest answer".***

Figure 14 Siemens' Mireo Plus H

Figure 15 Alstom's Coradia iLint

Figure 16 Porterbrook's HydroFLEX

4 Discussion

One of the key outcomes from the workshop was that while there are still many unknowns surrounding deployment of hydrogen as a fuel source for trains, there is an enthusiasm and desire from relevant stakeholders to pursue hydrogen as a potential energy pathway for rail. The workshop discussions identified barriers, but stakeholders indicated that these were not insurmountable and were open to ongoing discussions to identify helpful and outcome-focused ways of overcoming the barriers while keeping safety at the forefront of discussions.

Regarding the maturity of standards and regulations in hydrogen in rail, the stakeholders felt that the standards were at an appropriate level of maturity and clarity for this stage of technology development. However, there was a strong sense that there is more work to do in this area, which could be made more efficient with a coordinated approach to the development of safety standards.

In terms of barriers identified or potential showstoppers to the safe use of hydrogen in rail, the following key areas were identified by stakeholders:

- Maintenance of hydrogen fuel cells
- Refuelling hydrogen fuelled trains
- Travelling through tunnels
- Storage of hydrogen
- Distribution of hydrogen

As with road transport, the discussions emerging from the workshop revealed that some of the barriers may not come from explicit attempts to prevent the use of hydrogen, but rather unclear wording, or out of date legislation drafted before hydrogen was a viable option as a fuel.

The specific details of what a hydrogen train would look like, in terms of the location of the fuel cell and tanks, as well as whether the trains are retrofitted or newly built were unclear from the discussions. Regarding the location of the fuel tank, the views varied among stakeholders, but they agreed that a clearly articulated safety standard to aid train design based on the safest position was key. In terms of the retrofit versus new build discussion, stakeholders agreed that a deciding factor was the business imperative which needs to be confirmed.

5 Conclusions and Recommendations

After consulting with representative stakeholders from academia, the rail industry and the hydrogen supply chain, several recommendations have been drawn to help expedite the rollout of Hydrogen trains.

1. Standards and regulations should use clear and simple language. Before approval, final drafts should be open to review by industry to confirm that their interpretation in unequivocal.
2. Timely consultation with the appropriate bodies (e.g. governments, working groups, committees) responsible for drawing up such legislation to draw their attention to such issues and help them develop suitably worded updates should be considered.
3. Collaboration between stakeholders can accelerate the deployment of safety standards for hydrogen in the rail sector. It is therefore recommended that a working group(s) or hydrogen safety rail task force(s) is created to better understand what is needed to develop the necessary standards.
4. A review of the approaches alternative sectors in the UK (e.g. HGV and maritime) have taken is needed to identify efficient approaches to expedite the processes needed to integrate hydrogen into the UK rail network.
5. Germany is leading the deployment of hydrogen trains in Europe. The impact that a more robust rail manufacturing industrial sector on national rail hydrogen regulations should be explored and reviewed.
6. Infrastructure managers should evaluate whether existing tunnels are adequately ventilated to mitigate leak-related hazards. This would need to be led by Network Rail supported by RSSB surely would get involved.

Appendix A Recruitment Email #1

<Good morning/afternoon>

TRL are undertaking research to identify the safety standards and regulations required for the use of hydrogen in the rail sector as part of the ESPRC (Engineering and Physical Sciences Research Council) funded project iHYLAST (Impact of Hydrogen Standards on the UK Transportation System). You have been identified as a key stakeholder in this area, and we welcome your input into this research.

The virtual workshop provides attendees the opportunity to hear the initial results of our research and influence future government policy and regulation by sharing their insights into the safety issues and potential regulatory needs of hydrogen in rail. Your contribution will help the UK to develop and understand hydrogen standards, policy, and safety in order to fast-track the uptake of hydrogen trains.

How to Register

You can register to attend the event here: <link> between now and Wednesday 15th June.

Workshop Objectives

An objective of iHYLAST is to provide ESPRC and wider stakeholders with an understanding of:

1. What needs to be done in order to assure the safe use of hydrogen in rail applications
2. What obstacles will have to be overcome; and
3. What safety standards and/or legislation and approval processes must be met or followed

This is intended to de-risk the use of hydrogen by ensuring that key safety and regulatory issues are identified as soon as possible. The workshop will include an overview of the iHYLAST project, research findings so far, and interactive activities to:

1. Validate these findings; and
2. Seek consensus on regulatory and safety requirements for the use of hydrogen in rail

Workshop Output

Through the activities described above, the outputs of the workshop will be:

1. A number of high-level safety requirements
2. Identification of major barriers and innovations required for safe operation of hydrogen in rail

Further information

Confirmed attendees will receive an information pack and Teams invitation in the week prior to the workshop. If you have further questions or have suggestions for other people who you think would make a valuable contribution to the workshop, please email hydrogensafetyinrail@trl.co.uk

Kind regards, TRL Research Team

Appendix B Eventbrite Page

Jun 16

Virtual Workshop - Safety Standards for Hydrogen in the Rail Sector

by TRL

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Details

TRL are undertaking research to identify the safety standards and regulations required for the use of hydrogen in the rail sector.

Date and time

Thu, 16 June 2022
10:00 – 12:00 BST

Location

Online event

About this event

Background Information

TRL are undertaking research to identify the safety standards and regulations required for the use of hydrogen in the rail sector as part of the ESPRC (Engineering and Physical Sciences Research Council) funded project iHYLAST (Impact of Hydrogen Standards on the UK Transportation System).

The workshop provides attendees the opportunity to hear the initial results of our research and influence future government policy and regulation by sharing their insights into the safety issues and potential regulatory needs of hydrogen in rail. Your contribution will help the UK to develop and understand hydrogen standards, policy and safety in order to fast-track the uptake of hydrogen trains.

How to Register

You can register to attend the event between now and **Wednesday 15th June**.

Please note you will need to accept the conditions stated in the registration form to be eligible to take part.

Workshop Objectives

An objective of iHYLAST is to provide ESPRC and and wider stakeholders, with an understanding of:

1. What needs to be done in order to assure the safe use of hydrogen in rail applications;
2. What obstacles will have to be overcome; and
3. What safety standards and/or legislation and approval processed must be met or followed

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The workshop will include an overview of the iHYLAST project, research findings so far, and interactive activities to:

1. Validate these findings; and
2. Seek consensus on regulatory and safety requirements for the use of hydrogen in rail

Workshop Output

Through the activities described above, the outputs of the workshop will be:

1. A number of high-level safety requirements
2. Identification of major barriers and innovations required for safe operation of hydrogen in rail

Further information

Confirmed attendees will receive an information sheet, consent form and Teams invitation in the week prior to the workshop.

If you have any questions about the event, please contact hydrogensafetyinrail@trl.co.uk

Thank you for your interest in taking part in this important piece of research.

Appendix C Recruitment Email #2

<Good morning/afternoon>

Thank you for signing up for the virtual workshop TRL are hosting looking at the safety standards for hydrogen in the rail sector. Your contribution will be greatly valued.

Action

Attached is the information sheet and consent form – please fill in the consent form and email back to this address at your earliest convenience to confirm your spot for the workshop. Once received at our end, you will be sent a Microsoft Teams invitation for the event (Thursday 16th June, 10am – 12pm).

Thank you again for your interest in being a part of this research.

Kind regards,

TRL Research Team

Appendix D Information Sheet

Background Information

TRL are undertaking research to identify the safety standards and regulations required for the use of hydrogen in the rail sector as part of the ESPRC funded project iHYLAST (Impact of Hydrogen Standards on the UK Transportation System).

What is the purpose of the workshop?

The purpose of the workshop is to provide attendees the opportunity to hear the initial results of our research and influence future government policy and regulation by sharing their insights into the safety issues and potential regulatory needs of hydrogen in rail. Your contribution will help the UK to develop and understand hydrogen standards, policy, and safety in order to fast-track the uptake of hydrogen trains.

Why have I been chosen?

You have been chosen as a relevant stakeholder within the rail industry who can provide us with valuable information concerning the safety issues and regulatory needs of hydrogen in rail.

What are the possible benefits and disadvantageous of taking part?

It is expected that the responses from the workshop will ultimately be used to help the UK to accelerate the uptake of hydrogen trains. There are no anticipated disadvantages associated with completing the survey.

Will my participation be kept confidential?

Contact details, including your name and email address, will solely be used to arrange the workshop. This information will be collected, stored, and used in line with the General Data Protection Regulation (GDPR). All data and personal details will be kept in a secure password-protected computer with access only available by the immediate research team. These details will be kept for up to three months, after which they will be destroyed.

What will happen to the results of the research?

Following analysis of the workshop, TRL will write up a report for EPSRC. Responses from the workshop will be entirely anonymous, without any means of identifying the individuals involved.

Contacts for further information

If you have any questions, please contact the research team:

hydrogensafetyinrail@trl.co.uk

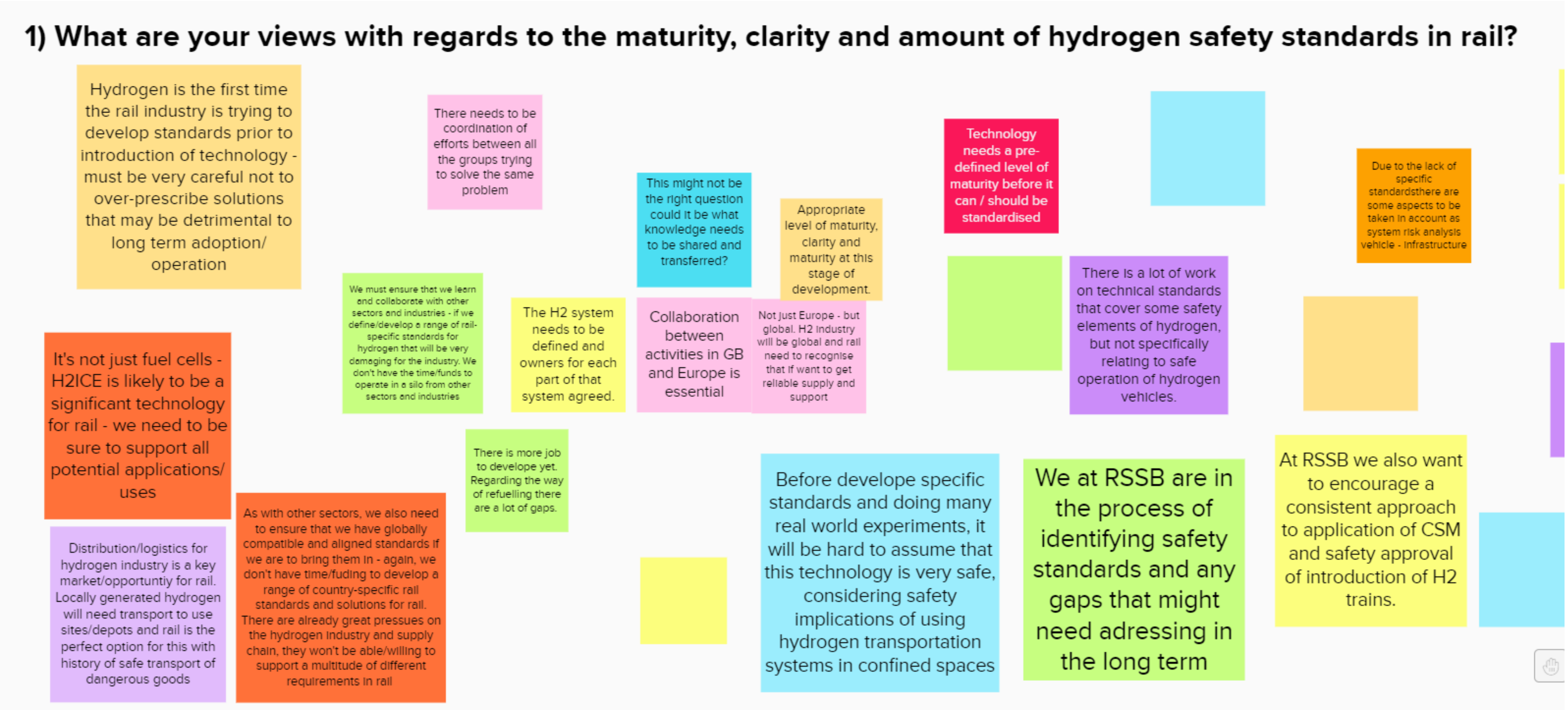
Appendix E Consent Form

Thank you for your interest in taking part in this research.

Please complete this form after you have read the Information Sheet and return it to hydrogensafetyinrail@trl.co.uk

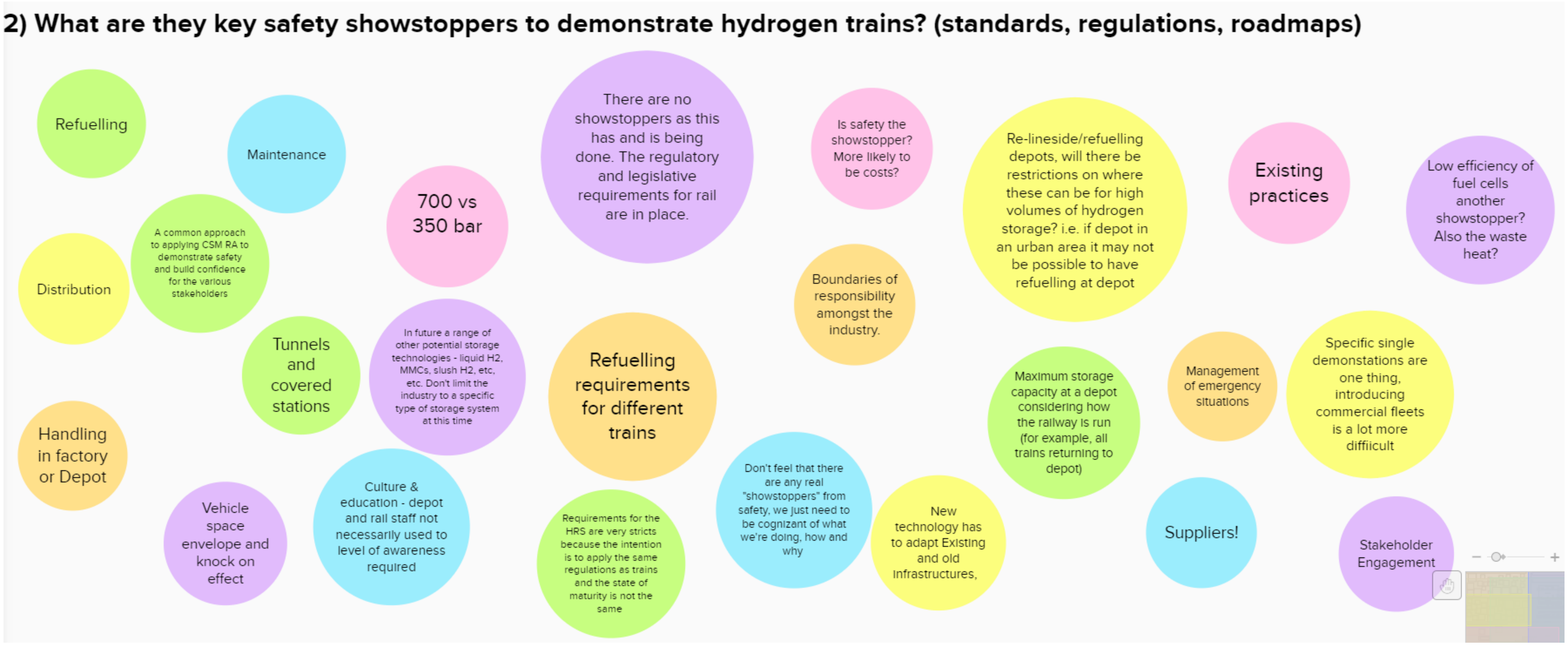
Please tick Y or N against each statement	Yes	No
I have read and understood the information sheet provided and have had the opportunity to ask questions about my participation prior to the workshop		
I understand I am under no obligation to take part in the workshop and have the right to withdraw at any time, without giving a reason		
I agree to keep any information presented and discussed in the workshop confidential		
I understand that TRL will use anonymised information from my contributions in the workshop in the project report which will be delivered to ESPRC		
I understand that TRL will record the workshop. The recording and workshop notes will not be published but will be used to support writing up the results of the workshop and pseudonomised quotes may be used in the project report		
Do you consent to the processing of your personal data including images, audio and text? The data will be handled and protected in line with data protection legislation		
Do you consent to your email address being used for contact purposes? You may contact the TRL representative via email		

Appendix F Mural Board Results - Current state of safety standards



Appendix G Mural Board Results - Key safety barriers to demonstrate hydrogen trains

Culture and education – depot and rail staff are not necessarily used to the level of awareness required



Appendix H Mural Board Results - ATEX Regulations

ATEX Regulations

H2 already covered by ATEX.

- Health and Safety at Work etc. Act 1974
- Railways and Other Guided Transport Systems (Safety) Regulations 2006
- The Railways (Interoperability) Regulations 2011
- EC Directive 2008/57/EC on the interoperability of the UK rail system
- The Railways (Interoperability) (Amendment) (EU Exit) Regulations 2019 (2019/345)
- Management of Health and Safety at Work Regulations 1999 (MHSWR)
- National Specification Notifications:
  - o Rolling Stock – Locomotive and Passenger (LOC and PAS)
  - o Safety in Railway Tunnels (SRT)
- Regulation (EC) No 79/2009 type-approval of hydrogen-powered motor vehicles, and amending Directive 2007/46/EC
- Pressure Equipment Regulations 2016
- Pressure Systems (Safety Regulations) 2016
- IISAE specification: J2719 for Hydrogen Fuel Quality
- EN/IEC 60204-1 and EN/ISO & Machinery Directive 2006/42/EC – Emergency stops.
- BS EN 50153:2014 Railway applications. Rolling stock. Protective provisions relating to electrical hazards
- IEC 60479-1:2018 Effects of current on human beings and livestock - Part 1: General aspects
- IEC 60479-2:2019 Effects of current on human beings and livestock - Part 2: Special aspects
- GM/RT2100 Issue 4 Rail Vehicle Structures and Passive Safety
- EN5021 Railway applications. Electromagnetic compatibility

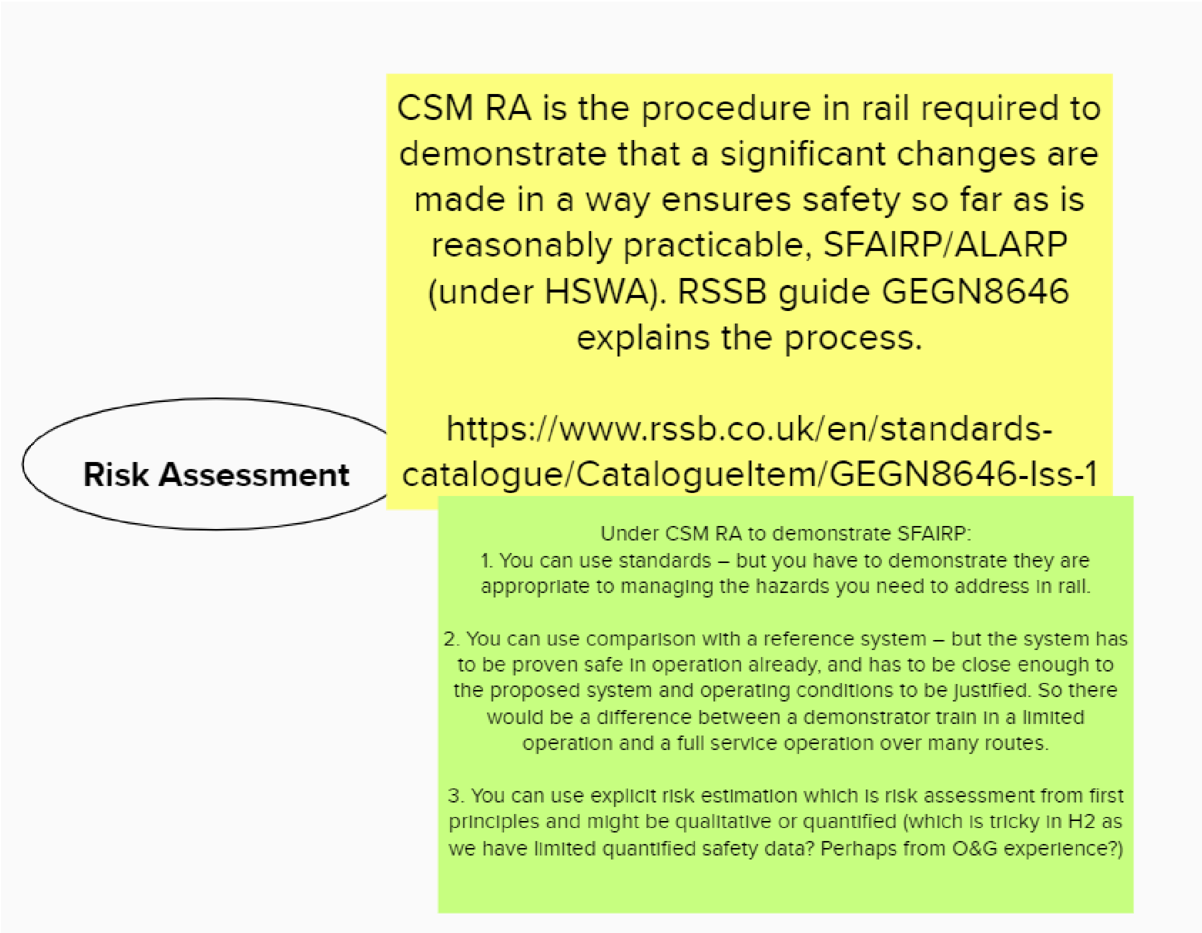
Appendix I Mural Board Results – Certification and Compliance

What is required in a technical file?
The technical file should contain the information required to show that the product properly complies with the requirements of the applicable directives, legislation, and standards.
The information provided is for the design, manufacture, and operation of a product and must contain all the details necessary to demonstrate the product conforms to these applicable requirements.
As a general guide, it should include:

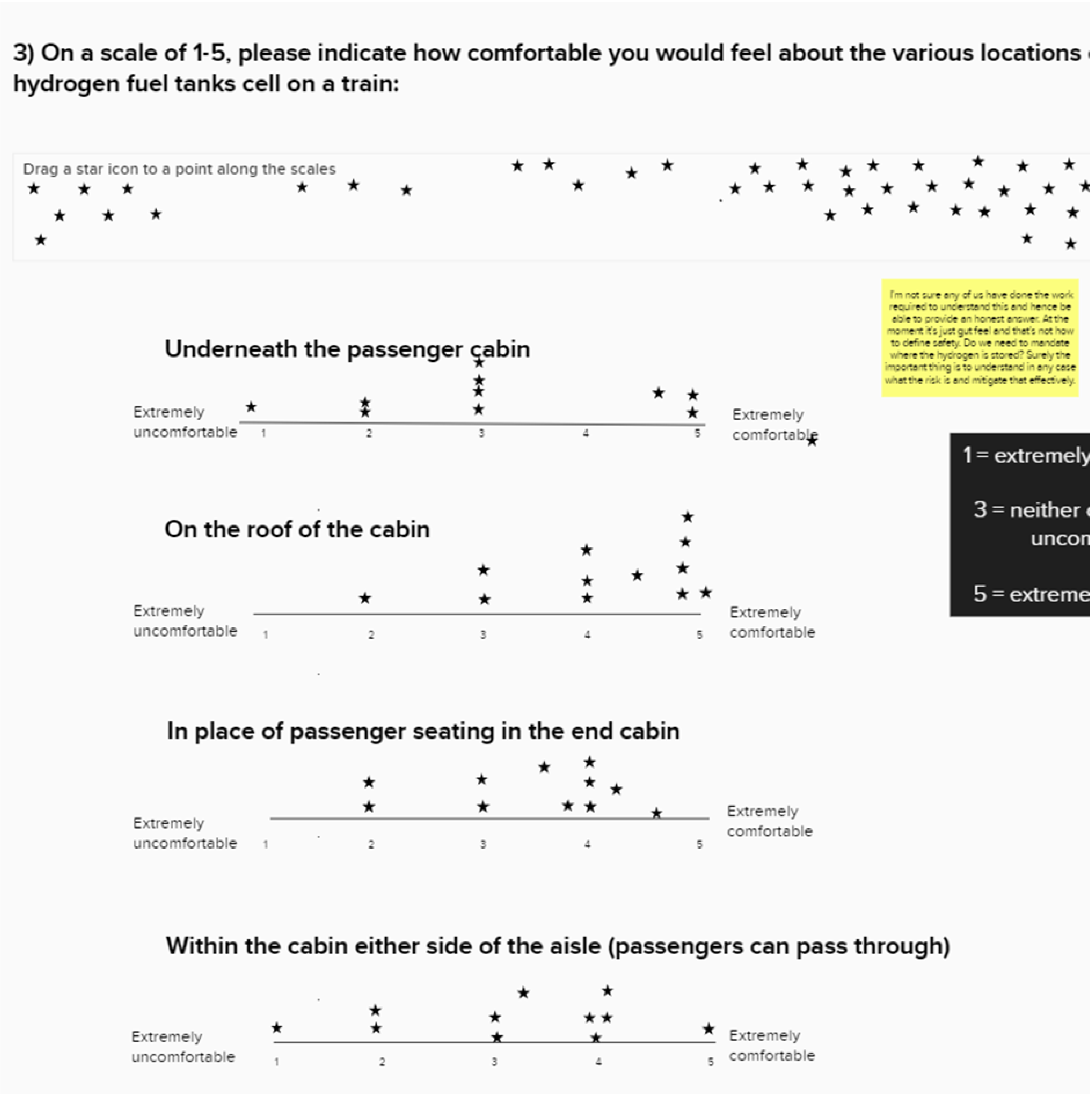
- Description of the apparatus, usually accompanied by a block diagram
- Wiring and circuit diagrams
- General Arrangement drawing
- List of standards applied
- Records of risk assessments and assessments to standards
- Description of control philosophy/logic
- Datasheets for critical sub-assemblies
- Part list
- Copies of any markings and labels
- Copy of instructions (user, maintenance, installation)
- Test reports
- Copies of certification

CE and UKCA Marking
To meet CE-marking legislation, the technical file provides a set of documents that demonstrate the conformity of a product. It must specify the applicable product safety requirements and cover the design, manufacture, and operation of the product.
Following to Brexit, the UKCA (UK Conformity Assessed) marking legislation was introduced. This is the UK product marking for goods being placed on the market in Great Britain (England, Wales and Scotland). It covers most goods which previously required the CE marking, known as 'new approach' goods.
The UKCA marking came into effect on 1 January 2021. However, to allow businesses time to adjust to the new requirements, in most cases they can continue to use the CE marking until 1 January 2023. It should be noted that the UKCA marking alone cannot be used for goods placed on the Northern Ireland market and that there is separate guidance for this.
For the supply of products in Great Britain, the technical requirements ('essential requirements') must be met and the conformity assessment processes and standards that can be used to demonstrate conformity are mostly as they were for the CE marking.
There are circumstances when self-declaration of conformity for UKCA marking can be used. They are the same as for CE marking. For businesses that used self-declared conformity for the CE marking, the same can be done for the UKCA marking.

Appendix J Mural Board Results – Risk Assessment



Appendix K Mural Board Results – Attitudes towards location of the hydrogen tanks and fuel cell on a train



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