HyApproval

WP4 - Deliverable 4.2

- PUBLIC -

Establishment of Best Practices for Safety:

- **Available industry best practices to identify accident scenarios and mitigating factors**

- **Available HySafe NoE best practices for Hydrogen Safety**

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1. Introduction

This document is serving as introductory background information on establishment of best practices for hydrogen refuelling station (HRS) safety and input for the further development of WP4 work activities of the HyApproval Project.

Deliverable D4.2 is referred to the task of 'establishing best practices for safety' of hydrogen refuelling stations considered within the HyApproval Project DoW of the following:

- **Available industry best practices to identify accident scenarios and mitigating factors.**
- **Safety studies from HySafe and other sources as background for determination of other best practices for hydrogen safety.**

2. Background

There are experiences from industry best practices related to on-site production of hydrogen, by water electrolysis or by natural gas reforming, to gaseous compressors, liquid hydrogen pumps, gaseous buffer storage and LH2 storage tanks which are applicable and relevant to be considered for the HyApproval Project, but as a general conclusion, comprehensive and wide ranging experiences of hydrogen vehicle gaseous and liquid dispensing is presently lacking for the HRS sizes considered in the DoW. The present hydrogen refuelling stations are often demonstration infrastructure projects provided to support the small numbers of demonstration hydrogen vehicle fleets trailed by OEMs to prove new H2 FCV and ICE technology. Hydrogen infrastructure facilities are not likely to be provided in big numbers and on a commercial scale until the mass introduction of hydrogen fuelled transportation vehicles.

3. Best practices for Hydrogen Safety – from HySafe

The overall goal of the part EC funded network of excellence HySafe is to contribute to the safe transition to a more sustainable development in Europe by facilitating the safe introduction of hydrogen technologies and applications[1]. This chapter outlines briefly the status of some HySafe activities that are considered relevant for the HyApproval project.

3.1 Hydrogen Incident and Accident Database (HIAD)

WP5 is jointly coordinated by Det Norske Veritas AS (DNV) and the European Commission's Joint Research Centre - Institute for Energy (JRC) with contributions from various HySafe partners.

HIAD intend to become an important European tool for open communication of safety status as well as risks associated with hydrogen technologies to all partners in the HySafe Consortium and beyond. In addition, HIAD will serve as a common

[1] http://www.hysafe.org/

methodology and format for data collection and storage. HIAD will hold high quality information of historical accidents and incidents related to hydrogen production, transport (road/rail/pipeline), supply and commercial use. The database will be maintained such that it is updated with the latest information concerning each event for example in order to take advantage of results from accident investigations. Hence, HIAD will, when fully operable be an important source for most tasks constituting a risk analysis process, and be an international hydrogen accident and incident database and a reporting platform, fulfilling the below given objectives set out for HIAD:

- contribute to the integration and harmonization of fragmented experience and knowledge on hydrogen safety in Europe and international across professions and countries;
- contribute to the progress in common understanding of hydrogen safety and risk; which are the hazards, causes and consequences of accidents/incidents associated with hydrogen;
- be a harmonised tool for safety and risk assessment associated with hydrogen applications by providing input to analyses and safety management work;
- enable generation of common generic accident and incident statistics;
- serve as a common methodology and reference format for future hydrogen incident/accident data collection and storage;
- be a source for the understanding and experience transfer of hydrogen accident phenomena, scenarios and hazard potential; what are the hazards; what can go wrong, how and why do accidents/incidents develop, etc.;
- keep all stakeholders (authorities, public, research, industry) updated and informed with recent accidents/incidents involving the use of hydrogen, thus contributing to spread of knowledge and best practice as well as to building up a realistic perception of the risks related to use of hydrogen in industrial applications.

Table 1 below outlines the HIAD database structure and the corresponding building blocks.

Table 1 – HIAD database structure

Block	Parameter examples
1. HIAD Administration	Event coding Information sources Dates of entry and last revision HIAD operator and data provider details
2. Pre-event conditions	Date and time of event Weather conditions Geographical location Type of H2 application Operation phase or mode
3. Nature of event	Systems and components affected or involved Chain of events Causal relations Relevant safety systems and emergency response Releases, fire and explosion specifications/details
4. Consequences of event	Fatalities and injuries Property, environment and economical loss and damage
5. Post-event actions	Clean-up and restoration Legal/legislation initiatives

	Lessons learned Investments made
6. References	Hyperlinks/references to files and documents, web-sites, etc. Specification of attachments, e.g. maps, drawings, photos, etc

In summary HIAD has now been developed as follows:

- A common methodology and procedure for data collection has been developed.
- A data entry template has been developed.
- The HIAD web-based interface has been developed, with data retrieval capability.
- Contributions from various partners have been received, using the HIAD Data Entry Template in Excel Format. This collected data has been inserted into the HIAD database. **There are now 30 hydrogen-related events reported in HIAD.**

The overall purpose of HIAD is to assist stakeholders in better understanding hydrogen-related undesired events (incidents, accidents) and provide a proposed methodology to contribute - in the long term when sufficient statistical evidence will eventually become available - towards improving hydrogen-related risk assessment and management.

As agreed by the HySafe consortium in the initial phases of WP5, it is important to highlight that HIAD is currently not a standard industrial accident database, but rather a collaborative and communicative safety/risk communication **process**, and hence not a tool for immediate use in quantitative risk assessments. However, as for all databases holding information about accidents and incidents, HIAD may already at this stage of the development serve as a source for the hazard identification exercise in risk assessments of hydrogen applications

3.2 CFD modelling in HySafe

All modelling activities are carried out in Work Package 6, which is coordinated by ForschungsZentrum Karlsruhe (FZK) in Germany.

The programme of work specifies that a number of simulation exercises, or Standard Benchmark Exercise Problems (SBEPs), shall be performed. This includes dispersion, fires, explosions and flame acceleration (DDT, detonation). One of the WP6 deliverables, D57, is a compilation of suitable experiments that are potential candidates to be SBEPs. There are also extended SBEPs or eSBEPs that partners participating in the WP6 can perform should they so wish. External organisations have also been invited to calculate SBEPs and whose results are also included in the model comparisons.

The intention is to investigate different types of flows, low-pressure and high-pressure releases of gaseous hydrogen with diffusion and mixing, ignited gaseous flows leading to deflagrations, flame acceleration leading to DDT or detonation and releases of liquid hydrogen. The performance of different turbulence models and other physical sub-models will be investigated. One possible outcome of WP6 might be recommendations for which types of models to use or how certain types of flows should be treated.

A number of different commercial, internal and research CFD codes are used in the simulations. Similarly a number of different turbulence models have also been used.

A number of SBEPs have been carried out to date:

- SBEPs
  - V1: Dispersion of hydrogen in a closed vessel (Russian test)
  - V2: Explosion of a hemi-spherical hydrogen-air gas mixture of stoichiometric concentration (Fh-ICT)
  - V3: Release of hydrogen in a garage-like enclosure (INERIS)
- eSBEPS
  - Dispersion of a liquid hydrogen release on sand (NASA)

Simulation results from two of SBEPs V1 and V2 were presented at the 1st International Conference on Hydrogen Safety in Pisa in September 2005, Gallego *et al.* (2005a) and Gallego *et al.* (2005b).

There were some queries relating to the experimental data and the information on initial and boundary conditions were scanned. Having identified a lack of experimental data, two internal HySafe projects have been initiated; a) InsHyde, which is concerned with dispersion, e.g. mixing and diffusion of hydrogen in an indoor environment and b) HyTunnel where hydrogen releases, both dispersion and combustion, in a tunnel environment are considered.

In InsHyde, it was decided to perform a set of experiments to investigate dispersion in a garage-like enclosure. Three rounds of simulations of the INERIS test were performed; first a set of pre-test calculations were carried out to provide information to aid in the design of the experiments; this was followed by a blind calculation of the selected scenario. The results from the different partners were then compiled and presented at a meeting. A third and final iteration was then performed where each partner was asked to draw upon the experience of the blind calculations to improve the accuracy of the simulations, e.g. to be in better agreement with the experiments. The output of the simulations were

- Size of the gas cloud
- Size of the cloud within the flammable range, e.g. 4-75 %
- Total mass of hydrogen
- Mass of hydrogen in the flammable range
- The hydrogen concentration was measured at twelve locations within the enclosure. In the CFD calculations the hydrogen concentration was monitored at a further four sensor locations for which there exist no information about the hydrogen concentration; the latter four sensor readings were used for model comparison only

A further set of SBEPs and eSBEPs are currently being calculated

- SBEPs
  - V4: High-pressure release of hydrogen in the atmosphere (HSL) or high-pressure release of hydrogen in a laboratory (FZK)
  - V5: Dispersion in an enclosure with baffles (GexCon)
  - V7: Explosion of premixed stoichiometric hydrogen-air cloud in a mock-up of a hydrogen refuelling station (Shell, HSL, BP, Exxon-Mobil)
  - V8: Explosion in a vented tube (FZK)
- eSBEPs
  - V6: Release of liquid hydrogen (BAM)

– V9: Transition from Deflagration to Detonation in a channel (Fh-ICT)

3.3 Risk Assessment Methodologies in HySafe

The remit of Work Package 12 in HySafe Network is to consider Risk Assessment Methodologies. The main focus has been hazardous zone classification and safety distances. The Work Package is led by Det Norske Veritas AS (DNV) in Norway.

WP12.4 Hazardous Zones

- Deliverable D64 "Classification of Hazardous Zones – methodology and examples" discussed. This report summarises the work in subtask 12.4 on classification of hazardous zones carried out. Based around EU directive1999/92/EC "Safety and Health Protection of Workers potentially at risk from explosive atmospheres" and IEC/EN60070-10 "Electrical apparatus for explosive gas atmospheres. Part 10 Classification of hazardous areas". A generic hydrogen refuelling station is to be used. The method used for zoning based on the Italian Methodology. Initial results were presented. The generic refuelling station was also presented with some initial results with CFD (FLACS) and PHAST modelling for zoning given. Comparison of the dispersion calculations using the Italian methodology and the PHAST calculations for the outdoor scenarios showed good agreement. The simulations had not been finalised at the time of the workshop at Risø. Remaining scenarios to be looked at are:
  - Dispenser;
  - Refuelling nozzle;
  - Vent line/relief point for safety valve;
  - Outdoor valves at gas storage high pressure vessels;
  - Valve at buffer tank; and
  - Shutoff valve outside gas processing house.

The choice of vent sizes was discussed, with the result being those used already were not always realistic and a way forward was decided.

WP12.5 Safety distances

Risk assessment methodology and uncertainties were presented. Assurance EU project and Aramis EU project that partially followed up on Assurance are relevant. More work needed to qualify terms and their numerical equivalents. IEC300-9-3 Risk analysis of technological systems cited as possible terms and numbers source. EIGA 75/01/E/rev Safety Distances may also be relevant.

Deliverable D26 Definitions.

Safety distances for hydrogen filling stations paper by RIVM was discussed with some concern about basis for data. Data taken from TNO Purple book but may not be appropriate.

Draft report deliverable on Safety Distance is due before the end of 2006.

Topics for further work were discussed. These included:

- Better information needed for failure frequencies;
- More appropriate consequence reference points (harm criteria) needed;
- Tolerance level/individual harm criteria/level;
- Acceptance criteria; and
- Threshold values for different materials.

A Memo on methods is to be produced. Sensitivity studies need to be carried out to determine sensitivity of frequency data.

4. Assumptions on HRS sizes

As stated in the HyApproval DoW, three different possible generic sizes for implementing a HRS will be considered by WP4 and investigated in principle. Taking into account the timely applicability of the Handbook to be developed in HyApproval, typical assumed capacities of HRS of 300, 1,500 and 3,500 kg/day respectively were chosen as being within the range of practical knowledge and adequate for the foreseeable range of uses for at least the next 10 years (up to 2015).
The '3 sizes' defined in the HyApproval DoW are in existence at the moment and reflect the real likelihood of an H2 infrastructure build-up (e.g. HyNet) in the next 5 – 10 years:

- a 'small' <350 kg storage is the H2 quantity an existing CGH2 ‘trucked-in’ tube trailer will delivery to a site or could be produced ‘on-site’ e.g. all existing CUTE sites with CGH2 supply (e.g. CUTE Luxembourg & Porto); on-site H2 production at Barcelona, Amsterdam, Stuttgart, Reykjavik, Stockholm, Madrid.
- a 'medium' <1,500 kg storage is the quantity an existing ‘trucked-in’ LH2 tanker could deliver to a number of existing sites in EU & overseas at the moment (e.g. Total/Linde Berlin, CEP Berlin; Shell Washington)
- a 'large' <3,500 kg storage is the LH2 quantity supplied by a full delivery of an existing ‘trucked-in’ LH2 tanker (e.g. BP CUTE London).

The Handbook will consider the case of all 3 sizes and the HRS scenarios of stand alone and/or integrated with other gaseous or liquid fuels at existing vehicle refuelling stations.
It will be assumed that a maximum of one H2 tanker delivery (CGH2 or LH2) per day is possible to any site:

- If buses are refuelled, assume refuellings of 35 kg CGH2 / bus / day (at 35 MPa).
- If cars are refuelled, assume refuellings in a **commercial market environment (i.e. HRS’s are accessible to the general public)**:
    - CGH2 35 MPa: 4 kg H2 / car @ 3 –4 mins / fill
    - CGH2 70 MPa: 4 kg H2 / car @ 3 – 4 mins / fill
    - LH2: 5 – 10 kg /car @ 3 – 4 mins / fill

5. Review of available Industry Incident Experiences for hydrogen vehicle refuelling stations (CFD simulations proposed)

WP4 will undertake a comprehensive risk assessment of a complete HRS to confirm final accident scenarios for CFD simulation modelling but credible accident scenarios (as per scope of DoW - WP4) from gas industry incident experiences are proposed for CFD simulation as follows:

1. CGH2 dispenser failure at 35 MPa
   Event: hose-break / connector nozzle / dispenser failure

Worst case estimated event (before excess flow valves &/or pressure sensing devices shut system down): loss of all contents from hose & dispenser
Worst case estimated H2 quantity lost:

- Length of hose: 3 metres for cars; 5 metres max for buses/HGVs
- Hose internal dia: 6 mm (for cars); 11 mm (for buses/HGVs)
- Dispenser contents: assume less than 0.1 kg H2 released

2. CGH2 dispenser failure at 70 MPa
Event: hose-break / connector nozzle / dispenser failure
Worst case estimated event (before excess flow valves &/or pressure sensing devices shut system down): loss of all contents from hose & dispenser
Worst case estimated H2 quantity lost is based on the following:
    - Length of hose: 3 metres for cars; 5 metres max for buses/HGVs
    - Hose internal dia: 6 mm (for cars); 11 mm (for buses/HGVs)
    - Dispenser contents: assume less than 0.15 kg H2 released

3. LH2 dispenser failure at 3 – 8 Bar
Event: hose-break / nozzle / dispenser failure
Worst case estimated event (before excess flow valves or pressure sensing devices shut system down): loss of all contents from hose & dispenser.
Worst case estimated H2 quantity lost is based on the following:
    - Length of hose: 3 metres max
    - Hose internal dia: 7 – 8 mm
    - Dispenser contents + hose: 0.16 kg H2 released (1L LH2 = 850L GH2; 1L H2 = 0.0708 kg H2)
    - Pressure sensing devices (2 off) will immediately detect loss of vacuum in hose & activate an emergency shut down valve (SDV) (assume SDV to close successfully within 5 secs)

4. CGH2 tanker discharge hose failure at 25 MPa
Event: hose break
Worst case estimated event: loss of all contents from hose & trailer.
Worst case estimated H2 quantity lost is based on the following:
    - Length of discharge hose: 3 metres max
    - Hose internal dia: 12.5 mm (1/2 inch)
    - Trailer contents: whole contents (250 kg) would be lost via 12.5mm dia hose outlet.

    Limiting factor is that max flow is more likely to be determined by the restriction of the trailer/tanker piping, than hose diameter.

5. LH2 tanker discharge hose failure (11 bar max WP)
Event: hose break

    Worst case estimated event (before excess flow valves or pressure sensing devices shut system down): loss of all contents from hose & partially from trailer.
Worst case estimated H2 quantity lost is based on the following:
    - Length of discharge hose: 3 metres min – 5 metres max
    - Hose dia: 25.4 mm (1 inch) OD; 22.5 mm ID
    - Discharge is at 25 kgs LH2/min

- Loss of trailer contents (before operation of fail-safe ESD or emergency shut-off valve): 100 kgs LH2 estimated.

Limiting factor is that max flow is more likely to be determined by the restriction of the trailer/tanker piping, than hose diameter.

Notes on CGH2 & LH2 releases:

- For a gaseous release, stationary situation is reached very rapidly, so the most important parameter will be flow.
- For a liquid release, estimate of both flow and release duration will be dimensioning. We will need to take into account all the flow restricting factors to avoid being excessively conservative on this scenario which dimensions radius of area concerned by emergency response and restrictions to station operation while LH2 is being delivered.

6. Underground line from CGH2 buffer storage or cascade priority panel to dispenser
   Event: U/G line failure (e.g. from external mechanical damage)
   - 35 MPa dispensing systems
     - Max working pressure: 43.8 MPa
     - Dia of line: 13 mm ID (Line pipe API Sch 160)
     - Length of line: 20 – 75 metres (assumed lengths)
     - 0.25 kgs H2 is estimated to be contained in a 20 m U/G length of piping.
   - 70 MPa dispensing systems
     - Max working pressure: 87.5 MPa Bar
     - Dia of line: 13 mm ID
     - Length of line: 20 – 75 metres (assumed lengths)

7. Opening of a safety relief valve (> 35 MPa)
   Event: overpressure in line/system; discharge via safety relief vent to a safe location

8. CGH2 minor leak (> 20 MPa)
   Event: small leak from hose perforation, screwed joint, fitting or flange
   Leak size: 0.10 mm dia (estimated)
   Mitigating factors: escaping H2 will be easily heard; leak can be easily detected by HRS system monitoring pressure.

9. CGH2 major leak (> 20 MPa)
   Event: major leak from hose perforation, screwed joint, fitting or flange
   Leak size: 0.20 mm dia (estimated)
   Mitigating factors: escaping H2 will be easily heard; leak can be easily detected by HRS system monitoring pressure.

10. LH2 minor leak (12 Bar max WP)
    Event: small leak from hose perforation, screwed joint, fitting or flange
    Leak size: 0.10 mm dia (estimated)
    Mitigating factors: escaping LH2 easily detected; freezing easily visible; leak can be easily detected by HRS system monitoring pressure.

11. LH2 major leak (12 Bar max WP)
    Event: major leak from hose perforation, screwed joint, fitting or flange
    Leak size: 0.20 mm dia (estimated)
    Mitigating factors: escaping LH2 easily detected; freezing easily visible; leak can be easily detected by HRS system monitoring pressure.

12. CGH2 leak in compressor building/enclosure (e.g. in the compressor, cooler equipment, valves, flanges etc.)
    Event: CGH2 minor/major (0.1 and 0.2 mm) leak in gas .
    Pressure: 45 MPa
    Amount of hydrogen to be released after gas detection 200 – 300 g (assessment of available amount of gas inside process equipment such as compressor, vessels in between shutoff valves)
    Dimensions of gas processing house l x b x h =6.5 x 2.5 x 2.5 m3
    Mitigating factors: Ventilation (natural or mechanical, 10, 50, 100, 200 ACH[2]).
    Gas detection will initiate automatic shutdown (shutoff valves) towards buffer storage and H2 production/supply and shutdown of compressor.

6. Accident scenarios considered improbable (no CFD simulations proposed)

The following accident scenarios were considered improbable (e.g. corresponding to a 10^{-5} per year.) by the industry. The industry therefore recommends that these scenarios be not prioritised for CFD simulations in the HyApproval project. The partners recognise that specific HRS design in other cases could affect this conclusion. It should be noted that this does not imply that these scenarios will represent negligible risk on a real HRS.

- Catastrophic failure of a CGH2 storage vessel (e.g. H2 cylinder or pressure vessel for buffer storage)
- Catastrophic failure of an underground LH2 storage tank and u/g fittings and pipe work exposed to fire (LH2 storage tanks are installed U/G so they CANNOT be exposed to fire)

There were some questions posed for further consideration as part of ongoing HyApproval activities:

- What scenarios could cause a CGH2 storage vessel to fail catastrophically?
- Mitigation factors: should water sprays protect H2 buffer storage vessels & are water sprays effective against high-pressure H2 jet fires?
- Catastrophic failure of an aboveground LH2 storage tank exposed to fire? Would a LH2 above ground tank ‘bleve’ if exposed to fire?
    - Mitigation factors: as LH2 is a cryogenic liquid, the storage tank would take much longer for the LH2 to change phase from liquid to the gaseous state to result in a ‘bleve’ situation.
- Any other accident scenarios considered improbable?

[2] ACH – Air Changes per Hour

7. Other credible accident scenarios recommended by industry for further discussion & risk assessment in WP4.

Further WP4 internal discussions recommended the following hydrogen related scenarios to be considered when undertaking the risk assessment for HRS's in HyApproval WP4. It should be noted that this list does not intend to be complete with respect to covering all potentially credible incidents in all HRS:

a) Leak at nozzle or other connections --> localized, release not detected automatically

b) Hose failure (without rupture) --> hose movement is partly restrained - release is not detected below a certain leak flow threshold

c) Hose rupture --> hose movement is partly restricted by anti-whipping cable --> roughly localized release, interrupted by pressure sensing device
Break-away release --> localized release interrupted immediately by breakaway system
Nozzle ejection --> hose is unrestrained; increased radius of mechanical impact & flame impact if ignited

Note: Scenarios in the cases of on-site production, scenarios related to oxygen (water electrolysis) and natural gas will not be covered as they are outside the scope of the HyApproval DoW.

The reference data we need to deal with each of the cases above is:

a) Max diameter for leak in equipment connections should be based on real dimensions: agreement on a typical reference dimension: 0.1 mm or 0.2 mm might be appropriate (ISO document hypothesis)?
In several sources, leak sizes to be used in risk assessment studies are listed as dependent on the overall dimension of the equipment, e.g.
   - a valve major leak area equal to e.g. 10 or 20 % area of full-bore rupture, and
   - a minor leak area equal to e.g. 1 or 2 % area of full-bore rupture.

   It should be a requirement to take into account that the equipment at gaseous HRS has significantly smaller dimensions than at large petrochemical plants.

   Some data sources:
   1) EIGA document (IC Doc 75/01/E/rev Determination of safety distances, available from the internet).
   2) IP[3] "Model Code of safe practice. Part 15 Area classification code for installations handling flammable fluids" 3rd Edition July 2005, ISBN 0 85293 418 1
   3) IP "A risk based approach to hazardous area classification", Nov. 1998, ISBN 0 85293 238 3

   In the last two of these sources a release size of 0.1 mm (corresponding to a failure frequency of 10^{-2} per valve yr) for valves is proposed for calculations as basis for extension of ex zone 2.

[3] IP – Institute of Petroleum, London

b) Max leak that will not be detected automatically.
c) Hose& line internal diameter, flow restrictions, hose & line length to isolation valve, max time to detect release and close isolation valve.
d) Hose & line internal diameter, flow restrictions, time for both ends to close.

The values taken above would be the maximum values that would be expected in a fueling station (according to its type: bus or car, gas or liquid).
WP4 should systematically compare the effects with those that we would have with alternative fuels already in use like LPG (when applicable), especially for the major accident scenarios used as a basis for siting.

8. Risk controlling measures relevant for HRS Accident scenarios selected for CFD simulations

For the purpose of satisfying public safety issues, it is assumed that HRS's have been built to recognised and currently accepted codes, standards and regulations, primarily based on national and local specific requirements.

1. **General risk controlling factors applicable to all Hydrogen Refuelling Stations:**
    - All HRS's are designed, constructed & operated to statutory requirements and approved codes & standards. The current limitation related to hydrogen specific approved and recognised codes & standards imply that additional measures in most cases are recommended to assure an acceptable safety level.
    - Classification of hazardous areas according to approved/agreed standards
    - All HRS's to have a prepared Emergency Response Procedure (ERP) plan
    - All HRS operator(s) shall be trained in ERP plans and operation of HRS as applicable.
    - All HRS's to have an emergency shutdown (ESD) system or equal.
    - Fire water supply & fire fighting equipment is available and appropriate to the size and/or risk of the HRS e.g. dry sprinkler, firewater monitor, and fire extinguishers. Special attention must be paid at stations where liquid hydrogen is stored to prevent plugging vent outlets. A Hydrogen/natural gas jet fire should generally not be extinguished until the release is stopped since this might lead to accumulation and delayed ignition. Cooling of storage tanks and other hydrogen containing equipment, e.g. by water spray, should be considered.
    - HRS's comply with separation (or isolation) distances required to achieve acceptable levels of as per agreed codes & standards
    - HRS's have a systematic preventative maintenance plan in place

2. **CGH2 Dispenser @ 35 MPa**
    Mitigation factors:
    - Hose break-away / hoses / connector nozzle are visually inspected daily to confirm no signs of mechanical damage or particulate present on connector nozzle seals
    - Dispenser to go through a self leak-check test before dispensing fuel
    - Hose fitted with a dry-breakaway connection

- Hose is tested and/or inspected at agreed service periods with inspection and service of break-away & nozzle connector
- Dispenser must be protected from external impact from vehicles. Means of protection can be bollards, curbs, guard rails etc.
- Excess flow valve is fitted underneath dispenser or else control by pressure transmitters, pressure differential detectors or equal; max fill rate limited to 3.6 kg/min (as per WP6 requirement).
- Assembled hose fitted with a suitable restraining cable or device, properly fitted to an anchor point to restrain the hose in the event of a hose assembly failure (anti-whip wire feature).
- ESD button positioned near dispenser
- Dispensers are made from flame-resistant materials

3. **CGH2 dispenser failure at 70 MPa**

   Mitigation factors:
   - Hose break-away / hoses / connector nozzle are visually inspected daily to confirm no signs of mechanical damage or particulate present on connector nozzle seals
   - Dispenser to go through a self leak-check test before dispensing fuel
   - Hose fitted with a dry-breakaway connection
   - Hose is tested and/or inspected at agreed service periods with inspection and service of break-away & nozzle connector
   - Dispenser must be protected from external impact from vehicles. Means of protection can be bollards, curbs, guard rails etc.
   - Excess flow valve is fitted underneath dispenser or else control by pressure transmitters, pressure differential detectors or equal; max fill rate limited to 3.6 kg/min (as per WP6 requirement).
   - Assembled hose fitted with a suitable restraining cable or device, properly fitted to an anchor point to restrain the hose in the event of a hose assembly failure (anti-whip wire feature).
   - ESD button positioned near dispenser
   - Dispensers are made from flame-resistant materials

4. **LH2 dispenser failure at 3 – 8 Bar**

   Mitigation factors:
   - Hose break-away / hoses / connector nozzle are visually inspected daily to confirm no signs of mechanical damage or particulate present on connector nozzle seals
   - Dispenser to go through a self leak-check test before dispensing fuel
   - Hose fitted with a dry-breakaway connection
   - Hose & connector is pressure tested annually or at a frequency by other agreed criteria for acceptable operation (hoses are of stainless steel metallic construction)
   - Dispenser must be protected from external impact from vehicles. Means of protection can be bollards, curbs, guard rails etc.
   - ESD button positioned near dispenser
   - Dispensers are made from flame-resistant materials

5. **CGH2 tanker discharge hose failure at 25 MPa**

Mitigation factors:

- Hose & end connections are visually inspected before each discharge to confirm no signs of mechanical damage or particulate/dirt present on end connection threads
- Hose & end connections are pressure tested annually or visually inspected to determine a predetermined lifetime.
- Assembled hose fitted with a suitable restraining cable or device, properly fitted to an anchor point to restrain the hose in the event of a hose assembly failure (anti-whip wire feature).
- Trailer discharge station is located in a controlled & secure area. Escaping gas can vent & disperse to atmosphere.

6. LH2 tanker discharge hose failure (11 bar max WP)

Mitigation factors:

- Hose & end connections are visually inspected before each discharge to confirm no signs of mechanical damage or particulate/dirt present on end connection threads
- Hose & end connections are pressure tested annually or at a frequency by other agreed criteria for acceptable operation (hoses are of stainless steel metallic construction)
- Hoses are double walled & vacuumed jacketed
- Trailer discharge station is located in a controlled & secure area. Escaping gas can vent & disperse to atmosphere.

7. Underground line from CGH2 buffer storage or cascade priority panel to dispenser

Mitigation factors:

- U/G lines are protected against external corrosion by external coatings, cathodic protection or equal
- U/G lines are pressure tested every 5 yrs or at a frequency by other agreed criteria for acceptable operation
- U/G lines are protected from external mechanical damage by installation inside another protective (jacketed) pipe or within concrete ducting or equal.
- U/G pipelines are fitted with 'Normally-closed' valves at either end of under-ground line sections if length of u/g pipeline is greater than 20 metres unless an alternative acceptable safety level has been determined by risk assessment or other equivalent method.

8. On-site Production building/enclosures

Mitigating factors:

- Gas and fire detection inside production building
- Relief points for oxygen and hydrogen (for electrolysers) are located at safe position at a certain distance from each other. The relief point for oxygen must be at a lower level than relief point for hydrogen
- Gas and fire detection will automatically close shut-off valves toward compressor and buffer storage
- Non return valves to prevent backflow from high pressure section
- Emergency buttons positioned inside enclosure
- Explosion relief areas

- If the ventilation system is a part of the safety system, the effect is documented by approved/agreed standard
- Ventilation inlet at low position
- Ventilation outlet at high position

9. Compressor building/enclosures

Mitigating factors:

- Gas and fire detection inside enclosure
- Gas and fire detection will automatically close shut-off valves towards H2 production/supply and buffer storage
- Safety valves/relief system from low pressure side will be separated from the high pressure safety relief system
- Non return valves to prevent backflow from high pressure buffer storage
- Emergency buttons positioned inside enclosure
- Explosion relief areas
- If the ventilation system is a part of the safety system, the effect is documented by approved/agreed standard
- Ventilation inlet at low position
- Ventilation outlet at high position

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9. Conclusions

WP4 work activities will continue to monitor best practices based on actual industry experiences with hydrogen refuelling stations in Europe, US and Japan and input into the HyApproval Handbook development as applicable.

The best practices will be also considered for input into Deliverables D4.3 and D4.5, when a comprehensive Risk Assessment study of HRS's will be undertaken and accident and incident scenarios finally selected for the CFD simulation and modelling.