Fire Safety of Hydrogen Facilities

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Fire Safety | Security | Natural Hazards

The CFPA Europe develops and publishes common guidelines about fire safety, security, and natural hazards with the aim to achieve similar interpretation and to give examples of acceptable solutions, concepts, and models. The aim is to facilitate and support fire protection, security, and protection against natural hazards across Europe, and the whole world.

Today fire safety, security and protection against natural hazards form an integral part of a modern strategy for survival, sustainability, and competitiveness. Therefore, the market imposes new demands for quality.

These Guidelines are intended for all interested parties and the public. Interested parties include plant owners, insurers, rescue services, consultants, safety companies and the like so that, in the course of their work, they may be able to help manage risk in society.

The Guidelines reflect best practice developed by the national members of CFPA Europe. Where these Guidelines and national requirements conflict, national requirements shall apply.

This Guideline has been compiled by the Fire Safety and is adopted by the members of CFPA Europe.

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Contents

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1 Introduction

Hydrogen facilities differ from conventional fuel installations due to frequent use of high pressures and/or cryogenic temperatures, low ignition energy, potential for rapid dispersion and accumulation in overhead pockets, and limited flame visibility in some conditions. The main accident pathway is: release → dispersion/accumulation → ignition → fire or explosion → escalation.

Hydrogen is increasingly being deployed as an energy carrier and industrial feedstock, with applications spanning mobility, power generation, heat production and a wide range of industrial processes.

With the growth of hydrogen technologies, the number and diversity of "hydrogen facilities" is expanding across the whole value chain: production (e.g., electrolysers and associated utilities), storage and distribution (compressed gas and cryogenic liquid systems, pipelines, cylinder filling, tube trailers), and end-use installations (fuel cells, hydrogen combustion equipment, industrial users and refuelling infrastructure).

Hydrogen has hazardous properties and can create severe fire and explosion scenarios if releases occur and are ignited; nevertheless, it can be used safely when its hazards are understood and risks are systematically managed. In practice, "zero risk" is not achievable; therefore, prevention, mitigation and emergency preparedness must be built on robust engineering design, effective operational controls, competent maintenance, and well-rehearsed response arrangements. Hydrogen fire safety requires particular attention because many systems operate at high pressure and/or cryogenic temperatures, and because flammable mixtures may form rapidly under certain release and dispersion conditions. In addition to preventing ignition, facilities must be designed to limit escalation (e.g., from a local leak to a larger event), to protect people and critical assets, and to enable safe intervention by emergency services. International incident experience shows that undesired events continue to occur and that valuable lessons can be drawn from systematic reporting and analysis. The Hydrogen Incidents and Accidents Database (HIAD) is an international open platform collecting structured information on hydrogen-related incidents, maintained and expanded by JRC and the European Hydrogen Safety Panel and used to derive statistics, lessons learnt and recommendations.

This guideline is aligned with that "learning from experience" approach: it translates recurring themes from incident experience into practical fire-safety measures. It provides risk-based recommendations for fire and explosion safety in hydrogen facilities, covering the lifecycle from concept and design through construction/commissioning, operation, inspection/testing, maintenance and modification, as well as emergency preparedness and response interfaces. It draws on three technical guides developed under the project "Komplexní vodíková bezpečnost v Moravskoslezském kraji (TK05010075)" and extends them into this guideline. As with all CFPA-Europe guidelines, where this guideline and national requirements conflict, national requirements prevail.

This guideline provides minimum and recommended fire safety measures applicable across hydrogen production, storage/transport interfaces, and stationary use.

2 Scope

This guideline provides fire safety and fire-protection recommendations for the design, siting, installation, commissioning, operation, inspection/testing, maintenance, modification and decommissioning of hydrogen facilities where hydrogen may be produced, stored, transferred, dispensed and/or used. It supports a consistent level of fire safety and offers practical concepts and examples that can be applied across Europe.

This guideline is intended for owners/operators, designers and contractors, insurers, rescue services/first responders, authorities having jurisdiction, consultants, safety companies and risk assessors, so that in the course of their work they may help to manage fire and explosion risk in society.

Vehicle onboard systems are not covered.

In any case, if national or local codes are in contrast with this guideline, national and local codes prevail.

3 Definitions

GH2 (gaseous hydrogen): Hydrogen in the gaseous phase (at ambient or elevated pressure). In many applications GH2 refers to compressed gaseous hydrogen used for storage, transfer, and refueling systems.

LH2 (liquid hydrogen): Hydrogen in the liquid (cryogenic) phase. LH2 systems operate at extremely low temperatures and require materials, insulation, and design provisions suitable for cryogenic service.

LFL/UFL (lower/upper flammability limit): Concentration limits of a fuel in air within which a flame can propagate after ignition. Below the **LFL** the mixture is too "lean" to burn; above the **UFL** it is too "rich." For hydrogen, operational alarm/shutdown setpoints are commonly expressed as a fraction of the LFL (e.g., 25% LFL).

ESD (emergency shutdown): A safety function/system that rapidly places a hydrogen installation or vehicle/fueling system into a safe state by stopping the process and isolating the hydrogen supply (typically by closing automatic shut-off valves and interrupting non-essential electrical power).

PRD/TPRD (pressure relief device / thermally activated pressure relief device): A protective device intended to prevent catastrophic overpressure of hydrogen equipment. A PRD opens (e.g., via rupture disc or valve) when pressure exceeds a set threshold to vent contents.
A TPRD (also TRD) incorporates a thermal element intended to actuate under fire/heat exposure to enable controlled venting and reduce the likelihood of vessel rupture.

Hazardous area classification (HAC): The systematic classification of locations where an explosive/flammable atmosphere may occur (due to hydrogen release) so that appropriate ignition-source controls and suitably rated electrical/mechanical equipment can be selected and installed ("electrical classification zones").

Confined and semi-confined spaces:

- **Confined space:** An enclosed or poorly ventilated volume where leaked hydrogen can accumulate and form a flammable atmosphere, particularly in stagnant zones or "dead legs."

- **Semi-confined space:** A partially enclosed volume (e.g., with limited openings) where accumulation is still possible and dispersion is constrained compared with open air.

Exposure cooling: The application of cooling (typically water spray/deluge/monitor streams) to equipment or vessels exposed to external fire or jet flame heat, to limit temperature rise, reduce heat-induced degradation, and help prevent escalation (including PRD actuation sequences, loss of strength, or fire spread).

Escalation: The worsening of an event due to spread or "cascading effects" (e.g., a leak leading to ignition, then secondary failures, additional releases, involvement of adjacent equipment, or broader consequences). Prevention focuses on containment/isolation, layout barriers, and design features that reduce cascading failures.

4 Field of application

This guideline applies to:

- new installations (design + commissioning),
- modifications to existing installations (MOC),
- operation and maintenance phases,
- indoor/containerised hydrogen installations where hydrogen is present in rooms/containers.

This guideline is intended to be applied as:

- a design and review framework for new installations,
- an audit and improvement framework for existing installations,
- a consistent basis for inspections and self-assessment,
- a common reference for coordination between operators, designers, insurers and emergency services.

It is expected that facility-specific risk assessment will determine which recommendations are essential as minimum measures and which additional measures are appropriate to achieve an acceptable level of risk.

Where national rules conflict with this guideline, national rules apply.

5 Fire risk assessment

Hydrogen facilities vary widely in hydrogen inventory, operating pressure and temperature, enclosure geometry, ventilation, occupancy, proximity to vulnerable receptors and critical assets, and the complexity of interfaces (transfer, maintenance, abnormal operations). Therefore, a **facility-specific fire risk assessment** should be performed to determine a proportionate set of preventive and mitigative measures and to demonstrate that the residual risk is acceptable for the given context.

This chapter describes:

- a practical, stepwise method for hydrogen fire risk assessment,

- typical initiating scenarios and outcome pathways,
- how incident experience can be used to focus prevention and mitigation,
- the minimum expected outputs for design, operation and emergency preparedness.

5.1 Principles and approach

A hydrogen fire risk assessment should consider the full accident pathway:

1. **Initiating event** (e.g., leak from fitting/valve, component failure, procedural error, purging error, external impact)
2. **Release characteristics** (rate, direction, pressure, liquid vs gaseous, duration, availability of isolation)
3. **Dispersion and accumulation** (open vs semi-confined vs confined; overhead pockets; shafts; canopies; containers)
4. **Ignition** (immediate or delayed; potential ignition sources; ignition control measures)
5. **Outcome** (jet fire, flash fire, deflagration/explosion, fireball in specific circumstances)
6. **Escalation** (impingement on equipment, heating of pressure systems, domino effects, impact on egress and emergency access)
7. **Emergency intervention** (isolation, evacuation, exposure cooling, access constraints)

The assessment should cover all relevant lifecycle phases:

- design and construction/installation,
- commissioning and start-up,
- normal operations,
- abnormal operations (upsets, trips, failure modes),
- maintenance and shutdown/restart,
- temporary states (purging, inerting, venting/blowdown, testing),
- modifications (management of change) and decommissioning.

5.2 Use of incident experience to focus the assessment (HIAD dataset)

Incident databases provide evidence of recurring patterns and are useful to prioritise controls. The hydrogen incident dataset used for this guideline (HIAD 2.1 export dated 2024-01-01; 755 records) supports the following high-level observations.

Evidence dimension	Key insight (3–5 takeaways)	Count(s)	Share (%)
Physical effects	Most recorded events involve ignition after a release	Hydrogen release and ignition: 549	72.7
Consequences	Explosion outcomes dominate over "fire only"	Explosion: 342; Fire: 217	45.3; 28.7
Consequences	Non-ignited outcomes are still frequent (leaks/near misses)	Leak no ignition: 112; Near miss: 81; False alarm: 3	14.8; 10.7; 0.4
Initiating system	Events are mostly initiated by hydrogen systems (not external systems)	Hydrogen system initiating: 527; Non-hydrogen: 222; Unknown/NS: 6	69.8; 29.4; 0.8
Causes (event-level presence)	Management and human/organisational factors are recurring contributors	Management: 338; Material/manufacturing: 260; Human: 217; Design: 185	44.8; 34.4; 28.7; 24.5
Confinement sensitivity (specified subset)	Confinement strongly correlates with explosion outcomes (subset where location is specified)	Explosion share: Confined 68.0% vs open 26.2% vs semi-confined 53.8%	(share within each location type)

Practical implication for risk assessment:
Hydrogen fire safety cannot rely on "hardware only". The assessment should explicitly verify:

- **accumulation control** in confined/semi-confined environments,
- **integrity + isolation** for high-pressure systems and interfaces,
- **competence, procedures, PTW and MOC**, because management and human-related factors appear frequently in incident records.

5.3 Typical initiating scenarios and consequence pathways (facility-relevant)

For the purpose of structured risk assessment, the following typical facility scenarios should be considered, as applicable:

1. **High-pressure gaseous hydrogen leak with immediate ignition → jet fire**
   Key concerns: flame impingement, high heat flux to equipment, escalation, limited visibility.
2. **Hydrogen release with delayed ignition in semi-confined/confined space → deflagration/explosion**
   Key concerns: accumulation under ceilings/voids, ignition control, structural consequences, impact on egress.
3. **Venting/blowdown/PRD discharge with ignition → sustained flame at discharge point**
   Key concerns: safe vent routing, clearance around outlet, protection of exposures, responder safety.

4. **Liquid hydrogen release (or cryogenic system failure) → cold vapour cloud, dispersion/accumulation, ignition**
   Key concerns: cryogenic effects, formation of combustible mixtures, reliability of relief/venting systems.
5. **Commissioning/maintenance/procedural errors (purging/inerting, breaking containment, hot work) → release + ignition or explosive mixture formation**
   Key concerns: PTW, verification steps, competence, supervision, temporary states.

These scenarios should be used to:

- identify where the most credible releases exist,
- select detector locations and alarm thresholds,
- define automatic shutdown and isolation logic,
- determine separation, shielding and escalation protection needs,
- develop emergency arrangements and training drills.

5.4 Minimum content of a hydrogen fire risk assessment (expected outputs)

A. Facility description and boundaries
• system description (process overview, inventories, pressures/temperatures), • indoor/outdoor/semi-confined classification for each area, • occupancy profile and "persons at risk" (including contractors and visitors), • exposure mapping (adjacent buildings, critical assets, public interfaces).
B. Hazard identification
• credible leak sources and interface points (valves, fittings, manifolds, couplings, compressors, transfer lines), • abnormal/temporary states (maintenance, purge/inert, venting/blowdown, start-up/shutdown), • ignition source inventory and control measures, • confinement/accumulation locations (ceilings, pockets, shafts, pits, canopies, containers).
C. Scenario assessment (For each credible scenario)
• release characteristics and expected duration (including isolation assumptions), • dispersion/accumulation considerations (qualitative or quantitative), • ignition likelihood considerations (immediate vs delayed), • outcome type (jet fire, flash fire, explosion) and escalation potential, • effect on evacuation routes, muster points and emergency access.
D. Safety functions and performance requirements
• required gas detection coverage and placement rationale, • required automatic actions (alarm, ESD/isolation, shutdown, ventilation responses), • venting/relief routing performance intent and clearance, • integrity and inspection/testing requirements for safety-critical elements.

E. Emergency preparedness outputs
• emergency response information for responders (layout, isolation points, vent outlets), • defined exclusion zones and safe approach routes (wind-aware), • strategy for exposure cooling / escalation prevention where relevant, • training and drill programme reflecting credible scenarios.
F. Action plan
• list of required measures (minimum) and recommended additional measures, • priorities and implementation timeline, • verification plan (commissioning tests, periodic proof testing, audits).

5.5 Proportionality: when qualitative methods are sufficient and when QRA is recommended

The chosen method should match the complexity and potential consequences.

Qualitative / semi-quantitative methods may be sufficient where:

- inventories and pressures are limited,
- installations are outdoors and not semi-confined,
- exposures are limited and separation is straightforward,
- safety functions are simple and easily verified.

More detailed quantitative work (e.g., dispersion modelling, consequence modelling, QRA) is recommended where one or more of the following apply:

- indoor or semi-confined installations where accumulation is credible,
- high-pressure systems with credible jet fire impingement potential,
- large inventories (including LH_2) or complex vent/relief routing,
- proximity to occupied buildings or high-consequence exposures,
- multiple interacting systems and complex shutdown logic,
- public-access interfaces or high occupancy.

In all cases, the assessment should be revisited when changes occur (equipment, layout, operating window, procedures, staffing/competence), and it should be integrated into the site's management of change process.

6 Minimum fire safety requirements

The requirements are structured to (1) prevent loss of containment and ignition, (2) prevent accumulation of flammable mixtures (especially in semi-confined and confined geometries), (3) provide rapid isolation and safe relief/venting, and (4) limit escalation so that evacuation and emergency intervention remain feasible.

The requirements in this chapter represent a **baseline expectation** for hydrogen fire safety. They should be applied proportionately: a small outdoor installation with limited inventory will implement the same principles with simpler solutions than a large, complex, high-pressure or indoor facility. Where facility-specific risk assessment indicates higher risk or higher consequences, **recommended additional measures** (included within each subchapter) should be adopted to achieve an acceptable level of residual risk.

6.1 Safety instructions and information

The operator should establish, maintain and make readily available clear safety instructions for normal operation, abnormal operation and emergency conditions. The instructions should be understandable to operators, maintenance staff and contractors, and should be usable under time pressure. As a minimum, the safety information should include:

- a concise description of the hydrogen installation (hydrogen inventories, operating pressures/temperatures, main equipment and interfaces);
- a simple site plan showing hydrogen equipment locations, emergency shutdown (ESD) points, isolation valves, vent/relief discharge points, muster points and emergency access routes;
- alarm meanings and required actions, including escalation paths and call-out arrangements;
- ignition source controls and restricted activities in hazardous zones (including rules for portable devices and hot work);
- clear assignment of responsibilities (who initiates ESD, who accounts for personnel, who supports emergency services, who authorises re-entry);
- a brief "do/don't" set of rules for abnormal conditions (e.g., suspected leak, gas detector alarm, unexpected pressure drop, PRD discharge).

Safety instructions should be controlled documents: updated after modifications, after relevant incidents/near misses, and periodically reviewed for continued validity.

For complex facilities, the operator should consider:

- issuing role-specific quick guides (operator card, maintenance card, contractor induction card);
- providing a responder information pack (laminated site plan, isolation map, contact list, hazardous zones) stored at an agreed access point;
- introducing a structured "abnormal situation management" guide aligned with key scenarios (high-pressure leak, indoor accumulation, PRD discharge).

6.2 Egress, muster points and emergency access

Egress and emergency access should remain effective under credible hydrogen release and fire scenarios, including scenarios that affect visibility, produce high noise (e.g., jet release) or require responders to approach from specific directions. As a minimum:

- evacuation routes and exits should remain unobstructed, clearly marked and suitable for expected occupancy;

- muster points should be located so that they are not exposed to likely discharge/vent paths and are not positioned where hydrogen could accumulate (e.g., under canopies or close to roof pockets);
- emergency access routes should enable responders to approach without passing directly through predicted accumulation zones or near potential jet impingement lines;
- gates, barriers and site security controls should be compatible with emergency access, including a defined method for rapid entry.

Where indoor areas are within scope, egress arrangements should consider that some hydrogen scenarios may degrade conditions near ceilings, in corridors or in local pockets, and the operator should avoid placing critical egress routes in areas prone to accumulation.

Where consequences could be high, the operator should consider:

- wind-direction awareness measures for outdoor sites (wind socks/indicators at key points);
- pre-agreed responder staging areas and approach routes for credible scenarios;
- periodic walk-through egress drills focusing on "alarm → move → muster → account" performance under realistic constraints.

6.3 Site control, occupancy and exclusion zones

The operator should control occupancy and activities in hydrogen hazard areas to reduce the probability of ignition and to limit the number of exposed persons. As a minimum:

- access to hydrogen process areas should be restricted to authorised personnel and inducted contractors;
- exclusion zones should be defined for transfer operations and for areas around vent/relief discharge points where ignition or sustained flame could occur;
- activities that increase ignition probability (hot work, non-rated electrical equipment use, uncontrolled mechanical work) should be prohibited or strictly controlled within hazardous zones;
- public interfaces (where present) should be arranged so that members of the public cannot enter hazardous areas or compromise emergency egress.

Exclusion zones should be described in procedures and reflected in site markings where practicable.

For larger or higher-risk sites, consider:

- controlled access systems (permit-based access, sign-in/out for contractors, visitor escorting);
- task-based exclusion zones that change with operational state (e.g., during unloading, purging, venting/blowdown);
- defined "no-go" overhead pocket zones in semi-confined structures where accumulation is credible.

6.4 Signage, emergency lighting and communications

Signage and communications should support safe operation and rapid response. As a minimum:

- signs should clearly identify hydrogen hazard areas, ignition source restrictions, and the locations of ESD and key isolation points;
- vent/relief discharge locations should be marked, and the "keep clear" principle should be communicated for normal and abnormal conditions;
- where indoor evacuation is relevant, emergency lighting should support safe egress during loss of normal lighting;
- communication methods for alarms and instructions should work reliably in both indoor and outdoor conditions, including high noise environments.

Where appropriate, consider:

- standardised, colour-coded signage for hydrogen safety functions (ESD, isolation, vents, muster points);
- backup communication methods (e.g., loudhailers, redundant alarm sounders) for noisy outdoor operations;
- multilingual signage where contractor workforce requires it.

6.5 Ventilation and accumulation control

Hydrogen accumulation control is essential in confined and semi-confined environments due to the potential for explosive mixtures in overhead pockets and dead spaces. As a minimum:

- indoor and containerised installations should provide ventilation that prevents hazardous accumulation at ceilings and in dead spaces (e.g., under beams, in roof voids, in service voids, in shafts and pits);
- semi-confined geometries (canopies, shelters, partially enclosed bays) should be assessed for accumulation potential and treated conservatively unless ventilation effectiveness is demonstrated;
- ventilation openings, supply and extraction arrangements should consider hydrogen buoyancy and expected release locations (high-level extraction is often needed where accumulation is credible);
- where forced ventilation is relied upon as a safety function, its availability and failure modes should be addressed (monitoring, alarm on failure, interlocks where appropriate, maintenance and proof testing).

Ventilation should be considered together with detector placement and automatic actions. Ventilation alone is not a substitute for integrity and isolation. Where geometry is complex or consequences could be high, consider:

- targeted dispersion assessment (including modelling where needed) to verify that credible releases do not create hazardous pockets;
- design measures that eliminate accumulation traps (avoid suspended ceilings, seal or ventilate roof pockets, manage penetrations and voids);
- independent power supply for ventilation safety functions where justified by risk.

6.6 Hazardous area classification (HAC) and ignition control

The operator (and designer for new installations) should ensure that ignition sources are controlled consistent with credible hydrogen releases and the defined hazardous zones. As a minimum:

- hazardous area classification should be performed for areas with credible hydrogen release, including abnormal and temporary states (maintenance, purging/inerting, venting/blow-down);
- electrical and instrumentation equipment should be selected and installed consistent with HAC zones;
- bonding and earthing should be implemented where electrostatic discharge could ignite hydrogen;
- controls should be in place to minimise ignition sources, including restrictions on portable electrical devices and control of hot surfaces in hazardous zones.

Ignition control should extend beyond electrical equipment to include mechanical sources (friction, impact, hot bearings), procedural sources (hot work), and transient sources (temporary equipment).

Where the ignition likelihood or consequence is high, consider:

- formal ignition source reviews linked to maintenance/contractor tasks;
- enhanced static control (workwear, flooring, bonding points, procedures for transfer interfaces);
- stricter controls on temporary installations (temporary lighting, instruments, tools) in hazardous zones.

6.7 Hydrogen system integrity, isolation and emergency shutdown (ESD)

The facility should be designed and operated to minimise loss of containment and to ensure rapid isolation when abnormal conditions occur. As a minimum:

- hydrogen systems should be designed, installed and maintained to minimise loss of containment, using suitable components, assembly quality controls and inspection/testing regimes appropriate to pressure/temperature and duty;
- the installation should provide rapid isolation of hydrogen sources (automatic and manual), including clearly identified ESD devices at safe and accessible locations;
- the isolation philosophy should consider fail-safe behaviour and maintainability, including the effects of loss of power or control signals;
- isolation and ESD functions should be periodically tested, with records maintained and deficiencies corrected.

Isolation capability should include credible interfaces (manifolds, transfer points, compressor skids, container boundaries) and should be aligned with the facility's emergency plan.

Where rapid escalation is credible (e.g., high-pressure jets, proximity exposures), consider:

- segmentation of hydrogen inventories (zoning) so isolation can limit inventory and duration of release;

- redundancy or diversity in critical shutdown paths (e.g., independent ESD triggers where justified);
- remote ESD capability where access could be compromised by fire, noise or plume location.

6.8 Pressure relief, venting and blowdown (PRD/TPRD)

Relief and venting systems should be designed on the assumption that hydrogen may ignite during discharge. As a minimum:

- PRD and venting systems should discharge to safe locations to reduce risk to people and to prevent flame impingement on equipment, and should avoid discharge toward air intakes, doors, escape routes and occupied areas;
- the area around vent/PRD outlets should be kept clear of combustibles and critical assets, recognising that hydrogen may burn at the outlet with low visibility in some conditions;
- for cryogenic systems, design should address icing/blockage risks, material compatibility, and reliable operation of relief devices across operating conditions;
- venting/blowdown operations (where used) should be governed by procedures defining when and how they are performed, and what area controls apply during the operation.

For sites with complex relief networks or close exposures, consider:

- dedicated vent stack routing with defined "keep clear" zones and physical barriers where practicable;
- assessment of vent outlet positioning to minimise re-entrainment into semi-confined areas or roof pockets;
- proof-testing regimes that include functional verification of relief paths and associated instrumentation where feasible.

6.9 Gas detection, flame detection, alarms and automatic actions

Detection and alarm systems should provide timely warning and trigger predefined actions to reduce the probability of ignition and limit release duration. As a minimum:

- hydrogen gas detection should be installed where releases could accumulate or remain undetected, particularly at high points near ceilings, within containerised systems, under canopies, and near credible leak sources such as manifolds, compressors and transfer interfaces;
- detector placement and alarm thresholds should be defined by risk assessment and linked to defined actions (alarm, shutdown, isolation, ventilation responses);
- alarm management should ensure alarms are recognisable and that required actions are trained and practised;
- where limited flame visibility or credible outdoor jet fires exist, flame detection should be considered to improve early recognition.

Automatic actions should be designed to avoid introducing new hazards (e.g., ventilation changes that worsen accumulation) and should be compatible with emergency response procedures.

Where detection is safety-critical, consider:

- redundancy in critical detection points (especially overhead accumulation zones);
- periodic performance checks beyond calibration (e.g., bump testing and end-to-end functional checks of alarm-to-action chains);
- trending and diagnostics to identify drift, recurring nuisance alarms, and weak coverage.

6.10 Fire protection strategy and escalation prevention

The fire protection strategy should prioritise preventing escalation and domino effects. As a minimum:

- the facility should adopt a clear escalation-prevention concept, using separation, layout, shielding and controlled areas as primary measures where practicable;
- where credible jet fire impingement or significant radiant heat exposure is possible, the design should limit exposure of critical equipment and define how escalation is prevented;
- firefighting resources and water supplies (where used for exposure cooling) should be consistent with the facility's risk profile and the chosen protection concept.

This guideline does not prescribe tactical firefighting methods in the main body; tactical considerations are addressed in the emergency annex.

Where escalation consequences are significant, consider:

- dedicated exposure protection for critical equipment (e.g., water spray for cooling) where justified by risk assessment;
- passive protection or structural measures where separation cannot be achieved;
- enhanced resilience of safety-critical supports (power, control, communications) under fire exposure.

6.11 Operations: PTW, maintenance, competence, and management of change (MOC)

Operational controls are fundamental barriers in hydrogen safety. As a minimum:

- a permit-to-work system should control hot work, confined space entry, and breaking containment activities involving hydrogen systems;
- isolation and verification steps (including lockout/tagout where applicable) should be defined for maintenance tasks that could release hydrogen;
- competence requirements should be defined for operations, maintenance and contractors, including hydrogen-specific hazards (high-pressure jets, accumulation, low-visibility flames, vent/relief hazards);
- management of change should be applied to modifications to equipment, layout, operating limits, control logic and procedures;
- near misses and incidents should be reported, investigated and used to improve barriers, procedures and training.

Where contractor activity is high or systems are complex, consider:

- task-specific safe work method statements with hydrogen-specific hazard prompts;
- enhanced supervision during non-routine work and commissioning activities;
- periodic barrier audits focusing on the quality of PTW and MOC implementation.

6.12 Confined and semi-confined spaces (including pits and shafts)

Spaces where hydrogen can accumulate should be identified, controlled and, where possible, designed out. As a minimum:

- pits, shafts, service voids, cable spaces, roof pockets and other confined volumes should be assessed as potential accumulation zones and controlled accordingly;
- entry to confined spaces where hydrogen may be present should be managed through permit-to-work, gas testing/clearance, ventilation verification and ignition source controls;
- design and housekeeping should minimise creation of unventilated pockets where hydrogen can accumulate.

Where confinement cannot be avoided, consider:

- engineered ventilation or venting solutions for known accumulation traps;
- dedicated detection at the highest point within the confined volume;
- physical measures that prevent ignition sources entering the zone during abnormal states.

6.13 Emergency preparedness interface

Emergency arrangements should support rapid isolation, evacuation, accountability and effective coordination with emergency services. As a minimum:

- emergency roles should be defined, including responsibility for initiating ESD/isolation, accounting for personnel, and supporting responders with hydrogen-specific information;
- responders should be provided with layout information showing hydrogen equipment, ESD/isolation points and vent/TPRD discharge locations;
- drills should include hydrogen-relevant scenarios such as high-pressure leaks (with and without ignition), indoor accumulation alarms, and vent/TPRD discharge events;
- procedures should define clear criteria for re-entry and restart after an incident or alarm, including verification that safety functions are restored.

Tactical firefighting guidance (priority of isolation and exposure protection) is addressed in the Annex 2.

For higher-risk facilities, consider:

- joint pre-planning with local responders (site familiarisation, access keys, staging areas, information pack);
- scenario-based drills that include communication under noise and limited visibility conditions;

- periodic review of emergency arrangements after modifications and after relevant external incidents.

Bundles of recommendations are available in the Annex 1 for recommendations on specific applications/triggers.

7 Existing hydrogen facilities and special situations

This guideline is applicable to both new and existing hydrogen facilities. For existing installations, full implementation of all baseline measures above may be constrained by layout, building geometry, legacy equipment, or operational interfaces. In such cases, the operator should apply a **risk-based gap closure approach** that (1) preserves the safety intent of previous chapter, (2) prioritises measures that reduce likelihood of loss of containment and ignition, and (3) adds robustness using the annex 1 table - implementation bundles.

Where significant constraints prevent implementation of baseline measures, an advanced facility-specific risk assessment should be performed and documented, defining compensating measures and verification requirements.

7.1 Existing facilities (retrofit and life extension)

For existing facilities, the recommended approach is:

1) Define the installation boundary and credible scenarios
Confirm the hydrogen inventory, operating envelope (pressure/temperature), states (normal, start-up/shutdown, maintenance, purging, venting/blowdown), and credible loss-of-containment scenarios, including those driven by non-routine work.
2) Perform a structured gap assessment against Chapter 6
Identify where baseline intent is not met (e.g., accumulation control, hazardous area classification, ignition controls, isolation/ESD accessibility, vent/PRD discharge clearance, emergency access and muster locations).
3) Prioritise gap closure by risk and feasibility
Prioritise measures that (a) prevent loss of containment, (b) shorten release duration via isolation, (c) prevent accumulation in confined/semi-confined spaces, and (d) keep people away from discharge/jet paths and escalation zones.
4) Apply the implementation bundles (Annex 1) as a retrofit tool
Select the relevant bundles (e.g., Indoor/Containerised, High-pressure, Transfer interfaces, Contractor-heavy operations) to add reliability and governance maturity without rewriting the baseline requirements.

5) Implement compensating measures where full retrofit is not feasible
Where physical changes are limited, compensating measures should preserve the safety function by operational and procedural means, for example: • restricting hydrogen inventory and/or operating pressure during certain states; • limiting occupancy, tightening access control, and increasing exclusion zones; • increasing monitoring, proof testing and maintenance frequency for safety-critical functions; • strengthening PTW/MOC controls and supervision for non-routine work; • adding physical barriers and clear "keep clear" controls around discharge zones.
6) Verify effectiveness and sustain performance
Verification should include commissioning checks after modifications, periodic functional testing of safety chains (detection → alarm → action), and periodic review following incidents, near misses, or operational changes.

7.2 Temporary, mobile and pilot installations

Temporary or pilot hydrogen installations (demonstrators, test skids, mobile generators, temporary refuelling arrangements) can present elevated risk because interfaces, procedures and competence may be immature. The operator should ensure that:

- responsibilities for operation, ESD/isolation, and emergency coordination are explicitly assigned for the temporary period;
- a temporary risk assessment is performed covering abnormal states, non-routine work, and credible confinement/accumulation conditions;
- temporary layouts avoid creating confined/semi-confined accumulation traps (e.g., containers placed against walls, under canopies, or in recessed bays without verified ventilation);
- exclusion zones, signage and "keep clear" controls are established and maintained for transfer operations and vent/PRD discharge areas;
- a pre-start verification is performed (isolation map correctness, detector functionality, alarm audibility/visibility, ventilation availability where used, access routes, muster points);
- drills or briefings are conducted so that all personnel understand alarms, actions and evacuation/muster processes.

7.3 Sites with layout constraints and co-located hazards

Where separation distances, egress routes, or vent/PRD discharge clearances are constrained by existing site conditions, the operator should:

- avoid routing egress or responder approach through likely discharge/accumulation zones;
- protect egress and emergency access routes from foreseeable escalation effects (layout refinements, controlled areas, shielding where justified);
- manage co-location with other hazards (flammable liquids, battery charging, confined machinery spaces) to prevent interacting escalation pathways and to keep emergency actions simple and reliable.

If constraints force non-standard arrangements (e.g., discharge zones near receptors, limited access to manual isolation, or persistent semi-confined states), the operator should document the rationale and implement equivalent risk-reducing measures (increased robustness, restrictions on operating states, enhanced monitoring, and governance upgrades).

7.4 When baseline measures cannot be met

If one or more baseline measures in Chapter 6 cannot be implemented due to unavoidable constraints, the operator should:

- document the constraint and the affected safety function;
- define compensating measures that achieve an equivalent safety outcome;
- define verification and maintenance requirements for the compensating measures;
- ensure personnel competence and emergency preparedness reflect the residual risk and the chosen compensations.

8 Inspection, testing and maintenance

Hydrogen fire safety depends not only on design, but on the **continued performance** of safety functions throughout the facility lifecycle. This chapter sets out expectations for inspection, testing and maintenance (ITM) of hydrogen systems and safety-critical functions, including verification after modifications and governance for non-routine work.

8.1 General requirements

The operator should establish and maintain an **inspection, testing and maintenance programme** that:

- identifies safety-critical elements and functions;
- defines inspection/test methods, acceptance criteria and intervals;
- ensures competent persons perform the work;
- maintains traceable records and corrective actions;
- is integrated with permit-to-work (PTW) and management of change (MOC).

The programme should cover all operating states, including start-up, shutdown, maintenance, purging/inerting, venting/blowdown and commissioning activities.

8.2 Safety-critical elements (SCE) and safety-critical functions (SCF)

The ITM programme should be risk-based and prioritised. As a minimum, it should identify and manage:

A. Containment and interface integrity (SCE)
• pressure equipment and piping; • valves, fittings, threaded joints and flanged connections; • manifolds, couplings and transfer interfaces; • compressor seals and high-duty components; • flexible connections (where used) and their suitability for duty.
B. Isolation and emergency shutdown functions (SCF)
• ESD devices and logic; • remotely operated valves and isolation devices; • fail-safe behaviour on loss of power/control; • manual isolation valves and their accessibility, labelling and operability.
C. Venting and pressure relief systems (SCE/SCF)
• PRD/TPRD devices and discharge paths; • vent stack integrity and clearances; • measures preventing blockage/icing for cryogenic systems; • discharge zone "keep clear" arrangements and site controls.
D. Detection, alarms and automatic actions (SCF)
• hydrogen gas detectors (sensing heads, controllers, signalling); • alarm annunciation (audible/visual) in relevant areas; • action chains (shutdown, isolation, ventilation responses).
E. Ventilation systems used as safety functions (SCF)
• fans, ducting, louvres/dampers and airflow monitoring; • power supply reliability where ventilation is safety-critical; • failure alarms and interlocks where applied.
F. Emergency interface measures
• signage and markings for ESD/isolation and vent/PRD outlets; • emergency access and route availability (site changes, obstructions); • responder information packs and site plans (document control).

8.3 Inspection and testing philosophy

The ITM programme should include three levels of verification:

1) Routine checks (operator walkdowns)
• visual checks for damage, leaks indicators, abnormal noise/vibration; • verification that access control, signage and "keep clear" zones are maintained; • housekeeping checks near vents/PRD outlets and hydrogen equipment.

2) Periodic functional tests (proof testing of safety functions)
• functional tests of ESD/isolation devices (including remote actuation where present); • verification that detectors and alarms operate and are recognisable in real operating conditions; • verification of ventilation availability where relied upon as a safety function.
3) End-to-end performance verification (where justified by risk)
• confirmation that key action chains operate as intended ("detector/alarm → logic → action"); • confirmation that emergency procedures align with actual system behaviour (shutdown states, isolation segmentation, venting arrangements).

Where the facility is indoor, containerised or semi-confined, greater emphasis should be placed on verification of accumulation control and the reliability of detector placement, ventilation performance and action chains.

8.4 Inspection and testing intervals (principles)

Intervals should be set based on:

- pressure/temperature duty and cycling;
- likelihood of loosening, vibration, fatigue or seal degradation;
- frequency of connection/disconnection at interfaces;
- environmental conditions (corrosion, icing risk for cryogenic systems, dust/contamination affecting detectors);
- criticality of the function and consequence of failure.

As a practical approach:

- high-duty interfaces (transfer points, compressor areas, frequently serviced components) should have **shorter** inspection cycles;
- safety functions whose failure could lead to delayed detection or delayed isolation should have **shorter** proof test intervals and clear "out-of-service" rules;
- detectors should be managed not only by calibration, but by functional checks and performance review (nuisance alarms, drift, repeated low-level alarms).

8.5 Maintenance execution and competence

Maintenance activities on hydrogen systems should be controlled to avoid creating new hazards.

Minimum expectations include:

- PTW controls for breaking containment, hot work and confined spaces;
- defined isolation, depressurisation and verification steps prior to work;
- use of appropriate tools and assembly methods (including controlled tightening and verification for safety-critical joints);

- competence requirements for both internal staff and contractors, including hydrogen-specific hazards and emergency actions;
- supervision and hold points for non-routine work and commissioning activities.

8.6 Defect management and corrective actions

The operator should define how defects are assessed and managed, including:

- classification of defects by safety criticality;
- criteria for immediate shutdown, restricted operation or continued operation with compensating measures;
- repair priorities and escalation paths;
- verification after repair (functional test and, where needed, end-to-end confirmation).

Recurring defects (e.g., repeated leaks at the same interface type, repeated detector nuisance alarms) should trigger root-cause review and design/procedure improvements.

8.7 Records, traceability and document control

The ITM programme should maintain records sufficient to demonstrate ongoing control of safety functions, including:

- inspection and proof test reports with dates, persons, results and acceptance criteria;
- calibration/functional test records for detectors and alarm systems;
- records of ESD/isolation function tests and any bypasses or temporary disablements;
- maintenance and repair history for safety-critical elements;
- lists of outstanding corrective actions and closure evidence;
- document-controlled versions of site plans, isolation maps and responder packs.

Records should be reviewed periodically to identify trends and weak signals (drift, rising alarm frequency, repeated component failures).

8.8 Management of change (MOC) and revalidation

Any change that can affect hydrogen safety functions should be managed through MOC, including:

- layout changes (walls, canopies, enclosure modifications, ventilation changes);
- changes to detector placement, thresholds, alarm logic or shutdown actions;
- changes to operating envelope (pressure/temperature, inventory, duty cycles);
- changes to vent/PRD routing, discharge zones, or access/egress arrangements;
- changes in procedures, staffing, contractor models or competence requirements.

After such changes, the operator should ensure that:

- hazard assumptions remain valid (especially for confinement/accumulation);
- affected safety functions are re-tested and revalidated;
- emergency plans and responder information are updated.

8.9 Audits and continuous improvement

In addition to ITM execution, the operator should periodically verify programme effectiveness through:

- barrier-focused audits (quality of PTW, isolation verification, alarm-to-action reliability, defect closure discipline);
- reviews of incidents and near misses and their translation into improvements;
- periodic emergency drill reviews aligned with credible hydrogen scenarios.

9 Training, competence and organisational preparedness

Hydrogen fire safety depends on both technical barriers and the quality of human and organisational performance. Even well-designed facilities may become vulnerable if personnel do not understand hydrogen-specific hazards, if non-routine work is poorly controlled, or if emergency actions are not rehearsed. This chapter describes expectations for training, competence and organisational preparedness that support the requirements in Chapters 6, 7, 8 and 9.

9.1 Competence objectives (who needs what)

The operator should define competence requirements for all roles that can influence hydrogen fire safety, including:

- operations personnel (start-up/shutdown, normal operation, abnormal response),
- maintenance staff (breaking containment, isolation verification, troubleshooting),
- contractors (construction, commissioning, non-routine maintenance),
- supervisors and permit issuers (PTW, isolation standards, MOC decisions),
- emergency coordinators and fire wardens,
- security personnel (access control, emergency access),
- management responsible for barrier assurance and resource allocation.

Competence should be proportionate to the hazards and responsibilities of the role. Where tasks are safety-critical, competence should be demonstrated (not assumed) and periodically reassessed.

9.2 Hydrogen-specific hazard knowledge (minimum learning content)

Training should include hydrogen-specific characteristics and the resulting fire-safety implications. As a minimum, training content should address:

- flammability and ignition behaviour relevant to facilities (rapid mixture formation under certain conditions);
- high-pressure release behaviour (jet releases, noise, potential for rapid escalation);
- accumulation in confined and semi-confined spaces, including overhead pockets and service voids;
- reduced flame visibility and implications for recognition and approach;
- venting and PRD discharge hazards, including "keep clear" expectations;

- cryogenic hazards where LH2 is present (icing/blockage risk, cold vapour cloud formation);
- the safety intent of detection, ventilation, ESD/isolation, and escalation prevention measures.

Training should link hazards to practical controls: what must be checked, what actions are expected on alarms, and what activities are restricted in hazardous zones.

9.3 Training structure and levels

The operator should implement a training programme that includes:

1) Induction and baseline awareness
• basic hydrogen hazards and site rules (signage, restricted activities, access control); • alarm signals and immediate actions (evacuation, ESD initiation where required, reporting); • muster points, emergency routes and accountability process.
2) Role-specific operational competence
• operating procedures for normal and abnormal conditions; • start-up/shutdown and temporary states (purging/inerting, venting/blowdown); • interpretation of alarms and instrumentation; escalation and call-out; • restrictions and compensating measures during degraded states (e.g., detector out-of-service).
3) Maintenance and contractor competence
• PTW requirements for breaking containment, hot work and confined spaces; • isolation, depressurisation and verification steps, including lockout/tagout where applicable; • assembly standards and verification practices for safety-critical joints and interfaces; • supervision expectations and hold points for non-routine work.
4) Supervisory and governance competence
• permit issuing quality, barrier thinking, and risk-based decisions; • management of change triggers and requirements; • defect management and acceptance criteria for continued operation vs shutdown.

9.4 Verification of competence

Competence should be verified through a combination of:

- written or digital knowledge checks (role-appropriate depth),
- practical demonstrations (ESD initiation, isolation verification steps, detector/alarm response drills),
- supervised task performance for safety-critical activities,

- periodic reassessment intervals (increased frequency for high turnover or contractor-heavy sites).

Records of competence verification should be maintained and linked to authorisation to perform safety-critical tasks.

9.5 Drills and exercising

Emergency drills should be scenario-based and reflect credible hydrogen facility conditions. Drills should include, as applicable:

- high-pressure leak with and without ignition (including noise, communication constraints);
- indoor accumulation alarm response and area control (including ventilation failure scenarios if relevant);
- PRD/vent discharge event with keep-clear enforcement and exclusion zone control;
- contractor/non-routine work incident response (e.g., during maintenance or commissioning);
- escalation risk scenarios requiring rapid isolation and exposure protection coordination.

Drills should test: alarm recognition, decision-making, communication, evacuation/muster/accountability, ESD/isolation actions, and coordination with responders.

9.6 Organisational readiness and barrier assurance

The operator should establish organisational measures to sustain fire safety performance, including:

- clear roles and responsibilities for barrier ownership (who "owns" detection, ventilation, ESD, PRD, PTW quality);
- resources and schedules for inspection, testing and maintenance (Chapter 9);
- governance for temporary disablement/bypasses and degraded modes;
- periodic barrier-focused audits and management reviews;
- processes for capturing and implementing lessons learned from near misses and external events.

Where contractor activity is high, organisational readiness should include enhanced contractor management (competence, induction, supervision and feedback loops).

9.7 Documentation and continuous improvement

Training materials, competence matrices, drill records and improvement actions should be documented and controlled. The operator should periodically review:

- training effectiveness (incident/near miss patterns, audit findings, drill performance);
- changes in facility risk profile (new equipment, layout changes, increased inventory/pressure);
- updates to procedures, emergency plans and responder interfaces.

Annex 1: Implementation bundles

Bundles for recommendations on specific applications/triggers

Select bundles based on facility triggers (e.g., indoor + high-pressure + transfer). For each selected bundle, document (a) why it applies, (b) which upgrades will be implemented, (c) how performance will be verified (commissioning/proof tests/audits), and (d) how it is maintained under management of change.

Bundle ID	When to apply (typical triggers)	Primary intent	Recommended upgrades (compact)	Links to Chapter 6 baseline
B1 Indoor / containerised hydrogen systems	Any indoor room; containerised packages; limited natural ventilation; overhead pockets/voids	Prevent accumulation; make safety functions robust	Verify accumulation control (targeted dispersion assessment where geometry is complex); design-out/ventilate roof pockets/voids; monitored ventilation performance (airflow/failure alarms) and defined degraded mode; redundant detection at critical overhead points; end-to-end functional proof testing "detector→alarm→action"; stricter control of temporary equipment and non-routine work	6.5, 6.9, 6.12, 6.11, 6.6
B2 Semi-confined canopies / shelters / recessed bays	Canopies, partially enclosed unloading/dispensing areas; wind-driven recirculation; potential re-entrainment	Reduce semi-confined explosion potential	Conservative accumulation review; verify ventilation effectiveness (incl. re-entrainment risk); keep-clear zones adapted to wind and geometry; detector placement validated for canopy flow patterns; operational constraints for "temporary confinement" states (screens/doors)	6.5, 6.9, 6.3, 6.2
B3 High-pressure GH2 systems (high release potential)	High operating pressures; credible jet release; close exposures; limited access during release	Limit release duration; prevent escalation	Rapid isolation segmentation (smaller isolatable inventories); remote ESD where local access can be compromised; diversity/redundancy in critical shutdown triggers where justified; enhanced mechanical integrity focus on joints/fittings and compressor seals; escalation shielding where separation cannot be achieved	6.7, 6.10, 6.9, 6.11

B4 LH2 storage and cryogenic transfer	LH2 tank, vapouriser, cryogenic lines/couplings; icing/blockage potential; cold vapour cloud hazards	Prevent cryogenic failures; ensure safe relief/discharge	Relief path robustness checks focused on icing/blockage; discharge zone protection (physical keep-clear and combustibles control); review vent/relief outlet positioning vs. semi-confined geometries and air intakes; enhanced transfer procedures and supervision; targeted consequence review for larger inventories	6.8, 6.3, 6.5, 6.11, 6.10
B5 Transfer interfaces (loading/unloading, coupling/decoupling, frequent connections)	Frequent connection/disconnection; tube trailer/tanker interface; manual steps; contractor presence	Reduce human/assembly error at interfaces	Controlled assembly standards (torque/verification/traceability for critical joints); interface-specific exclusion zones and workflow controls; breakaway/engineered interface protection where relevant; enhanced supervision for non-routine transfers; focused competency checks for transfer personnel	6.3, 6.11, 6.7, 6.1
B6 Public-access or high-occupancy interfaces	Public nearby; public refuelling areas; adjacent occupied buildings; higher reputational/impact sensitivity	Reduce exposure; keep people out of hazard zones	Stronger physical segregation and access control; conservative placement of muster points and public boundaries relative to vents/PRD outlets; enhanced signage/communications and user guidance; additional drills focusing on crowd management and rapid area control	6.3, 6.2, 6.4, 6.13, 6.8
B7 High consequence / domino potential (tight sites, critical assets, neighbours)	Close equipment spacing; sensitive adjacent assets; limited separation distances; major BI risk	Prevent escalation and preserve critical functions	Escalation resilience package: shielding/passive measures where separation is limited; defined exposure cooling concept where justified; resilience of safety-critical utilities (power/control/communications) for shutdown and emergency coordination; responder staging and access pre-planning	6.10, 6.2, 6.13, 6.7
B8 Contractor-heavy, commissioning, frequent maintenance or modifications	High volume of PTW; complex MOC; non-routine work dominates risk	Reduce management/human-factor driven failures	Barrier-quality audits (PTW, isolation verification, alarm-to-action chain); enhanced supervision for non-routine work; contractor competence and induction standards; structured learning system for near misses and external events; leading indicators (overdue proof tests, repeated alarms, PTW deviations)	6.11, 6.1, 6.9, 6.13
B9 Complex control logic / high automation dependence	Multiple interlocks; reliance on automated actions; remote operation; multiple systems interacting	Avoid hidden failures; keep protective functions reliable	End-to-end proof tests for critical action chains; defined degraded modes and permissives; independence/diversity for critical shutdown paths where justified; structured alarm management and trending; periodic functional reviews after changes (MOC-linked)	6.9, 6.7, 6.11, 6.1

Annex 2: Baseline gap assessment checklist

Structured Assessment Against Baseline Requirements

Ref (Ch.6)	Check item (baseline)	Rating (Y/N/NA)	Priority (H/M/L)	Evidence / Notes (what was checked)	Corrective action (what to do)
6.1	Safety instructions exist, are current, and controlled under MOC (revision/date/owner).				
6.1	Site plan available and fit-for-purpose (H2 equipment, ESD/isolation, vents/PRD, muster points, access routes).				
6.1	Alarm meanings and required actions are defined and communicated (including escalation/call-out).				
6.1	Roles and responsibilities defined (ESD initiation, accounting, responder liaison, re-entry authority).				
6.2	Egress routes are unobstructed, marked, and adequate for occupancy.				
6.2	Muster points located away from credible vent/PRD paths and accumulation-prone geometries.				
6.2	Emergency access routes allow safer approach (avoid predicted accumulation / jet impingement areas).				
6.2	Gates/barriers compatible with emergency access (rapid entry method defined and tested).				
6.3	Access to hydrogen process areas controlled (authorised persons; contractor induction).				
6.3	Exclusion zones defined for transfer operations and near vent/PRD outlets (documented and applied).				
6.3	Ignition-increasing activities controlled in hazardous zones (hot work, non-rated devices, uncontrolled mechanical work).				
6.3	Public interfaces prevented from entering hazardous areas (barriers/layout/controls).				

Ref (Ch.6)	Check item (baseline)	Rating (Y/N/NA)	Priority (H/M/L)	Evidence / Notes (what was checked)	Corrective action (what to do)
6.4	Hydrogen hazard signage present, clear, and consistent with site layout and HAC zones.				
6.4	ESD and key isolation points clearly marked and accessible.				
6.4	Vent/PRD discharge points marked; "keep clear" principle communicated and enforced.				
6.4	Alarm communication effective in operating conditions (including high noise areas).				
6.5	Indoor/containerised: ventilation prevents hazardous accumulation at ceilings and dead spaces.				
6.5	Semi-confined areas assessed for accumulation; conservative controls applied if effectiveness not demonstrated.				
6.5	Vent openings/extraction consider buoyancy and credible release locations (high-level extraction where needed).				
6.5	Where forced ventilation is safety-critical: availability monitored; failure response defined; maintenance/testing evidence exists.				
6.6	HAC performed for credible release areas including abnormal/temporary states (maintenance, purging, venting/blowdown).				
6.6	Equipment selection/installation consistent with HAC zoning (incl. temporary equipment controls).				
6.6	Bonding/earthing implemented where electrostatic ignition could occur; verification evidence available.				
6.6	Ignition controls extend beyond electrical (mechanical/procedural/transient sources).				
6.7	Integrity programme exists for hydrogen pressure system (inspection/testing appropriate to duty).				
6.7	ESD and isolation philosophy documented; devices accessible, labelled, and operable.				

Ref (Ch.6)	Check item (baseline)	Rating (Y/N/NA)	Priority (H/M/L)	Evidence / Notes (what was checked)	Corrective action (what to do)
6.7	Fail-safe behaviour considered for loss of power/control; evidence in design/logic documentation.				
6.7	Periodic testing of ESD/isolation performed; records and corrective actions maintained.				
6.8	PRD/vent discharge routed to safe locations; avoids air intakes, doors, egress routes, occupied areas.				
6.8	Discharge zones kept clear of combustibles and critical assets; housekeeping verified.				
6.8	Cryogenic systems: icing/blockage and material compatibility addressed; evidence available.				
6.8	Venting/blowdown operations governed by procedures (area controls, exclusion, responsibilities).				
6.9	Detectors installed where accumulation/undetected release is credible (high points, containers, canopies, leak sources).				
6.9	Detector placement and thresholds are risk-based and linked to defined actions (alarm/shutdown/isolation/ventilation).				
6.9	Alarm management supports recognition and trained response (audible/visual adequacy verified).				
6.9	Where credible: flame detection considered/implemented to improve early recognition of jet fires.				
6.10	Escalation-prevention concept defined (layout/separation/shielding/controlled areas) and implemented.				
6.10	Jet impingement/radiant exposure: exposures identified and mitigated; escalation controls defined.				
6.10	Where used: exposure cooling/firewater concept matches risk profile and is reliable.				
6.11	PTW implemented for hot work, confined space entry, breaking containment; evidence of use in practice.				

Ref (Ch.6)	Check item (baseline)	Rating (Y/N/NA)	Priority (H/M/L)	Evidence / Notes (what was checked)	Corrective action (what to do)
6.11	Isolation/depressurisation/verification steps defined and followed (incl. LOTO where applicable).				
6.11	Competence requirements defined for operators/maintenance/contractors; training records current.				
6.11	MOC applied to layout, operating envelope, logic, procedures; evidence of recent changes managed.				
6.12	Confined volumes (pits/shafts/voids/roof pockets) identified and controlled as accumulation zones.				
6.12	Confined space entry managed via PTW, gas testing/clearance, ventilation verification, ignition controls.				
6.12	Design/housekeeping minimises creation of unventilated pockets; site walkdown confirms.				
6.13	Emergency roles defined; ESD/isolation responsibility clear; personnel accounting process established.				
6.13	Responder information available (layout, isolation/ESD points, vent/PRD outlets) and controlled/updated.				
6.13	Drills cover hydrogen-relevant scenarios; records and learning actions exist.				
6.13	Re-entry/restart criteria defined; verification of restored safety functions required.				

Annex 3: Implementation Bundles Checklist

Recommended Additional Measures for Enhanced Reliability

Bundle	Upgrade check item (recommended additional measure)	Rating (Y/N/NA)	Priority (H/M/L)	Evidence / Notes	Corrective action
B1 (Indoor/containerised)	Targeted dispersion verification performed where geometry is complex (or justified not needed).				
B1 (Indoor/containerised)	Accumulation traps designed out or ventilated (roof pockets/voids/suspended ceilings managed).				
B1 (Indoor/containerised)	Ventilation performance monitored (airflow/failure alarm) and degraded mode defined.				
B1 (Indoor/containerised)	Redundant detection at critical overhead points (or equivalent reliability demonstration).				
B1 (Indoor/containerised)	End-to-end proof test of "detector → alarm → action" implemented periodically.				
B2 (Semi-confined canopies)	Re-entrainment risk assessed; ventilation effectiveness demonstrated or conservative controls applied.				
B2 (Semi-confined canopies)	Detector placement validated for canopy flow patterns (not only generic ceiling logic).				
B2 (Semi-confined canopies)	Operational constraints defined for "temporary confinement" (screens/doors/closures).				
B2 (Semi-confined canopies)	Keep-clear/exclusion zoning adapted to geometry and wind; enforcement verified.				
B3 (High-pressure GH2)	Inventory segmentation enables limiting release duration and quantity via isolation.				
B3 (High-pressure GH2)	Remote ESD available where local access could be compromised (fire/noise/plume).				
B3 (High-pressure GH2)	Diversity/redundancy in critical shutdown triggers applied where justified by risk.				

Bundle	Upgrade check item (recommended additional measure)	Rating (Y/N/NA)	Priority (H/M/L)	Evidence / Notes	Corrective action
B3 (High-pressure GH2)	Focused integrity controls for joints/fittings/compressor seals; elevated inspection where needed.				
B4 (LH2)	Relief/vent paths inspected for icing/blockage risks; condition management implemented.				
B4 (LH2)	Discharge zones physically protected (barriers/markings) to prevent human presence and combustibles.				
B4 (LH2)	Outlet positioning reviewed vs. semi-confined geometries/air intakes; re-entrainment risk addressed.				
B4 (LH2)	Enhanced transfer procedures and supervision implemented for cryogenic interfaces.				
B5 (Transfer interfaces)	Controlled assembly standards (torque/verification/traceability) used for critical joints.				
B5 (Transfer interfaces)	Interface workflow controls strengthened (task steps, supervision, hold points for non-routine transfers).				
B5 (Transfer interfaces)	Engineered interface protections used where relevant (e.g., breakaway arrangements).				
B5 (Transfer interfaces)	Transfer competence checks and refresher training documented.				
B6 (Public/high occupancy)	Physical segregation strengthened; public cannot enter hazard zones under any operational state.				
B6 (Public/high occupancy)	Muster points/public boundaries reviewed conservatively vs vents/PRD and plume paths.				
B6 (Public/high occupancy)	User-facing instructions/signage enhanced; area control capability verified.				
B7 (Domino/high consequence)	Shielding/passive measures applied where separation is limited; performance intent documented.				

Bundle	Upgrade check item (recommended additional measure)	Rating (Y/N/NA)	Priority (H/M/L)	Evidence / Notes	Corrective action
B7 (Domino/high consequence)	Exposure protection concept validated (where required) and resources assured.				
B7 (Domino/high consequence)	Safety-critical utilities resilience improved (power/control/comms for shutdown and coordination).				
B7 (Domino/high consequence)	Responder staging/access pre-planned and verified on-site.				
B8 (Contractor-heavy/non-routine)	Barrier-quality audits performed (PTW quality, isolation verification, alarm-to-action integrity).				
B8 (Contractor-heavy/non-routine)	Contractor mobilisation process mature (pre-qualification, induction, supervision, close-out).				
B8 (Contractor-heavy/non-routine)	Learning system active (near misses/external events → actions → verified closure).				
B8 (Contractor-heavy/non-routine)	Leading indicators tracked (overdue proof tests, repeated alarms, PTW deviations, MOC bypasses).				
B9 (Complex automation)	End-to-end functional testing periodic for key action chains (not calibration only).				
B9 (Complex automation)	Defined degraded modes/permissives; operations restrictions when safety functions impaired.				
B9 (Complex automation)	Independence/diversity for critical shutdown paths applied where justified.				
B9 (Complex automation)	Post-change functional reviews mandated after MOC affecting logic or actions.				

European guidelines

Fire (https://cfpa-e.eu/category-guidelines/fire-prevention-and-protection/)
Guideline No 1 F - Internal fire protection control
Guideline No 2 F - Panic & emergency exit devices
Guideline No 3 F - Certification of thermographers
Guideline No 4 F - Introduction to qualitative fire risk assessment
Guideline No 5 F - Guidance signs, emergency lighting and general lighting
Guideline No 6 F - Fire safety in care homes
Guideline No 7 F - Safety distance between waste containers and buildings
Guideline No 8 F - withdrawn
Guideline No 9 F - Fire safety in restaurants
Guideline No 10 F - Smoke alarms in the home
Guideline No 11 F - Recommended numbers of fire protection trained staff
Guideline No 12 F - Fire safety basics for hot work operatives
Guideline No 13 F - Fire protection documentation
Guideline No 14 F - Fire protection in information technology facilities
Guideline No 15 F - Fire safety in guest harbours and marinas
Guideline No 16 F - Fire protection in offices
Guideline No 17 F - Fire safety in farm buildings
Guideline No 18 F - Fire protection on chemical manufacturing sites
Guideline No 19 F - Fire safety engineering concerning evacuation from buildings
Guideline No 20 F - Fire safety in camping sites
Guideline No 21 F - Fire prevention on construction sites
Guideline No 22 F - Wind turbines – Fire protection guideline
Guideline No 23 F - Securing the operational readiness of fire control system
Guideline No 24 F - Fire safe homes
Guideline No 25 F - Emergency plan
Guideline No 26 F - withdrawn
Guideline No 27 F - Fire safety in apartment buildings
Guideline No 28 F - Fire safety in laboratories
Guideline No 29 F - Protection of paintings: transports, exhibition and storage
Guideline No 30 F - Managing fire safety in historic buildings
Guideline No 31 F - Protection against self-ignition end explosions in handling and storage of silage and fodder in farms
Guideline No 32 F - Treatment and storage of waste and combustible secondary raw materials
Guideline No 33 F - Evacuation of people with disabilities
Guideline No 34 F - Fire safety measures with emergency power supply
Guideline No 35 F - Fire safety in warehouses
Guideline No 36 F - Fire prevention in large tents
Guideline No 37 F - Photovoltaic systems: recommendations on loss prevention
Guideline No 38 F - Fire safety recommendations for short-term rental accommodations
Guideline No 37 F - Fire protection in schools
Guideline No 38 F - Fire safety recommendations for short-term rental accommodations
Guideline No 39 F - Fire protection in schools
Guideline No 40 F - Procedure to certify CFPA-E Fire Safety Specialists in Building Design
Guideline No 41 F - Safety instructions for the use and charging of small and medium size lithium ion powered devices

Guideline No 42 F – Guidance document for Selection of Fire Protection Systems
Guideline No 43 F – Foam concentrates – The Selection Criteria
Guideline No 44 F – Fire safety recommendations for electric vehicles
Guideline No 45 F – Fire Safety Recommendations for Medium-size Electric Vehicles
Guideline No 46 F – Fire Safety Recommendations for Battery Energy Storage Systems (BESS)
Guideline No 47 F – Transport and storage of batteries
Guideline No 48 F – Fire Protection in Bus Depots

Natural hazards (https://cfpa-e.eu/category-guidelines/natural-hazards/)
Guideline No 1 N - Protection against flood
Guideline No 2 N - Business resilience – An introduction to protecting your business
Guideline No 3 N - Protection of buildings against wind damage
Guideline No 4 N - Lighting protection
Guideline No 5 N - Managing heavy snow loads on roofs
Guideline No 6 N - Forest fires
Guideline No 7 N - Demountable / Mobile flood protection systems
Guideline No 8 N - Ensuring supplies of firefighting water in extreme weather conditions
Guideline No 9 N - Protection against hail damage
Guideline No 10 N - Heavy rain and flash floods: Recommendations on flood prevention and protection

Security (https://cfpa-e.eu/category-guidelines/security/)
Guideline No 1 S - Arson document
Guideline No 2 S - Protection of empty buildings
Guideline No 3 S - Security systems for empty buildings
Guideline No 4 S - Guidance on keyholder selections and duties
Guideline No 5 S - Security guidelines for museums and showrooms
Guideline No 6 S - Security guidelines emergency exit doors in non-residential premises
Guideline No 7 S - Developing evacuation and salvage plans for works of art and heritage buildings
Guideline No 8 S - Security in schools
Guideline No 9 S - Recommendation for the control of metal theft
Guideline No 10 S - Protection of business intelligence
Guideline No 11 S - Cyber security for small and medium-sized enterprises
Guideline No 12 S - Security Guidelines for Businesses
Guideline No 13 S - Cybersecurity basic level – Basic IT security
Guideline No 14 S - Security Report Rental, Storage and Exhibition of Art Objects

Bibliography and Additional Resources

Project background documents (Moravian-Silesian Region hydrogen safety project)
The present CFPA-Europe guideline "Fire Safety in Hydrogen Facilities" consolidates and builds upon three original project guides covering (a) hydrogen production, (b) hydrogen storage and transport, and (c) hydrogen use/applications.

Selected standards and technical references (examples used across the project guides)
TPG 304 03 – Technical rules for hydrogen refuelling stations (Czech Gas Association / Czech gas sector practice).
ČSN EN 17127 – Outdoor hydrogen refuelling stations (gaseous hydrogen) including refuelling protocols.
ČSN EN 17124 – Hydrogen fuel quality for PEM fuel cell road vehicles.
ČSN EN ISO 17268 – Gaseous hydrogen refuelling connection devices (vehicle–station interface).
ČSN ISO 19880-1 – Gaseous hydrogen refuelling stations – General requirements.
ČSN EN IEC 60079-10-1 – Explosive atmospheres – Classification of areas – Explosive gas atmospheres.
ČSN EN 1127-1 – Explosive atmospheres – Explosion prevention and protection – Basic concepts and methodology.
ISO/TR 15916 – Basic considerations for the safety of hydrogen systems.
ISO 26142 – Hydrogen detection systems – Requirements for detection of hydrogen leaks.

Risk assessment and separation distance background (selected)
Risk-based safety approach for hydrogen refuelling stations (quantitative risk-based determination of safety/effect distances; representative scenarios).

Incident and lessons-learned sources (project dataset)
HIAD – Hydrogen Incidents and Accidents Database (analysis report and export dataset).
Hydrogen incident examples and lessons learned reports (project dataset).
Specific incident review reports included in the project dataset (e.g., refuelling station incidents).

Comments and corrective actions:

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