H_2 SAFETY CHECKLIST

It is a common application of hydrogen technologies to have an outdoor hydrogen supply system providing for an indoor use. The Hydrogen Safety Panel developed a checklist to help both new and experienced hydrogen users identify considerations necessary to ensure a safe installation. The checklist is not intended to replace or provide guidance on compliance. Rather, it presents a concise table of critical safety measures compiled by some of the hydrogen industry's foremost safety experts. Figure C.1 illustrates the system considered by the Panel in developing the checklist. The general principles in the checklist apply to all types and sizes of hydrogen systems.

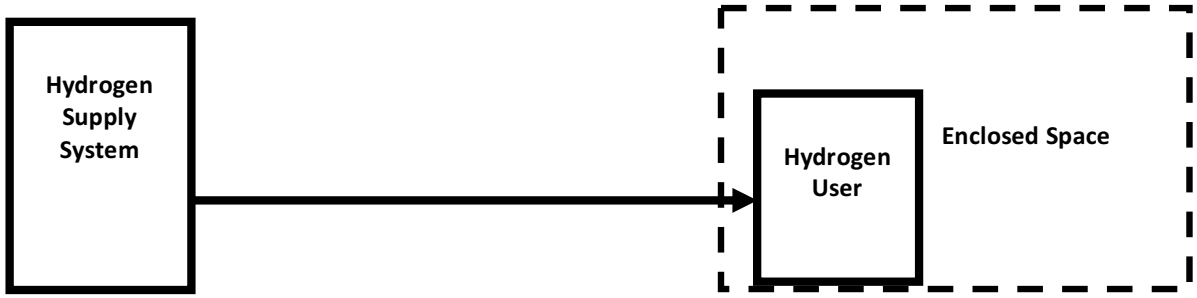

Figure C.1. Outdoor Hydrogen Supply System for Indoor Use

Hydrogen safety, much like all flammable gas safety, relies on five key considerations:

1. Recognize hazards and define mitigation measures (plan).
2. Ensure system integrity (keep the hydrogen in the system).
3. Provide proper ventilation to prevent accumulation (manage discharges).
4. Ensure that leaks are detected and isolated (detect and mitigate).
5. Train personnel and ensure that hazards and mitigations are understood and that established work instructions are followed (manage operations).

The checklist is organized using these key considerations. Examples are included to help users identify specific prevention techniques.

The checklist is intended to assist people developing designs for hydrogen systems as well as those involved with the risk assessment of hydrogen systems. While these considerations are fairly inclusive, it is not possible to include all variables that need to be considered. The hazard analysis process should therefore include personnel who are familiar with applicable codes and standards in addition to team members with expertise in the technical aspects of the specific project.

Useful References:

Hydrogen Incident Reporting and Lessons Learned Database: https://h2tools.org/lessons

Hydrogen Safety Best Practices: https://h2tools.org/bestpractices

NFPA 2, "Hydrogen Technologies Code": http://www.nfpa.org

Hydrogen Tools Portal: http://h2tools.org/

H_2 SAFETY CHECKLIST

	Approach	Examples of Actions
Plan the Work	**Recognize hazards and define mitigation measures**	☐ Identify risks such as flammability, toxicity, asphyxiates, reactive materials, etc. ☐ Identify potential hazards from adjacent facilities and nearby activities ☐ Address common failures of components such as fitting leaks, valve failure positions (open, closed, or last), valves leakage (through seat or external), instrumentation drifts or failures, control hardware and software failures, and power outages. ☐ Consider uncommon failures such as a check valve that does not check, relief valve stuck open, block valve stuck open or closed, and piping or equipment rupture. ☐ Consider excess flow valves/chokes to size of hydrogen leaks ☐ Define countermeasures to protect people and property. ☐ Follow applicable codes and standards.
	Isolate hazards	☐ Store hydrogen outdoors as the preferred approach; store only small quantities indoors in well ventilated areas. ☐ Provide horizontal separation to prevent spreading hazards to/from other systems (especially safety systems that may be disabled), structures, and combustible materials. ☐ Avoid hazards caused be overhead trees, piping, power and control wiring, etc.
	Provide adequate access and lighting	Provide adequate access for activities including: ☐ Operation, including deliveries ☐ Maintenance ☐ Emergency exit and response
	Approach	**Examples of Actions**
Keep the Hydrogen in the	**Design systems to withstand worst-case conditions**	☐ Determine maximum credible pressure considering abnormal operation, mistakes made by operators, etc., then design the system to contain or relieve the pressure. ☐ Contain: Design or select equipment, piping and instrumentation that are capable of maximum credible pressure using materials compatible with hydrogen service. ☐ Relieve: Provide relief devices that safely vent the hydrogen to prevent damaging overpressure conditions. ☐ Perform system pressure tests to verify integrity after initial construction, after maintenance, after bottle replacements, and before deliveries through transfer connections.

H_2 SAFETY CHECKLIST

	Protect systems	☐ Design systems to safely contain maximum expected pressure or provide pressure relief devices to protect against burst. ☐ Mount vessels and bottled gas cylinders securely. ☐ Consider that systems must operate and be maintained in severe weather and may experience earthquakes and flood water exposures. ☐ De-mobilize vehicles and carts before delivery transfers or operation. ☐ Protect against vehicle or accidental impact and vandalism. ☐ Post warning signs.
	Size the storage appropriately for the service	☐ Avoid excess number of deliveries/change-outs if too small. ☐ Avoid unnecessary risk of a large release from an oversized system.
	Provide hydrogen shutoff(s) for isolation	☐ Locate automatic fail-closed shutoff valves at critical points in the system (such as storage exit, entry to buildings, inlets to test cells, etc.) to put the system in a safe state when a failure occurs. ☐ Consider redundant or backup controls. ☐ Install manual valves for maintenance and emergencies.
	Prevent cross-contamination	☐ Prevent back-flow to other gas systems with check valves, pressure differential, etc.
	Approach	**Examples of Actions**
Manage Discharges	**Safely discharge all process exhausts, relief valves, purges, and vents**	☐ Discharge hydrogen outdoors or into a laboratory ventilation system that assures proper dilution. ☐ Direct discharges away from personnel and other hazards. ☐ Secure/restrain discharge piping.
	Prevent build-up of combustible mixtures in enclosed spaces	☐ Do not locate equipment or piping joints/fittings in poorly ventilated rooms or enclosed spaces. Use only solid or welded tubing or piping in such areas. ☐ Provide sufficient ventilation and/or space for dilution. ☐ Avoid build-up of hydrogen under ceilings/roofs and other partly enclosed spaces.
	Remove potential ignition sources from flammable spaces/zones	☐ Proper bonding and grounding of equipment. ☐ No open flames. ☐ No arcing/sparking devices, e.g., properly classified electrical equipment.

H_2 SAFETY CHECKLIST

	Approach	Examples of Actions
Detect and Mitigate	**Leak detection and mitigation**	☐ Provide detection and automatic shutdown/isolation if flammable mixtures present, particularly in enclosed spaces. ☐ Consider methods for manual or automatic in-process leak detection such as ability for isolated systems to hold pressure. ☐ Periodically check for leaks in the operating system.
	Loss of forced ventilation indoors	☐ Automatically shut off supply of hydrogen when ventilation is not working.
	Monitor the process and protect against faults	☐ Provide alarms for actions required by people, e.g., evacuation. ☐ Provide capability to automatically detect and mitigate safety-critical situations. ☐ Consider redundancy to detect and mitigate sensor or process control faults. ☐ Provide ability for the system to advance to a “safe state” if power failures or controller faults are experiences.
	Fire detection and mitigation	☐ Appropriate fire protection (extinguishers, sprinklers, etc.). ☐ Listed hydrogen specific flame detection ☐ Automatic shutdown and isolation if fire detected.
	Approach	**Examples of Actions**
Manage Operations	**Establish and document procedures**	☐ Responsibilities for each of the parties involved. ☐ Operating procedures. ☐ Emergency procedures. ☐ Preventive maintenance schedules for equipment services, sensor calibrations, leak checks, etc. ☐ Safe work practices such as lock-out/tag-out, hot work permits, and hydrogen line purging. ☐ Review and approval of design and procedural changes.
	Train personnel	☐ MSDS awareness for hydrogen and other hazardous materials. ☐ Applicable procedures and work instructions for bottle change-out, deliveries, operation, maintenance, emergencies, and safety work practices.
	Monitor	☐ Track incidents and near-misses, and establish corrective actions. ☐ Monitor compliance to all procedures and work instructions.