HYDROGEN
Safety Panel

# Safety Planning Guide for Hydrogen Projects

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# A. Purpose

The purpose of this guide is to assist projects in improving their safety culture and developing and implementing formal hydrogen safety planning. It provides specific guidance for projects supported by the Hydrogen Safety Panel (HSP), including contracted scope by the U.S. Department of Energy (DOE), the California Energy Commission, the American Institute of Chemical Engineers (AIChE) Center for Hydrogen Safety (CHS), and Pacific Northwest National Laboratory (PNNL).

This guidance document is offered freely in the public domain as a resource for organizations worldwide needing to develop or improve their safety planning for flammable gas. Projects that involve very small quantities of hydrogen and minimal flammable gas risks may alternatively consider using the Simplified Safety Planning Guide for Hydrogen Projects (PNNL-31037).[1]

The HSP uses this guide as a standard for reviewing safety plans. Appendix C provides more details on HSP review protocols.

# B. Revision Highlights

This revision restructures the guide to simplify information access, emphasize safety culture, and apply process safety management (PSM) principles. The application of safety culture and PSM standards is based on the growing worldwide body of knowledge, with specific technical guidance from the AIChE CHS and Center for Chemical Process Safety. The recommendations herein for improved safety plan development are based on the HSP's extensive experience reviewing project design, safety documentation, operations, and incidents since 2003.

This document is published on the HSP's website portal, https://h2tools.org. Earlier versions are available by request at the portal.

# C. Focus

This guide focuses on two aspects of safety management: safety culture and a safety plan.

Safety culture is the combination of group values and behaviors that determine how process safety is managed. Safe management of the production, storage, distribution, and use of hydrogen is essential to protect people, equipment, and the environment. A project's or organization's safety culture is manifested both formally and informally via documents, work processes, and employee values.

A formally documented safety plan addressing hydrogen operations is the principal method for a project team to gauge the quality of its safety culture and implement a structured process for preventing and mitigating hazards. An effective project safety plan is an essential tool for identifying risks, avoiding potential incidents, guiding the safe conduct of work, and continuing to ensure stakeholder and public acceptance of hydrogen use.

# D. Safety Culture

A robust safety culture includes the following elements. Appendix B provides additional background for applying PSM principles.

## Leadership

Designate a safety manager or lead to oversee hydrogen safety throughout all phases of the project. This individual's technical and professional qualifications should match the project scope, and the individual

[1] https://h2tools.org/sites/default/files/Simplified_Safety_Planning_for_Low_Volume_Hydrogen_and_Fuel_Cell_Projects.pdf

should have the support of executive management. Any gaps in competence should be identified, and suitable training and support should be arranged accordingly. Strong leadership support promoting shared values is essential to an effective safety culture.

## Shared Values

Establish and document a set of shared values to ensure the protection of people, equipment, and the environment, and continuously communicate these values to all organizational personnel and project participants. A key value for all parties is complying with regulations, codes, and standards (RCS), such as the International Fire Code and NFPA 2, “Hydrogen Technologies Code.” These are crucial for protecting people, equipment, and the environment, as well as maintaining public confidence, especially in projects that use new technologies. If the project team is uncertain about whether strict compliance with codes is required for a specific design, installation, or operation, it is important to develop a solid technical basis and consensus among design authorities for alternatives.

## Empowered Employees and Involved Teams

Ensure that all members of the project team and related organizational teams – such as those in environment, health, and safety; quality assurance; and maintenance – are actively involved in identifying hazards and planning for risk management. Recognizing that safety is everyone’s responsibility, a thorough and integrated approach to project safety planning must also identify and involve project partners, stakeholders, emergency responders, and the public.

## Methods to Identify and Control Hazards

The project should assess general safety-related risks and, using a graded approach, formally apply methods to identify specific hazards. A separate formal process should be used for risk prevention and mitigation of these hazards. The project should also research and evaluate the growing body of lessons learned and best safety practices to effectively identify hazards and devise suitable approaches for continuous improvement.

The organizational topics related to safety planning outlined here should be included in a new formal safety plan for hydrogen or a revised general safety plan. The plan must address all elements specified in this guide. Effective safety planning is an ongoing process; therefore, the safety plan should be reviewed periodically and updated whenever changes occur.

## Ongoing Communication, Education, and Training

Project execution planning should focus on open, timely, and effective communication with workers, stakeholders, and the public. This includes providing suitable educational materials and training. It is essential to track action items and review them periodically. Special attention should be given to unique equipment systems and the expertise needed to operate them. The project also should hold regular discussions about safety status and planning to build mutual trust.

A safety culture must be consistently promoted and maintained. It is an ongoing process that involves inspiring, educating, and encouraging the project team.

## Application Through All Project Phases

Safety planning is typically applied early in a project’s design phase. However, it should be prioritized by project managers and principal investigators during all project phases. The following describes how safety culture is applied to the widely accepted phases of standard project management:

1. **Initiation.** Project sponsors should be aware of relevant hydrogen safety issues and RCS before defining and funding the project.

2. **Planning.** The project work breakdown structure, schedule, and execution plan should identify and enhance the project team's safety culture and formal hydrogen safety planning.
3. **Execution.** Safety should be planned formally and continuously re-evaluated throughout all design and build phases, including development, procurement, fabrication, construction, acceptance testing, commissioning, operations, maintenance, and decommissioning.
4. **Monitoring and Controlling.** Formal methods should be in place to assess safety performance and adjust approaches as needed. An approved hydrogen safety plan and hazard controls should be in place prior to hydrogen operations.
5. **Closeout/Continuous Improvement.** Ensure safety planning and operational safety management protocols are updated from changes throughout the project and lessons learned.

## E. The Safety Plan

A formal hydrogen safety plan is crucial to protecting people (workers and the public), equipment, and the environment from hydrogen hazards. The safety plan can be documented three ways:

- Detailed in the project execution plan
- Amplified in existing formal safety analysis documentation
- Published as a separate, standalone document

Regardless of format, the safety plan should address the elements in Table 1. Projects may add topics as needed to address their scope. Safety management should be addressed for the entire range of project activities and design/build phases.

The HSP uses the criteria Table 1 as a measure for all of its safety plan reviews, evaluating the strengths and weaknesses of plan relative to each element in the table and providing an overall summary in its review report. An example fictional safety plan (PNNL-30457) involving two project partners is available on the HSP website.[2]

Safety plans should be living documents that acknowledge the types of work being performed, consider human error factors and equipment life, and address the inevitable changes that occur in all project phases. See Appendix A for a more detailed explanation of the criteria in Table 1.

**Table 1**. Safety Plan Elements

| Element | The Safety Plan Should Include |
|---|---|
| **Description of Work** | • Project scope, goals, general nature of the work, and partner organizations<br>• Project schedule for start of hydrogen operations<br>• Description of hydrogen process conditions, design parameters, hydrogen-wetted equipment, and facility for each partner involved with hydrogen operations<br>• Drawings or sketches of geography, facility, and system layout<br>• Piping and instrumentation and process flow diagrams |
| **Hydrogen Safety Competency** | • Application of high-level safety-related policies and procedures to the work being performed<br>• Project leadership responsible for safety approvals<br>• Competency of project personnel with hydrogen technologies and plans to mitigate inexperience, by project phase<br>• How previous organizational experience with hydrogen is applied<br>• How competency will be improved |

[2] https://h2tools.org/sites/default/files/2020-10/Example_Hydrogen_Safety_Plan_September_2020.pdf

| Element | The Safety Plan Should Include |
|---|---|
| **Workforce Involvement** | • How the project will engage workers at all levels of the organization in implementing its safety culture, identifying hazards, and performing risk planning, across all project phases<br>• How the project will integrate safety planning across project partners |
| **Hazards Identification and Risk Analysis (HIRA) with Prevention and Mitigation Controls** | • The methods used to identify and analyze hazards<br>• Name/title of the person(s) or group that leads and stewards the use of the HIRA<br>• A summary of significant hazards and accident scenarios from a completed hazard analysis<br>• Prevention and mitigation controls matched to the hazards<br>• Critical safety equipment and shutdown (interlock) planning (matrix) |
| **Compliance with Regulations, Codes and Standards (RCS)** | • Application of global, national, and local governing RCS applicable to the project, site, or facility<br>• Any deviations or alternative methods used along with their technical basis |
| **Procedures** | • Procedures applicable to the location and work performed, including safe work practices for using hydrogen |
| **Asset Integrity and Reliability** | • How mechanical integrity is assured through all project phases<br>• Preventative maintenance plan<br>• Development of the integrity operating window<br>• Safety system calibration, testing, and inspection types and schedule |
| **Management of Change** | • The formal processes used to review proposed changes to materials, technology, equipment, procedures, personnel, facilities, and operation, and their effect on safety vulnerabilities |
| **Safety Reviews** | • How HIRA is reviewed across all project phases, from design reviews to pre-start checks |
| **Safety Documentation** | • How safety information is communicated and made available to all participants, including partners |
| **Contractor Management** | • Practices to ensure that contract workers can perform their jobs safely with hydrogen hazards, and that contracted services do not increase facility operational risk |
| **Training** | • Flammable gas and hydrogen-specific training – initial and refresher<br>• How the project manages participation and verifies understanding |
| **Safety Events and Lessons Learned** | • The incident reporting procedure<br>• The process used to investigate events<br>• How corrective measures will be implemented<br>• How lessons learned from incidents and near-misses are documented and disseminated |
| **Operational Readiness** | • Ensuring the safe commissioning and startup of processes from all types of shutdown conditions |
| **Emergency Management** | • The plan/procedures for responses to emergencies<br>• Plans for communicating and interacting with project and local emergency response officials and incident commanders |
| **Safety Plan Approval** | • Safety plan review and approval process<br>• How project partners are involved in review and approval |

# F. Resources

The following internet resources provide additional information on safety planning.

| | | |
|---|---|---|
| **Primary Hydrogen Safety Organizations** | | |
| 1 | Hydrogen Safety Panel | https://h2tools.org/ |
| 2 | Center for Hydrogen Safety | https://www.aiche.org/chs |
| **Other Key Safety Organizations** | | |
| 3 | Center for Chemical Process Safety | https://www.aiche.org/ccps |
| 4 | European Hydrogen Safety Panel | https://www.clean-hydrogen.europa.eu/get-involved/european-hydrogen-safety-panel-0_en |
| 5 | European HySAFE | http://www.hysafe.net/ |
| 6 | Australia Hydrogen Safety | https://www.hydrogen.sa.gov.au/green-hydrogen/hydrogen-safety |
| 7 | Japan Hydrogen Safety Portal | https://www.meti.go.jp/english/press/2023/0630_002.html |
| **HSP Client Sources** | | |
| 8 | DOE Hydrogen Program | https://www.hydrogen.energy.gov/ |
| 9 | California Energy Commission | https://www.energy.ca.gov/programs-and-topics/programs/clean-hydrogen-program |
| 10 | CHS/PNNL HSP Contracting | https://h2tools.org/form/request-for-hydrogen-safety-pane |
| **Process Safety Management** | | |
| 11 | Occupational Safety and Health Administration | https://www.osha.gov/process-safety-management |
| **Project Management** | | |
| 12 | Project Management Institute | https://www.pmi.org/ |
| **Codes and Standards** | | |
| 13 | DOE | https://www.hydrogen.energy.gov/program-areas/codes-standards |
| 14 | H2tools HySCAN | https://h2tools.org/hyscan/ |
| **Best Practices** | | |
| 15 | HSP Collection | https://h2tools.org/bestpractices/best-practices-overview |
| **Lessons Learned** | | |
| 16 | HSP Collection | https://h2tools.org/lessons |
| **Safety Culture** | | |
| 17 | General | https://safetyculture.com/topics/process-safety-management/ |
| 18 | Case Studies | https://h2tools.org/safety-culture-case-studies |
| 19 | HSP | https://h2tools.org/safety-culture-spotlight |
| 20 | DOE | https://www.energy.gov/safety-culture/doe-safety-culture |
| 21 | NASA | https://sma.nasa.gov/sma-disciplines/safety-culture |
| 22 | Nuclear Regulatory Commission | https://www.nrc.gov/about-nrc/safety-culture.html |
| **Risk Management** | | |
| 23 | DOE | https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-07a/@@images/file |

# Appendix A – Safety Plan Element Details

This appendix amplifies the details presented in Table 1 of the main report. The text boxes provide useful background information and highlight good safety practices.

## Description of Work

### *How does the project intend to use or produce hydrogen?*

The safety plan should describe the specific nature of the work being performed. It should distinguish between laboratory-scale research, bench-scale testing, engineering development, prototype operation, and commercial application. It should identify all project partners/participants and their respective roles.

All related project execution phases should be considered: conceptual planning, design, procurement, fabrication, construction, acceptance testing, commissioning, operations, maintenance, and decommissioning.

> *Projects with multiple partners have unique challenges. The safety plan should describe the work scope for every partner involved with hydrogen operations (i.e., using or producing hydrogen). Unless requested by the project or the DOE, the HSP normally does not review partner scope with hydrogen operations performed by national laboratories (e.g., the National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories), and instead only summarizes this scope.*

The process conditions include the volumes of hydrogen as well as the pressures, temperatures, and estimated usage rates. Other important design parameters include hydrogen supply options, such as commercial cylinders and tube trailers, as well as storage equipment and distribution systems. It's essential to describe the equipment used to contain or generate hydrogen, with particular attention to ventilation systems. The plan should also specify the quantity of hydrogen stored, the storage pressure, and how frequently the hydrogen is replenished and by what method. It's important to note that even laboratory-scale experiments can pose significant risks.

> *Other hazardous materials involved in the project may need to be considered. For example, handling oxygen in electrolyzer systems can significantly affect project safety. Never mix electrolyzer oxygen and hydrogen vent streams, and always evaluate the potential for liquid waste streams to absorb both gases.*

The plan should discuss the locations of activities, including a description of facilities, types of personnel, other operations/testing performed at the facility, and relevant activities at adjacent facilities.

> *Descriptions of hydrogen fueling stations should include information such as the location of the station (at an existing gasoline station, convenience store, etc.), the number of assumed fills per day, hydrogen source (gaseous, liquid, electrolyzer, reformer, etc.), traffic patterns, quantity of the hydrogen stored on site, maximum pressures and pipe diameters, vent pipe design criteria, and other relevant details.*

When applicable, the description of work should include:

- A drawing or sketch showing the site where hydrogen operations will occur.
- Facility and/or laboratory layout showing equipment involved in hydrogen operations (e.g., storage, processing, ventilation), general floor plan and dimensions, location of flammable gas sensors, emergency stops, location of personnel and the public during operations, egress paths, other flammable gas storage or operations, ventilation systems, and vent pathways to treatment and exhaust.
- Piping and instrumentation diagram (P&ID).
- Process flow diagram (PFD).
- A simplified diagram like the one shown in Appendix G may provide the needed information as an alternative to the P&ID and PFD.

> *Often overlooked, the plan should describe the ventilation systems, including exhaust pathways, potential merging from other ventilation sources, and stack exits.*

## Hydrogen Safety Competency

### *How knowledgeable is the project team about the hazards of hydrogen?*

**Organizational Policies.** The plan should describe how the high-level safety policies and procedures of the organization(s) are implemented for the work performed. This is a check for the project team to ensure there are programs for implementing safety in all project phases. A listing with several descriptors is usually sufficient. High-level organizational policies and procedures should address the following topics, taken from process safety management standards:

- Conducting hazard and safety reviews
- Risk management
- Management of change
- Contractor management
- Training and performance assurance
- Incident investigations
- Measurement and metrics
- Auditing

**Hydrogen Experience.** The plan should identify the project personnel responsible for safety approval by name and describe their specific hydrogen experience relevant to the project. It is important to explain how the project plans to address gaps in leadership or workforce experience.

## Workforce Involvement

### *How does the project plan to involve workers in protecting themselves and the public from hydrogen hazards?*

Describe the organization's approach to incorporating personnel contributions into safety planning, detailing how operators, maintenance personnel, internal safety organizations, corrective action groups, and emergency response teams will engage in the safety culture. Examples include involving these

organizations in the development and review of the safety plan, preparation of the hazard analysis, and formal walkdowns and inspections.

If the current workforce has significant weaknesses, the project should identify methods for improving their understanding. This may include engaging outside training resources and experts.

> *The HSP, Center for Hydrogen Safety (CHS), and multiple equipment suppliers provide expert support for awareness training, specific equipment operations, and safety reviews.*

Projects that involve multiple partners should consider how to share and communicate safety knowledge and lessons learned.

## Hazards Identification and Risk Analysis (HIRA)

### *What are the hazards from operational uses or production of hydrogen and the controls needed to prevent or mitigate the hazards?*

**Identification of Hazard Analysis Methods.** Assessment of the potential hazards associated with work at any scale, from laboratory to operations, begins with identifying an appropriate assessment technique. Proper planning involves determining the analysis method to be used (which may change between project phases or partners), who will steward the process, and who will comprise the expert support team.

If there is uncertainty about which hazard identification method to apply, a project should first identify high-level safety vulnerabilities. Low-risk hazards may allow the use of simple approaches such as What-if analyses, job safety analyses, or safety checklists. Higher risk projects should consider using failure modes and effects analysis (FMEA), hazard operability analysis (HAZOP), fault or event tree, or probabilistic risk assessment. Appendix D provides examples of hazard analysis methods.

> *The gold standard of hazard analyses is a HAZOP. A HAZOP maximizes the evaluation of all related operating systems and external events for hydrogen leakage, ignition, or loss of control. An FMEA is also good but sometimes misses systemic issues such as loss of power, ignition hazards from other equipment, or secondary impacts (e.g., fire impingement from other sources).*

**Determine Hazards.** The plan should discuss the results of a completed hazard analysis that addresses the storage and use of hazardous materials and related topics, including possible ignition sources, fire and explosion hazards, material interactions, possible leakage and accumulation, likelihood of creating a combustible mixture, and potential for overpressure. The hazard analysis should address any production, use, storage, and distribution systems, including volumes, pressures, and estimated use rates.

**Perform Risk Reduction Planning.** Proper risk planning eliminates hazards or reduces their impacts. If eliminating a hazard is not practical, the plan should describe prevention and mitigation features, consistent with accepted hierarchy of controls: engineered controls first, and when those are not practical, administrative controls. Personnel protective equipment should be the last control relied on. Controls should be tied to the identified hazards using a matrix, table, or text references. A critical safety shutdown matrix (identifying key alarms and interlocks) should also be included. (See Appendix H.)

> *Hydrogen gas controls address the following basic strategies: prevention and mitigation of leaks and ignition sources and keeping concentrations out of the flammable limit range.*

Risk binning is an analysis tool used to classify vulnerabilities. (See Appendix E.)

## Compliance with Codes and Standards

### *How is the project following established hazard codes and standards for flammable gas and how are gaps being addressed?*

Recognition of the applicable national and international regulations, codes, and standards (RCS) (e.g., NFPA 2) is essential for project safety. The plan should list relevant governing RCS covering facilities, hydrogen design and operations, emergency planning, minimization of ignition sources, electrical zoning, ventilation systems, and fire codes. Issues with applications, gaps, or the need for alternatives should be discussed in detail.

Where compliance with a requirement cannot be achieved, and alternatives are proposed, a sound technical basis should be formally agreed upon by all the relevant parties. For example, Chapter 5 of NFPA 2 outlines a general process for validating alternative methods.

> *The HSP's safety data repository website, at h2tools.org, provides tools and information for identification of applicable RCS. The Fuel Cell and Hydrogen Energy Association, at fchea.org, provides support for hydrogen RCS through various programs, working groups, and publications.*

## Procedures

### *Are the working procedures for the project adequate to address hydrogen hazards?*

The safety plan should include a comprehensive list of current and planned procedures for testing, design, installation, commissioning, operations, and maintenance related to the use of hydrogen and hydrogen-related equipment. It is essential that the procedures identify key safety hold points, operating limits, emergency response protocols, and stop-work conditions. The plan should also reference specific safe work practices used to manage hazards during operations, such as lockout/tagout; confined space entry; safe opening of equipment or piping; and controlling access to facilities by maintenance staff, contractors, laboratory personnel, and other support personnel. Appendix I provides an example of a procedure list.

## Asset Integrity and Reliability

### *How is integrity assured for piping, tubing, valves, tanks, instruments, sensors, control systems, and other devices that are needed to prevent or mitigate hydrogen hazards?*

Integrity control should be emphasized at the project's design and build phases. Examples of effective integrity management include reviewing procurement specifications to ensure compatibility with hydrogen and proper calibration of instruments.

The safety plan should identify specific procedures (if not already mentioned), fail-safe applications used, preventive and active maintenance programs, routine inspections, and applicable maintenance training. The project should ensure that records are maintained throughout its life and that all applicable personnel have access to them.

**Integrity Operating Window (IOW).** Projects should consider key safety process parameters that can affect the integrity of the equipment if the process operation deviates from the established limits for a predetermined duration. The owner-operator should implement and maintain an effective program for creating, establishing, and monitoring IOWs. IOWs are implemented to avoid process parameter exceedances that may have an unanticipated impact on the integrity of pressure equipment.

Inspection plans are typically based on prior experience with similar systems. Without an effective IOW and process control program, there often is no warning of changing operating conditions that could affect

the integrity of equipment or validation of the current inspection plan. Deviations from and changes in trends within established IOW limits should be brought to the attention of inspection and engineering personnel so they may modify or create new inspection plans, depending on the seriousness of the exceedance.

IOWs should be established for both physical and chemical parameters that could compromise the integrity of safety equipment if not properly controlled. Examples include temperatures, pressures, number of cycles, fluid velocities, pH, flow rates, chemical or water injection rates, levels of corrosive constituents, and chemical composition. IOWs for key process parameters may have both upper and lower limits established, as needed. Particular attention should be paid to monitoring IOWs during startup, shutdown, and significant process upsets. API 584, “Integrity Operating Windows,” provides more information on developing an IOW program.

## Management of Change (MOC)

### *Is there a program in place to address changes in design and operation against the previously analyzed hazards?*

An MOC program ensures that an equipment or process change does not cause unintended detrimental consequences, initiate a new or revised hazard, or impede the function of hazard controls. The plan should describe how the project will apply MOC to review proposed changes to design, materials, technology, equipment, procedures, personnel, and facility operation for their effect on safety vulnerabilities. All modifications to materials, process conditions, and equipment that are not an in-kind replacement should be reviewed. For example, if a regulator is to be replaced with a different model or one constructed of a different material, the proposed change should be subject to MOC review.

> *Next to improper design, an inadequate MOC program is one of the leading causes of serious injuries.*

The MOC program should be formally documented and involve project team members, and any change warranted should be evaluated against existing HIRA documentation. Through established communication protocols, all personnel should be made aware of the change and its impact on the HIRA controls. The program should include robust training to ensure personnel can safely implement the change.

> *An inadequate quality assurance program for overseeing changes in control systems can place personnel at risk. If the sole controller of safety systems (e.g., alarms, interlocks, emergency stops) is a programmable logic controller (i.e., there are no hard-wired relays in the electrical interlock system), the software should be verified and validated. The quality assurance program should also ensure that changes to the software do not impact the safety system logic, but if questionable, should outline steps to re-verify and re-validate the logic. See IEEE 1012-2012 for an example of verification and validation methodology.*

Scaling up a process, modifying equipment, and changing materials are commonly encountered and should be considered changes that may result in the need to update the safety plan. Change may also refer to the need to train new personnel involved in the work.

## Safety Reviews

### *Are there sufficient and high-quality safety reviews during the life of the project?*

The plan should describe safety reviews that will be conducted during the project's design, construction, and operation phases. The involvement and responsibilities of individual project staff in such reviews and how the reviews will be documented should be described. The safety reviews conducted for a project should generally include the following:

- **Early Project HIRA.** The identification of safety vulnerabilities early in the project to pinpoint the major safety concerns that may affect the cost and timing of the project.
- **Design Stage HIRA.** The identification of safety vulnerabilities when the design is nearly complete to pinpoint safety concerns related to project details.
- **Pre-Startup Safety Review.** A review to make sure the following has been done:
  - Risk reduction plans have been implemented
  - Recommendations from incident investigation or compliance audits have been reviewed and addressed
  - System has been verified through examination, inspection, and testing
  - Initial startup and normal operating procedures have been fully evaluated to ensure a safe transition to operating mode
  - Safety and operational training have been conducted

**Self-Audits.** The plan should describe how the project team will verify that safety-related procedures and practices are being followed throughout the project and the continued use of the equipment. In addition to the safety plan template, the HSP has developed a Hydrogen Safety Checklist (Appendix F) to assist with safety self-audit and verification.

> *A compliance audit conducted by knowledgeable external personnel can identify safety weaknesses for the project team. Actions taken to address findings and recommendations should be formally tracked.*

## Safety Documentation

### *How is safety documentation managed to maintain safety awareness throughout the project life?*

The plan should describe how safety documentation is maintained, including who is responsible, where documents are kept, and how documents are accessed by project team members and partners.

Safety information includes the safety plan, HIRA documentation, procedures, training and references such as handbooks and standards, safety review reports, and communications plans.

> *Formal communication planning is a valuable tool for providing safety awareness to the public, authorities having jurisdiction, emergency responders, and other stakeholders. Input from outside the project can often identify safety blind spots.*

## Contractor Management

### *What safety protocols are communicated to project subcontractors?*

The plan should describe how project safety information is communicated and made available to all relevant participants, including project team members; testing, operations, and maintenance personnel; external partners; fabricators; construction firms; flammable gas delivery companies; and visitors.

## Training

### *How are project personnel (including construction workers, operators, and maintenance crews) and members of the public who interact with the project informed about hydrogen hazards?*

The plan should outline formal programs and specific training related to the hazards associated with the project. It should detail how the organization manages training participation and verifies understanding among personnel.

Training for project staff may include initial sessions that provide an overview of the process, a thorough understanding of operating procedures, and a focus on specific safety and health hazards. This initial training should also address emergency operations, including shutdown procedures, as well as safe work practices that are relevant to the employees' job tasks. Additionally, refresher training should be provided to reinforce current standard operating procedures and to address any newly identified hazards.

Specific training may be necessary for individuals responsible for maintaining process equipment, performing calibrations, or working with hydrogen-related equipment, such as changing out hydrogen gas cylinders.

The project should also specify how training on hydrogen hazards is provided to ensure all personnel are adequately prepared.

> *The CHS provides webinars and training courses on many hydrogen safety topics (https://aiche.org/CHS-training). The CHS offers a free extensive course on hydrogen safety in the laboratory (https://www.aiche.org/ili/academy/courses/ela210/hydrogen-laboratory-safety).*

## Safety Events and Lessons Learned

### *How does the project track near-misses and incidents, learning from their own and others' mistakes?*

The plan should describe how the project will handle historical and project-related safety events (near-misses and incidents), including:

- The reporting procedure within the organization
- Methods used to investigate events
- How corrective measures will be implemented
- How lessons learned from incidents and near-misses are documented and disseminated

> *An INCIDENT is an event that results in a lost-time accident and/or injury to personnel; damage to project equipment, facilities, or property; impact to the public or environment; or an emergency response (or should have resulted in an emergency response). A NEAR-MISS is an event that, under slightly different circumstances, could have become an incident, such as an unintentional hydrogen release that ignites or is sufficient to sustain a flame if ignited.*

Understanding the likelihood, severity, causal factors, setting, and relevant circumstances of past safety events better prepares projects to prevent similar, potentially more serious, incidents. It is important to document relevant historical incidents in this section or in the HIRA assessment.

> *The HSP maintains a database of incidents on its h2tools.org website to assist with project safety planning: https://h2tools.org/lessons. There is also a mechanism to report a near-miss or incident to inform others. All identifying information, including names of individuals, companies, organizations, vendors of equipment, and locations, is removed to ensure confidentiality and to encourage projects to report future events.*

The safety plan should describe the project or organizational program that addresses near-misses and incidents. This program should require a thorough investigation as promptly as possible using standard corrective action processes, such as evaluating root causes and extent of conditions, developing recommendations, and tracking actions.

## Operational Readiness

### *How does the project ensure it is safe to begin hydrogen operations?*

The project team should evaluate and document the organizational tools used to formally ensure that the HIRA and all safety action items have been completed and implemented using checklists or a more formal independently-reviewed process. The readiness review should ensure that MOC has been properly addressed for any changes that might impact HIRA results.

A formal operational readiness process should include an authorized and trained reviewer/approver, and results documented and maintained in project records.

> *DOE has published a thorough operational readiness standard that can be applied to any project on a graded approach: "Planning and Conduct of Operational Readiness Reviews (ORR)," DOE-STD-3006-95.*

## Emergency Management

### *How is the project planning to respond to incidents?*

The plan should outline the project documentation established for emergency response. The documentation should identify designated evacuation locations and specify the actions required to control or halt an emergency. The documentation must also include communication protocols for first responders, facility staff, and the public, as well as procedures for personnel accountability. It should also cover labeling and signage for emergency stops, alarm notifications, egress routes, and requirements for safe re-entry into the facility.

The h2tools.org website offers a presentation on the delivery of various training regimens to various audiences, titled “National Hydrogen and Fuel Cell Emergency Response Training Resource.”[3]

> *Emergency planning often overlooks the interactions and results from a fire department response. It is very difficult to visually identify a hydrogen fire, especially in daylight. The plan should identify appropriate safe distances for those responding to an incident and address secondary fires. Spraying water on a vessel relief valve that is releasing hydrogen gas is not recommended because it could freeze the valve, causing a vessel rupture. Often the safest response to a hydrogen fire is to let it burn to prevent the formation a large gas cloud that may ignite. Firefighting can involve copious amounts of water, which may flow into other energized safety equipment and collect in protected water environs. It is recommended that projects involve the local fire department in emergency planning prior to hydrogen operations.*

## Safety Plan Approval

### *How will the final safety plan be approved?*

If the project does not a have a formal policy or procedure for safety plan review and approval, as noted in the Hydrogen Safety Competency section, details should be included about how peer review, safety experts, and all appropriate approval authorities are involved in developing the final safety document.

Projects should involve safety personnel from all partners for review. Approval from all partners is valuable.

An alternative to this section in a standalone hydrogen safety plan is to identify all reviewers and approvers on the cover sheet or addendum approval sheet.

[3] https://h2tools.org/national-hydrogen-and-fuel-cell-emergency-response-training-resource

# Appendix B – Application of Process Safety Management

To help ensure safe workplaces, the Occupational Safety and Health Administration (OSHA) has issued "Process Safety Management of Highly Hazardous Chemicals" (29 CFR 1910.119), which contains requirements for managing hazards associated with processes using highly hazardous chemicals under the banner of process safety management (PSM).[4]

PSM is a cornerstone of safety planning for the chemical industry. A chemical industry safety program closely related to hydrogen project safety is the implementation of PSM by the American Institute of Chemical Engineers (AIChE) Center for Chemical Process Safety (CCPS). CCPS' premier summary publication states:

> *Process safety management is widely credited for reductions in major accident risk and improved process industry performance. Process safety practices and formal safety management systems have been in place in some companies for many years. Over the past 20 years, government mandates for formal process safety management systems in Europe, the U.S., and elsewhere have prompted widespread implementation of a management systems approach to process safety…the Center for Chemical Process Safety (CCPS) created the next generation process safety management framework – Risk Based Process Safety (RBPS).*[5]

OSHA PSM regulations may apply directly to a facility handling hydrogen, depending on the quantity of hydrogen involved in the process and/or local or national regulations. PSM represents a best practice for safety in the hydrogen value chain and should be considered even when not required by regulation. PSM is scalable, so the effort required is commensurate with the scale and complexity of the operation.

CCPS describes four main pillars of accident prevention and 20 elements that are needed for each organization (Figure B.1).

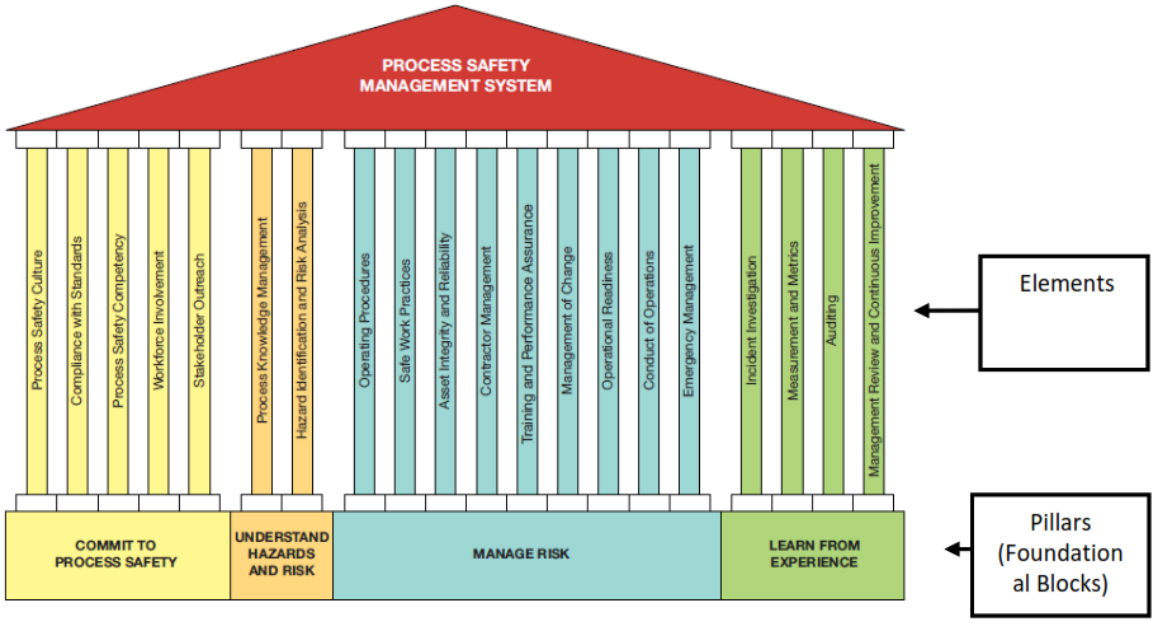



**Figure B.1**. PSM Pillars[6]

[4] https://www.osha.gov/process-safety-management
[5] *Guidelines for Risk Based Process Safety* (https://www.wiley.com/en-us/Guidelines+for+Risk+Based+Process+Safety-p-9780470925119)
[6] *Guidelines for Risk Based Process Safety*, page 8

The Hydrogen Safety Panel assessed these pillars and integrated appropriate criteria into the safety plan elements described in this guide. This guide will be reviewed and updated to ensure that hydrogen safety planning considers changes in PSM pillar criteria. The Center for Hydrogen Safety and CCPS are working groups in the AIChE, supporting continual quality integration of PSM standards in both programs.

The following table provides a general overview of the four pillars from the CCPS guide and details on how their elements were applied to the structure of a hydrogen safety plan.

| Pillar | Specific Safety Plan Topic? | Notes |
|---|---|---|
| **Pillar 1: Commit to Process Safety** | | |
| Safety Culture | No | This guide directly highlights the value of a good safety culture. A project can demonstrate its safety culture by preparing a quality safety plan. |
| Compliance with Standards | Yes | |
| Process Safety Competency | Yes | |
| Workforce Involvement | Yes | |
| Stakeholder Outreach | No | This safety plan guide indirectly addresses this concept in multiple elements recommending involvement of stakeholders in formal communications and emergency planning. |
| **Pillar 2: Understand Hazards and Risks** | | |
| Process Knowledge Management | No | This safety plan guide indirectly addresses this concept in multiple elements recommending documentation, analysis, and management of change control of process conditions and parameters, and inclusion of integrity operating window data. |
| Hazards Identification and Risk Analysis | Yes | |
| **Pillar 3: Manage Risk** | | |
| Operating Procedures | Yes | |
| Safe Work Practices | No | Addressed indirectly in multiple elements. |
| Asset Integrity and Reliability | Yes | |
| Training and Performance Assurance | Yes | |
| Contractor Management | Yes | |
| Management of Change | Yes | |
| Operational Readiness | Yes | |
| Conduct of Operations | No | Addressed indirectly in multiple elements. |
| Emergency Management | Yes | |
| **Pillar 4: Learn from Experience** | | |
| Incident Investigation | Yes | The concept is directly addressed in the safety plan guide element Safety Events and Lessons Learned. |
| Measurements and Metrics | No | Addressed indirectly in multiple elements. |
| Auditing | No | Addressed indirectly in multiple elements. |
| Management Review and Continuous Improvement | No | Addressed indirectly in multiple elements. |

# Appendix C – HSP Review Protocols

## Hydrogen Safety Panel Review Process

The Hydrogen Safety Panel (HSP) was established by the U.S. Department of Energy (DOE) in 2003 and brings together experts from diverse hydrogen-related sectors. Rather than conducting audits or regulatory enforcement, the HSP focuses on engagement, learning, and discussion. It builds on existing efforts by codes and standards development organizations instead of duplicating them.

## Scope of Work

The HSP provides the following services to clients:

- Participating in hazards identification and risk assessment (HIRA)
- Responding to technical inquiries
- Offering safety planning guidance
- Reviewing project designs and safety plans
- Sharing best practices and safety knowledge
- Conducting site inspections
- Assisting in incident investigations

## General Protocols

HSP members act as independent reviewers, subcontracted for evaluations. When engaged by DOE, the California Energy Commission (CEC), the Center for Hydrogen Safety (CHS), or U.S. national laboratories, the Panel involves the following actions and protocols:

- The HSP chair, administrative coordinator, or program manager assigns 2-3 panel members based on availability and expertise.
- Most panel members are contracted through Pacific Northwest National Laboratory (PNNL) and have non-disclosure agreements (NDAs) in place. Clients may request additional NDAs with PNNL, but this may extend contract setup time. Extensive legal reviews cannot typically be accommodated.
- Clients may exclude panel members due to perceived conflicts of interest. The HSP chair and program director assess potential conflicts before making assignments. Member bios are available on the HSP h2tools.org website.[7]
- Safety plan reviews for DOE and CEC clients remain confidential.
- Design reviews typically include kick-off and team meetings, making assigned reviewers known to the client.
- If a safety plan includes an inadequate HIRA, the plan will be reviewed but must be resubmitted. Clients should avoid submitting draft safety plans. Questions should be directed to DOE/CEC, the HSP program manager, or the HSP chair before submission.
- Virtual meetings cannot be recorded. Clients may request official meeting notes or minutes, which are compiled into a formal report.

[7] https://h2tools.org/hsp

## Review Exclusions

The HSP does not:

- Generate design basis documents; it only provides recommendations.
- Certify compliance with regulations, codes, and standards.
- Review safety plans that:
  - Do not meet the simplified safety plan guide.
  - Are too general or lack a completed HIRA. Preliminary hazard analyses are acceptable if properly documented.
  - Have incomplete pre-review contract criteria.

## Review Process

- Reviews typically take 6-8 weeks, depending on complexity.
- Comments are compiled and reconciled by Panel members and/or the HSP chair.
- A final report is issued after technical editing by an independent PNNL or CHS editor.
- Safety plans are assessed against criteria outlined in Table 1 of this guide. Comments are structured accordingly, and a summary table is included in the report. Upon resubmission, the summary may be updated to reflect improvements.

## Post-Review

- DOE safety plan clients may be required to respond to HSP comments. In such cases, the HSP reviews the responses and provides feedback. Responses are not appended to the review report and are stored separately.
- The contracting entity (DOE, CEC, CHS, or a national laboratory) has access to all client data and review reports.
- If a revised safety plan is submitted, the HSP will re-review. If new comments are warranted, they may be provided in a new review document or email message, or embedded in the original review as a revision dependent on the quantity and scope of the plan changes.

# Appendix D – Hazard Analysis Options

| Method | Description | References |
|---|---|---|
| **FMEA** (Failure Modes and Effects Analysis) | The FMEA process has these elements:<br>• Identify top-level hazards and events<br>• Identify related equipment, components, and processes<br>• Identify potential failure modes and effects<br>• Identify designs that provide inherent safety<br>• Identify potential prevention and mitigation corrective action | • Government documents, including MIL-STD-882C and MILSTD-1629A<br>• NASA Scientific and Technical Information http://www.sti.nasa.gov/<br>• A discussion and example can be found in *Guidelines for Hazard Evaluation Procedures*, *Second Edition with Worked Examples*, Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992. |
| **"What If" Analysis** | A speculative process formulating and reviewing questions in the form "What if (hardware, software, instrumentation, or operators) (fail, breach, break, lose functionality, reverse, etc.)?" | A discussion and worked example can be found in *Guidelines for Hazard Evaluation Procedures*, *Second Edition with Worked Examples*, Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992. |
| **HAZOP** (Hazard and Operability Analysis) | Systematically evaluates the impact of deviations using project information. Method was developed to identify both hazards and operability problems at chemical process plants. | An extensive description and worked example of the HAZOP procedure can be found in *Guidelines for Hazard Evaluation Procedures*, *Second Edition with Worked Examples*, Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992. |
| **Checklist Analysis** | Evaluates the project against existing guidelines using a series of checklists. This technique is most often used to evaluate a specific design, equipment, or process with which an organization has a significant amount of experience. | A discussion and worked example can be found in *Guidelines for Hazard Evaluation Procedures*, 3rd Edition, Center for Chemical Process Safety, American Institute of Chemical Engineers, 2008. |
| **Fault Tree Analysis** | A deductive (top-down) method used for identification and analysis of conditions and factors that can cause a specific failure or undesirable event. This method addresses multiple failures, events, and conditions. | A discussion and worked example can be found in *Guidelines for Hazard Evaluation Procedures*, 3rd Edition, Center for Chemical Process Safety, American Institute of Chemical Engineers, 2008. |
| **Event Tree Analysis** | An inductive approach used to identify and quantify a set of possible outcomes. The analysis starts with an initiating event or initial condition and includes the identification of a set of success and failure events that are combined to produce various outcomes. This method identifies the spectrum and severity of possible outcomes and determines their likelihood. | A discussion and worked example can be found in *Guidelines for Hazard Evaluation Procedures*, 3rd Edition, Center for Chemical Process Safety, American Institute of Chemical Engineers, 2008. |
| **Probabilistic Risk Assessment** | An organized process for answering the following three questions:<br>• What can go wrong?<br>• How likely is it to happen?<br>• What are the consequences? | A detailed description of this method can be found in *Guidelines for Chemical Process Quantitative Risk Analysis*, Center for Chemical Process Safety, American Institute of Chemical Engineers, 1999. |
| **Others** | Other methods or combinations of methods, including those developed by the project team's organization, may be used. | A discussion and worked example can be found in *Guidelines for Hazard Evaluation Procedures*, 3rd Edition, Center for Chemical Process Safety, American Institute of Chemical Engineers, 2008. |

# Appendix E – Example Risk Binning Matrix

Risk binning is one analysis tool used to classify vulnerabilities. Each vulnerability can be assigned a qualitative risk using a frequency-consequence matrix, such as the example shown below.[8]

Highest consequences are generally assigned to events that could reasonably result in an unintended release of hazardous material, destruction of equipment and/or facilities, or injury to people.

**Risk Binning Matrix: Frequency/Consequence Criteria**

| | | Frequency | | | |
|---|---|---|---|---|---|
| | | **Beyond extremely unlikely** | **Extremely unlikely** | **Unlikely** | **Anticipated** |
| **Consequence** | **High** | | **7** | **4** | **1** |
| | **Moderate** | **10** | **8** | **5** | **2** |
| | **Low** | | **9** | **6** | **3** |
| | **Negligible** | **12** | **11** | | |

Higher risk

Lower risk

Moderate risk

Negligible risk

[8] *Preliminary Safety Evaluation for Hydrogen-fueled Underground Mining Equipment*, D.A. Coutts and J.K. Thomas, Westinghouse Safety Management Solutions, Aiken, SC, Publication WSRC-TR-98-00331, September 1998. (This reference includes information from *Preparation Guide for US Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports,* DOE-STD-3009-94, July 1994.)

**Frequency criteria used for risk-binning**

| Acronym | Description | Frequency Level |
|---|---|---|
| A | Anticipated, Expected | $> 1*10^{-2}$/yr |
| U | Unlikely | $10^{-4}$/yr $< f \leq 10^{-2}$/yr |
| EU | Extremely Unlikely | $10^{-6}$/yr $< f \leq 10^{-4}$/yr |
| BEU | Beyond Extremely Unlikely | $\leq 10^{-6}$/yr |

| Consequence Level | Impact on Populace | Impact on Property/Operations |
|---|---|---|
| High (H) | • Prompt fatalities<br>• Acute injuries – immediately life threatening<br>• Permanent disability | • Damage > $50 million<br>• Production loss in excess of 1 week |
| Moderate (M) | • Serious injuries<br>• Non-permanent disability Hospitalization required | • $100,000 < damage ≤ $50 million; equipment destroyed, or<br>• Critical equipment damaged; production loss less than 1 week |
| Low (L) | • Minor injuries<br>• No hospitalization | • Damage ≤ $100,000<br>• Repairable damage to equipment<br>• Significant operational downtime<br>• Minor impact on surroundings |
| Negligible (N) | • Negligible injuries | • Minor repairs to equipment required<br>• Minimal operational downtime<br>• No impact on surroundings |

# Appendix F – HSP Safety Checklist

The following checklist can be found on the Hydrogen Safety Panel's h2tools.org website at https://h2tools.org/sites/default/files/HydrogenSafetyChecklist.pdf.

The checklist is not meant as a substitute for a hazards identification and risk analysis but rather is provided to help both new and experienced hydrogen users identify considerations necessary to ensure a safe installation.

**Hydrogen 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.<br>☐ Identify potential hazards from adjacent facilities and nearby activities<br>☐ 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.<br>☐ 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.<br>☐ Consider excess flow valves/chokes to size of hydrogen leaks<br>☐ Define countermeasures to protect people and property.<br>☐ Follow applicable codes and standards. |
| | **Isolate hazards** | ☐ Store hydrogen outdoors as the preferred approach; store only small quantities indoors in well ventilated areas.<br>☐ Provide horizontal separation to prevent spreading hazards to/from other systems (especially safety systems that may be disabled), structures, and combustible materials.<br>☐ Avoid hazards caused be overhead trees, piping, power and control wiring, etc. |
| | **Provide adequate access and lighting** | Provide adequate access for activities including:<br>☐ Operation, including deliveries<br>☐ Maintenance<br>☐ Emergency exit and response |
| | **Approach** | **Examples of Actions** |
| **Keep the Hydrogen in the System** | **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.<br>☐ Contain: Design or select equipment, piping and instrumentation that are capable of maximum credible pressure using materials compatible with hydrogen service.<br>☐ Relieve: Provide relief devices that safely vent the hydrogen to prevent damaging overpressure conditions.<br>☐ Perform system pressure tests to verify integrity after initial construction, after maintenance, after bottle replacements, and before deliveries through transfer connections. |
| | **Protect systems** | ☐ Design systems to safely contain maximum expected pressure or provide pressure relief devices to protect against burst.<br>☐ Mount vessels and bottled gas cylinders securely.<br>☐ Consider that systems must operate and be maintained in severe weather and may experience earthquakes and flood water exposures.<br>☐ De-mobilize vehicles and carts before delivery transfers or operation.<br>☐ Protect against vehicle or accidental impact and vandalism.<br>☐ Post warning signs. |
| | **Size the storage appropriately for the service** | ☐ Avoid excess number of deliveries/change-outs if too small.<br>☐ 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.<br>☐ Consider redundant or backup controls.<br>☐ 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.<br>☐ Direct discharges away from personnel and other hazards.<br>☐ 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.<br>☐ Provide sufficient ventilation and/or space for dilution.<br>☐ 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.<br>☐ No open flames.<br>☐ No arcing/sparking devices, e.g., properly classified electrical equipment. |
| | **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.<br>☐ Consider methods for manual or automatic in-process leak detection such as ability for isolated systems to hold pressure.<br>☐ 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.<br>☐ Provide capability to automatically detect and mitigate safety-critical situations.<br>☐ Consider redundancy to detect and mitigate sensor or process control faults.<br>☐ 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.).<br>☐ Automatic shutdown and isolation if fire detected. |
| | **Approach** | **Examples of Actions** |
| **Manage Operations** | **Establish and document procedures** | ☐ Responsibilities for each of the parties involved.<br>☐ Operating procedures.<br>☐ Emergency procedures.<br>☐ Preventive maintenance schedules for equipment services, sensor calibrations, leak checks, etc.<br>☐ Safe work practices such as lock-out/tag-out, hot work permits, and hydrogen line purging.<br>☐ Review and approval of design and procedural changes. |
| | **Train personnel** | ☐ MSDS awareness for hydrogen and other hazardous materials.<br>☐ 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.<br>☐ Monitor compliance to all procedures and work instructions. |

# Appendix G – Example Flow and Piping and Instrumentation Diagram

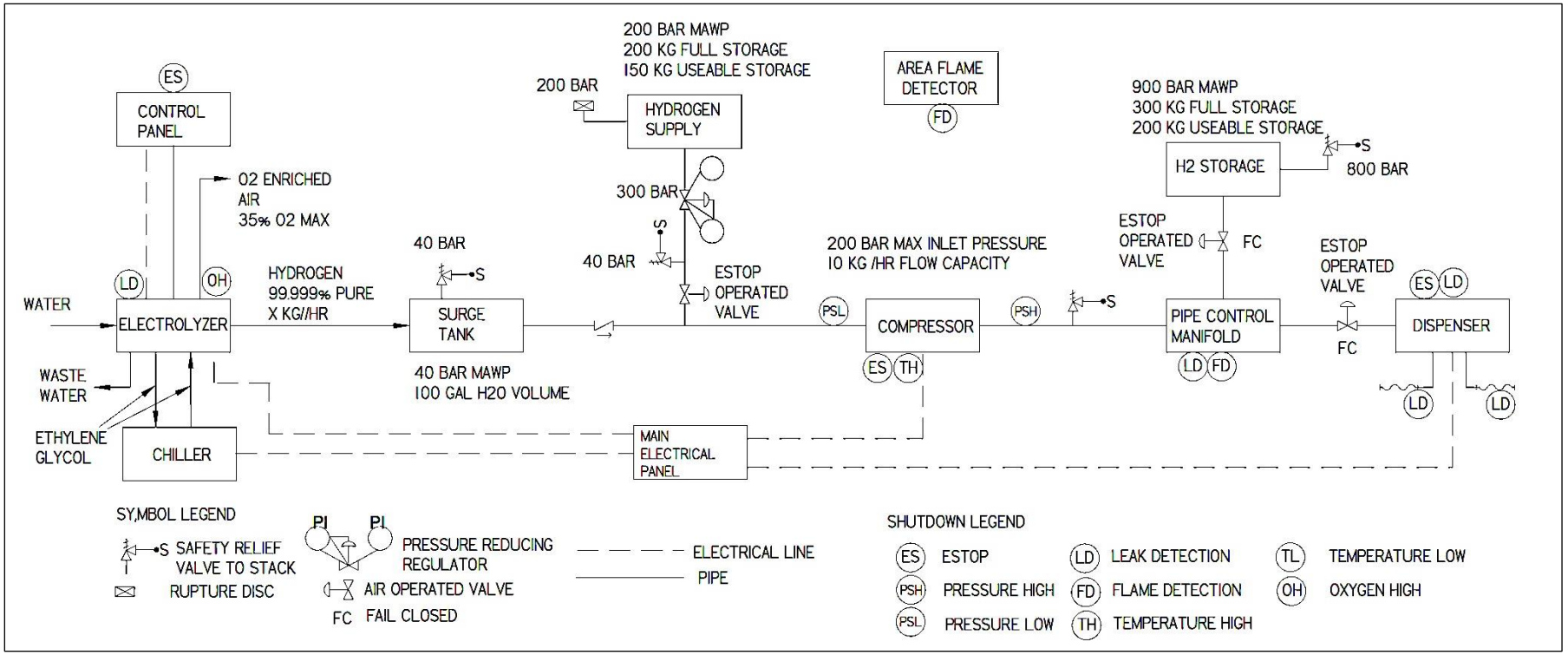



**Figure G.1.** Example Flow Diagram of Hydrogen Fueling Station

# Appendix H – Example Critical Safety Shutdown Table

| Equipment/Alarms | Instrument Air | Dispenser | Compressor Control Panel | Compressor | Compressor Diaphragm | H2 Storage | Hydrogen System Entry way | 25 ft away from H2 System | Hydrogen Fill | Hydrogen Equipment Enclosure | Equipment Shutdown Scenario | Site Shutdown Scenario |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E-Stop | | ● | ● | ● | | | ● | ● | | | | ● |
| Heat Detection | | ● | | ● | | ● | | | | ● | | ● |
| Flame Detection | | ● | | ● | ● | ● | | | | ● | | ● |
| Leak Detection | | ● | | ● | ● | ● | | | | | | ● |
| Hose Break | | ● | | | | | | | ● | | ● | |
| Mechanical Ventilation | | | | | | | | | | ● | ● | |
| High Pressure | | | | ● | | | | | | | ● | |
| Low Pressure | ● | | | ● | | | | | | | ● | |
| High Temperature | | ● | | ● | | | | | | | ● | |
| Low Temperature | | ● | | ● | | | | | | | ● | |
| Mechanical Relief Device | ● | ● | | ● | | ● | | | ● | | N/A | N/A |

**Equipment Shutdown -** Stops fill and isolates valves to the dispenser and contacts system operator

**Site Shutdown Scenario -** Stops Fill, isolates storage system, shuts down compressor and contacts fire department and/or system operator

# Appendix I – Example Procedures List

| PROCEDURE PHASE | Design | Installation & Commissioning | Operations | Maintenance |
|---|---|---|---|---|
| E-Stop Procedures | ● | ● | | ● |
| Electrical Safe Work Practices | ● | ● | ● | ● |
| Emergency Planning and Management | ● | | ● | |
| Emergency Response Operations | ● | | ● | |
| Energy Isolation | | ● | | ● |
| Equipment/Line Opening and Clearing | | ● | | ● |
| Fire and Hydrogen Detection Systems | ● | ● | ● | ● |
| Grounding Design and Procedures | ● | ● | | ● |
| Hazardous Enclosures | ● | ● | ● | ● |
| Hose Change out Requirements | | | | ● |
| Leak Detection and Repair | | ● | | ● |
| Lockout/Tag | ● | ● | ● | ● |
| Management of Change | ● | ● | ● | ● |
| Managing Onsite Chemicals | | ● | ● | ● |
| Mechanical Integrity of Equipment | ● | ● | | ● |
| Nonroutine Work Authorization | | ● | ● | ● |
| Operational Readiness Inspection | | ● | | |
| Personal Protective Equipment | | ● | ● | ● |
| Planned Inspection and Maintenance | | | | ● |
| Project Documentation, Retention and Sharing Requirements | ● | ● | ● | ● |
| Project Hazard Review Process | ● | | | |
| Purging Flammable Systems | ● | ● | | ● |
| Relief Device Testing and Inspection | | ● | | ● |
| Risk Analysis | ● | | | |
| Safety Integrity Level Design Criteria | ● | | | |
| Safety Signs | ● | ● | ● | ● |
| Testing of Safety Equipment | | ● | | ● |
| Training Requirements and Procedures | ● | ● | ● | ● |
| Welding and Brazing Safety | | ● | | ● |

The **Hydrogen Safety Panel** (http://h2tools.org/hsp) was formed in 2003 by the U.S. Department of Energy to help develop and implement practices and procedures that would ensure safety in the operation, handling and use of hydrogen and hydrogen systems. The primary objective is to enable the safe and timely transition to hydrogen and fuel cell technologies. This is accomplished by:

- Providing expertise and recommendations and assisting with identifying safety-related technical data gaps, best practices, and lessons learned, and
- Ensuring that safety planning and safety practices are incorporated into hydrogen projects.

The 24-member panel has over 700 years of combined experience and is comprised of a cross-section of expertise from the commercial, industrial, government, and academic sectors. Panel members participate in a variety of standards development organizations including the ASME, CSA, ISO, NFPA, SAE, and UL. Panel members also contribute to peer-reviewed literature and trade magazines on hydrogen safety and present at national and international forums. The Panel has reviewed over 500 projects covering vehicle fueling stations, auxiliary power, backup power, combined heat and power, industrial truck fueling, portable power, mobile applications, and R&D activities.

If you have interest in utilizing the expertise of the Panel, contact the program manager by email at **hsp@h2tools.org**.

HYDROGEN
Safety Panel