HYDROGEN
Safety Panel

Safety Planning for Hydrogen and Fuel Cell Projects

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Table of Contents

Safety Planning for Hydrogen and Fuel Cell Projects

A. Introduction

Safe practices in the production, storage, distribution, and use of hydrogen are essential to protect people, equipment, and the environment. A catastrophic failure in any project could damage the public's perception of hydrogen and fuel cells and prevent its widespread acceptance. An effective **project safety plan** is essential to identify risks, avoid potential incidents, and guide the safe conduct of all work related to the development and operation of hydrogen and fuel cell equipment.

This **Safety Planning Guide**, developed by the *Hydrogen Safety Panel* (HSP), instructs project teams on the essential safety planning principles (Section B), safety plan content (Section C), and supporting plan documentation (Section D) for effective safety plans. Applicable risk assessment methods, safety checklists, and selected examples are provided in the Appendixes.

Effective safety planning identifies, analyzes, and mitigates or eliminates potential hazards, failure mechanisms, and their related incidents associated with any work process or system. Other safety aspects that may be adversely affected by a failure should be considered. These aspects include threats or impacts to the following:

- **People.** Hazards that pose a risk of injury or loss of life to people must be identified and eliminated or mitigated. A complete safety assessment considers not only those personnel who are directly involved in the work, but also others who are at risk due to these hazards.
- **Equipment.** Damage to or loss of equipment or facilities must be prevented or minimized. Damage to equipment can be both the cause of incidents and the result of incidents. An equipment failure can result in collateral damage to nearby equipment and property, which can then trigger additional equipment failures or even lead to additional risks. Effective safety planning considers and minimizes serious risk of equipment and property damage.
- **Environment.** Damage to the environment must be prevented. Any aspect of a natural or built environment that can be harmed due to a failure should be identified and analyzed. A qualification of the failure modes resulting in environmental damage must be considered.

Effective safety planning is a continuous process. A safety plan should be revisited periodically and revised whenever changes are made as part of an overall effort to give continuous and priority attention to project safety.

B. Principles for Safety Planning

Best safety practices, incorporating a wealth of experience with new knowledge and insights gained, are an important aspect of continuous and priority attention for project safety.

The following critical elements help ensure that safety is integrated into projects and demonstrations:

Involve All Parties and Stakeholders

A thorough and integrated approach to project safety planning needs to identify and involve all parties, project partners, and stakeholders. For example, in the case of a system installation, the parties could include hydrogen equipment suppliers, facility operators, maintenance/repair providers, and local safety authorities with area jurisdiction.

Early Involvement of Safety Expertise

Safety expertise should be sought early in a project's life to ensure that safe design features and practices are consistently applied as part of project implementation. Work scope could include

- reviewing designs with the intent of approving or assisting with the approval of the project,
- assisting with the identification of safety vulnerabilities and development of mitigation plans
- inspecting the installation,
- investigating and lessons learned reporting for incidents and near-misses, and
- safety-related change management issues.

Compliance with Codes and Standards

Codes and standards describe requirements that are developed with safety as the primary concern. Compliance with applicable codes and standards (e.g. the International Fire Code and NFPA 2 *Hydrogen Technologies Code*), is essential for ensuring public confidence in commercial projects, particularly for those deploying new technologies. Where strict code compliance for a specific design, installation, and/or operation cannot be achieved, a sound technical basis for the proposed alternative safety approach should be formally agreed upon by all of the relevant parties, including stakeholders and building and fire code officials.

Project teams should consult local code and zoning officials early in the project. Early engagement will facilitate a greater understanding of the locally adopted building and fire codes, which in some cases could be more restrictive than national codes. Also, significant alterations may be needed to comply with unique local zoning and planning ordinances.

A Knowledgeable Emergency Response Team

A suitably trained emergency response force is essential component of a viable hydrogen infrastructure because these personnel need to understand how to respond to an incident. The project team should work with their local first responders to make them aware of the activities and their hazards. The team should also ensure that they have access to appropriate training materials. This includes information not only on the hazardous characteristics such as the flammable and explosive properties of hydrogen, but also other topics such as those associated with the hydrogen and fuel cell equipment, e.g., charged electrical circuits and high-pressure storage containers. Resources such as the National Hydrogen and Fuel Cell Emergency Response Training Resource (http://h2tools.org/fr/nt/) and the online Introduction to Hydrogen Safety for First Responders (https://h2tools.org/firstresponder) may be helpful.

C. The Safety Plan

As an integral part of any hydrogen project, the safety plan should reflect sound and thoughtful consideration for the identification and analysis of safety vulnerabilities, control or elimination of hazards, and mitigation of risks. Safety plans should be "living documents" that recognize the type of work being conducted, the factors of human error, the nature of equipment life, and consider the inevitable changes that occur in project development, design, execution, operation, and maintenance. A thorough Safety Plan is the primary tool for effective communication with stakeholders and the public.

It is important to note that appropriate hazard and change communication should be described in the safety plan. Development of a comprehensive safety plan may be done by multiple organization teams and coordinated by team leaders so as to integrate the approaches for assessing all safety vulnerabilities.

The plan should cover all experimental/operational work being conducted, with particular emphasis on the aspects involving hydrogen, hazardous materials handling, and fuel cell systems. When a preliminary safety plan is developed as part of a predesign bid package, elements such as risk analysis and mitigative features may be covered more generally with a focus on what risk analysis activities will be completed during a later design phase. The **Safety Plan Template** is intended to help project teams verify that their safety plan addresses all of the necessary elements and can be a valuable tool over the life of the project. Template elements should not be considered an exhaustive list of safety considerations for all projects. All project phases should be addressed in each section as applicable (design, installation, commissioning, operations, and maintenance).

Safety Plan Template

Element	The Safety Plan Should Describe
Description of Work	• Nature of the work being performed, including a description of the facility, pertinent processes or systems, partner organizations, and the anticipated quantity of stored/used hydrogen
Organizational Policies and Procedures	• Application of safety-related policies and procedures to the work being performed • Project leadership responsible for safety approvals
Hydrogen and Fuel Cell Experience	• How previous organizational experience with hydrogen, fuel cell and related work is applied to this project

Identification of Safety Vulnerabilities (ISV)	• The ISV methodology applied to this project, such as FMEA, What If, HAZOP, Checklist, Fault Tree, Event Tree, Probabilistic Risk Assessment, or other method
	• Who leads and stewards the use of the ISV methodology
	• Significant accident scenarios
	• Significant vulnerabilities associated with the scenarios
	• Safety critical equipment
	• Storage and handling of hazardous materials and related topics
	  ○ ignition sources, explosion hazards
	  ○ materials interactions
	  ○ possible leakage and accumulation
	  ○ detection
	• Hydrogen handling systems
	  ○ supply, storage, and distribution systems
	  ○ volumes, pressures, estimated use rates
	• Additional Documentation provided (see section below)

Risk Reduction Plan	• Prevention and mitigation measures for significant vulnerabilities
Codes and Standards	• Governing codes, standards, and regulations applicable to the project • Alternate methods including their technical basis
Procedures	• Procedures applicable for the location and performance of the work • Operating steps that need to be written for the particular project: critical variables, their acceptable ranges, and responses to deviations from them

Element	The Safety Plan Should Describe
Equipment and Mechanical Integrity	• Design basis, proof testing and commissioning • Preventative maintenance plan • Calibration of sensors • Test/inspection frequency basis • Documentation
Management of Change Procedures	• The system and/or procedures used to review proposed changes to materials, technology, equipment, procedures, personnel, and facility operation for their effect on safety vulnerabilities
Safety Reviews	• Pre startup review to verify initial conformity to ISVs, mechanical integrity, etc. • Safety audits to verify continued conformity to ISVs, mechanical integrity, procedures, etc. • Other reviews normally conducted by the organization(s)
Project Safety Documentation	• How needed safety information is communicated and made available to all participants, including partners. Safety information includes the safety plan, the ISV documentation, procedures, and references such as handbooks and standards, and safety review reports.
Training	• Required general safety training - initial and refresher • Hydrogen-specific and hazardous material training - initial and refresher • How the organization stewards training participation and verifies understanding
Safety Events and Lessons Learned	• The reporting procedure within the team • The process used to investigate events • How corrective measures will be implemented • How lessons learned from incidents and near-misses are documented and disseminated
Emergency Response	• The plan/procedures for responses to emergencies • Plans for communication and interaction with local emergency response officials
Other Comments or Concerns	• Any information on topics not covered above
Supporting Documentation	• Layout of the system at the planned location • Flow diagram (see Appendix IV for an example) • Equipment component descriptions • Critical safety and shutdown table (see Appendix IV for an example)
Safety Plan Approval	• Safety plan review and approval process

The following sections describe each Template element. The included text boxes provide useful background information on good safety practices and should be thoughtfully considered in preparing your safety plan. Detailed documentation related to this background information does not need to be included in the safety plan itself.

Project teams may also find H_2 Safety Best Practices (https://h2tools.org/bestpractices) to be a useful reference for safety planning. This website captures the experience that already exists in a wide variety of industrial, aerospace, and laboratory settings with topics covering safety practices, design, and operations. An extensive reference list is also supplemented with lessons learned from incidents and near-misses.

Description of Work

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 along with their respective roles. All intended project phases should also be described. In describing the work, quantify the amount of hazardous materials generated, used, and stored should be identified. For example, the plan should include the quantity of hydrogen stored and at what pressure, along with a description of how often the hydrogen is replenished and by what method (see example in Appendix IV). Even laboratory-scale experiments may result in substantial risks when a quantity of hydrogen or other hazardous material is stored in or near the laboratory.

The plan should discuss the location of activities (description of facilities, types of personnel, other operations/testing performed at the facility, adjacent facilities) and describe how the activities will be coordinated and approved. Any relevant permits that apply to current and planned operations should be listed.

> *For hydrogen fueling stations, description of work 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, the source (gaseous, liquid, electrolyzer, reformer, etc.) and the quantity of the hydrogen stored onsite, pipeline maximum pressures and diameters, vent pipe design criteria, etc.*

Organizational Safety Information

Organizational Policies and Procedures. The plan should describe how the safety policies and procedures of the organization(s) are implemented for the work being performed. Project team member involvement is important in the development and implementation of comprehensive project safety plans. Project leadership having safety approval responsibility should be identified.

Hydrogen and Fuel Cell Experience. Knowledge gained over a period of time can be an important asset in effective safety planning. The plan should describe the types of previous operations, degree of experience of team personnel, and how previous organizational experience with hydrogen and fuel cells will be applied to the project.

Project Safety

Identification of Safety Vulnerabilities (ISV). Assessment of the potential hazards associated with work at any scale from laboratory to operations begins with the identification of an appropriate assessment technique. The ISV is the formal means for identifying potential safety issues associated with laboratory or process steps, materials, equipment, operations, facilities, and personnel. ISVs are expected to be performed at least twice before construction: 1) a preliminary analysis based on information known at the beginning of the project, and 2) a more detailed analysis based on the nearly finished design. The plan should describe the following:

- The ISV methods to be used
- Who leads the ISV processes
- Who stewards the results of the ISV processes
- Significant accident scenarios identified as part of the first ISV exercise (e.g., higher consequence, higher frequency)
    - Significant vulnerabilities (risks) identified as part of the first ISV exercise
    - Safety critical equipment

To assist with the identification of less frequently encountered vulnerabilities, the project team should consider reviewing relevant past incidents found at https://h2tools.org/sites/default/files/Hydrogen_Incident_Examples.pdf.

> ***Hazardous Materials.*** *The plan should discuss the storage and handling of hazardous materials and related topics including possible ignition sources, explosion hazards, material interactions, possible leakage and accumulation, likelihood of creating a combustible mixture, potential for overpressure, and detection. For hydrogen handling systems, the plan should describe the source and supply, storage and distribution systems including volumes, pressures, and estimated use rates.*

Two other questions should be addressed in the first ISV and described in the safety plan:

- What risk associated with this system design, installation, operation or maintenance is most likely to result in an incident/accident?
- What hazard associated with this system design, installation, operation or maintenance has the potential to result in the worst consequence?

> *In general, a good safety plan identifies immediate (primary) failure modes as well as secondary failure modes that may come about as a result of other failures. For effective safety planning, an attempt is made to identify every conceivable failure, from catastrophic failures to benign collateral failures. Identification and discussion of perceived benign failures may lead to the identification of more serious potential failures.*

The ISV method used for the first ISV is often different than the ISV method used for the second ISV. Typical ISV methods are described in Appendix I.

Risk Reduction Plan. The purpose of a risk reduction plan is to reduce or eliminate significant risks. The plan should describe prevention and mitigation measures for the significant safety vulnerabilities previously identified. The development of prevention and mitigation measures is usually done in conjunction with the ISV, which assesses the scenarios and identified hazards. Risk binning is one available analysis tool used to classify vulnerabilities. Appendix II shows an example risk binning approach.

Codes and Standards. Recognition of the applicable codes, standards and regulations (e.g. NFPA 2) is essential for project safety and ensuring public confidence. Relevant governing codes, standards and regulations should be described in the plan. Standards for individual pieces of equipment or piping fittings need not be included. 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.

Procedures. All project phases should be addressed as applicable. The plan should list existing and planned design, installation, commissioning, operations, and maintenance procedures that describe the steps for the system, apparatus, equipment, etc. It should also reference specific safe work practices used to control hazards during operations such as lockout, confined space entry, opening equipment or piping, and control over entrance into a facility by maintenance, contractor, laboratory, or other support personnel. Appendix IV provides an example of a procedure list.

Background Information: Procedures should be developed for each activity with the active involvement of the project team members. These written procedures should provide clear instructions for conducting activities in a safe manner. The procedures should include:

- *Steps for each operating phase, such as startup, normal operation, normal shutdown, emergency shutdown*
- *Operating limits*
- *Safety considerations, such as precautions necessary to prevent exposure and measures to be taken if physical contact or airborne exposure occurs*
- *Safety systems and their functions*
- *Nonroutine work authorizations*
- *Maintenance activities*

Procedures should be updated promptly to reflect changes to chemicals and other materials, equipment, technologies and facilities.

Equipment and Mechanical Integrity. The plan should describe how the integrity of equipment, piping, tubing, and other devices associated with the hazardous material handling systems will be assured.

Background Information: Mechanical integrity generally involves:

- *Written procedures*
- *Proper design, testing, and commissioning*
- *Use of fail-safe features*
- *Validation of materials compatibility*
- *Preventative maintenance plan*
- *Calibration of safety related devices – The frequency should be consistent with applicable manufacturers' recommendations, adjusted as indicated by operating experience*
- *Testing and inspection – The types and frequency of inspections and tests should be consistent with applicable manufacturers' recommendations, adjusted as indicated by operating experience*
- *Training for maintenance, calibration, testing, and inspection personnel*
- *Documentation – Each calibration, inspection, and test should be recorded. Typical records include date, name of the person, identifier of the device, description of what was done, and results. Any deficiencies outside acceptable limits should be highlighted*
- *Correcting deficiencies that are outside acceptable limits*

Management of Change (MOC) Procedures. MOC reviews are conducted to ensure that a change does not create any unintended detrimental consequences. The plan should describe the procedure that will be followed to review proposed changes to 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 replaced "in kind" should be reviewed. For example, if a regulator was replaced with a different model, or one that was constructed of a different material, the proposed change should be subjected to the MOC review process. Changes to procedures should also be MOC reviewed to avoid unanticipated safety concerns. This includes performing a MOC review for any change that may affect the original hazard assessment or system safeguards.

The MOC procedure should also identify the project team members that will approve changes.

> *Background Information*: [1] *For changes resulting in a change to the safety information such as to the ISV or an operating procedure, the applicable safety information should be updated accordingly. Personnel whose job tasks will be affected by the change must be informed of the change and retrained prior to resumption of work.*
>
> *Scale-up of a process, modification of equipment, and changes in materials are commonly encountered and should be considered as changes that may result in the need to update the safety plan. Change may also refer to new personnel involved in the work, necessitating training.*

Safety Reviews. The plan should describe safety reviews that will be conducted for the project during the design, development, and operational phases. The involvement and responsibilities of individual project staff in such reviews and how the reviews will be documented should be included. The safety reviews conducted for a project should generally include the following:

- **Early Project ISV.** The identification of safety vulnerabilities early in the project to identify major safety concerns that may affect cost and timing of the project.
- **Design Stage ISV.** The identification of safety vulnerabilities when the design is nearly complete to identify safety concerns related to the details of the project.
- **Pre-Startup Safety Review.** A review is held to make sure all the following have been completed:
    - Risk reduction plans have been implemented
    - Recommendations from incident investigation or compliance audits have been reviewed and addressed
    - System verification through examination, inspection and testing
    - Initial startup and normal operating procedures have been fully evaluated to assure a safe transfer into the operating mode
    - Safety and operational training
- Self-Audits**.** The plan should describe how the project team will verify that safety-related procedures and practices are being followed through the duration of the project and continued use of the equipment.

[1] *Management of Change*, U.S. Chemical Safety and Hazard Investigation Board, Safety Bulletin No. 2001-04- SB, August 2001.

Background Information: A compliance audit should be conducted by at least one person knowledgeable in the process who is external to the project. A report of the findings of the audit should be developed. The project team should promptly determine and document an appropriate response to each of the findings of the compliance audit with an appropriate action plan.

In addition to the Safety Plan Template, the Hydrogen Safety Panel has developed a Hydrogen Safety Checklist (Appendix III – Hydrogen Safety Checklist) to assist with safety self-audit and verification.

- **Other Safety Reviews.** Reviews that may be needed during the life of the project, including those required by organizational policies and procedures.

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

Background Information: Safety documentation includes:

- Information pertaining to the technology of the project
  - *A block flow diagram or simplified process flow diagram (see Appendix IV for an example)*
  - *Process chemistry*
  - *Maximum intended inventory of materials*
  - *Safe upper and lower limits for such items as temperatures, pressures, flows, and concentrations*
  - *An evaluation of the consequences of deviations, including those affecting the safety and health of personnel*
- *Information pertaining to the equipment or apparatus*
  - *Materials of construction*
  - *Electrical classification*
  - *Pressure relief system design and design basis*
  - *Ventilation system design*
  - *Design codes and standards employed*
  - *Alternatives to the use of listed equipment*
  - *Material and energy balances*
- *Safety systems (e.g. alarms, interlocks, detection or suppression systems)*
- *Safety review documentation, including the ISV*
- *Operating procedures (including response to deviation during operation)*
- *Material Safety Data Sheets*
- *References such as handbooks and standards*
- *Siting issues (alternatives to required setbacks)*
- *Safety documentation should be updated regularly to reflect changes to chemicals/other materials and their quantities, equipment, technologies, and facilities*

Communications Plan

The plan should describe how project safety information is communicated and made available to all relevant participants, including project team members and external partners.

Training. The plan should describe formal programs and planned hazard-specific training related to the various hazards associated with the project. It should describe how the organization stewards training participation and verifies understanding.

Background Information: It is crucial to provide hydrogen and other safety training for all project personnel responsible for handling equipment and systems containing hazardous materials. The training program should include:

- *Initial training that includes an overview of the process, a thorough understanding of the operating procedures, an emphasis on the specific safety and health hazards, emergency operations including shutdown, and safe work practices applicable to the personnel's job tasks*
- *Refresher training that is provided to all personnel involved in operating a process to assure that the personnel understand and adhere to the current standard operating procedures*
- *Training documentation that shows all personnel involved in operating a process has received and understood the training*
- *For people maintaining process equipment, performing calibrations, etc., training needs to ensure that the personnel can perform the job tasks in a safe manner*

Safety Events and Lessons Learned. The plan should describe how safety events (incidents and near-misses) will be handled by the team. The description should include:

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

By learning about the likelihood, severity, causal factors, setting, and relevant circumstances regarding safety events, teams are better equipped to prevent similar, perhaps more serious, events in the future. To be effective, this process requires a thorough investigation, a comprehensive report, and a great deal of information sharing as openly and thoroughly as possible.

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
- 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. Examples include:

- Any unintentional hydrogen release that ignites, or is sufficient to sustain a flame if ignited, and does not fit the definition for an incident
- Any hydrogen release that accumulates above 25% of the lower flammability limits within an enclosed space and does not fit the definition of an incident

Background Information: The investigation of an incident should be initiated as promptly as possible. An event investigation team should consist of at least one member who is independent from the project team, at least one person knowledgeable in the process *chemistry and actual operation of the equipment and process, and other persons with the right knowledge and experience to thoroughly investigate and analyze the incident. The event report should include:*

- *Date of incident*
- *Date investigation began*
- *A description of the incident*
- *The factors that contributed to the incident*
- *Lessons learned from the incident*
- *Any recommendations resulting from the investigation*

The team should promptly address and resolve the incident report findings and recommendations. Resolutions and corrective actions should be documented. The report should be reviewed with all affected personnel whose job tasks are relevant to the incident findings.

Hydrogen Lessons Learned from Incidents and Near-Misses *(https://h2tools.org/lessons) is a database that provides a voluntary mechanism for anyone to report an incident or near-miss and to benefit from the lessons learned from other reported incidents. All identifying information, including names of individuals, companies, organizations, vendors of equipment, and locations are removed to ensure confidentiality and to encourage the unconstrained future reporting of events as they occur.*

Emergency Response. The plan should describe the emergency response procedures that are in place. [Note: The National Hydrogen and Fuel Cell Emergency Response Training Resource (https://h2tools.org/fr/nt) serves as a guide and resource for the delivery of a variety of training regimens to various audiences and is available for the project team's use.]

Background Information: Emergency response procedures describe what actions participants are to take when there is an unwanted release including:

- *Evacuation to safe locations*
- *Specific participant action to take to control or stop a minor emergency*
- *Communication and interaction with neighboring occupancies*
- *Communication and interaction with local emergency response officials*

D. Documentation

To give a reviewer the best opportunity to judge the quality of the safety plan, the submittal should include, but not be limited to, the following additional documentation, as applicable:

<table>
<tr><th>Minimum Required</th><th>Desired if Available</th></tr>
<tr><td>Flow diagram showing equipment</td><td>Flow diagram showing components including equipment, and safety related devices such as block valves, instruments and relief devices. See Appendix IV for an example.</td></tr>
<tr><td>Preliminary functional description for equipment shown in the flow diagram</td><td>Design or functional description for each component in the diagram</td></tr>
<tr><td>Preliminary layout</td><td>Layout of the system including as applicable:
a) Site plan showing distances to property lines and other separation distances
b) Vehicle access to/from the equipment (including delivery vehicle)
c) Hydrogen vent system considerations, including the number of vent stacks, and pressure/flow design of each stack
d) Electrical classification and ignition source control
e) Ventilation requirements for any enclosed spaces</td></tr>
<tr><td colspan="2">Critical safety and shutdown table identifying shutdown events described in the ISV or risk reduction plan, including automatic and manual shutdowns, loss of electricity, and fail-safe features – see Appendix IV for an example.</td></tr>
</table>

The Hydrogen Equipment Certification Guide (https://h2tools.org/hsp/certification-guide) provides a good overview of the certification process for the listing of hydrogen components (see Chapter 2). Additional information for the use of good engineering judgement to support permitting agency approval of unlisted components can be found in Chapter 4 of the Guide.

E. Hydrogen Safety Panel

The HSP (https://h2tools.org/hsp) was established by the U.S. Department of Energy in 2003 and represents a broad cross-section of hydrogen-related sectors and technical areas of expertise. The HSP includes committee members from NFPA 2 – Hydrogen Technologies Code, NFPA 55 – Compressed Gases and Cryogenic Fluids Code, and technical committees of ASME, CSA, ISO, SAE and UL. The Hydrogen Safety Panel was created to address concerns about hydrogen as a safe and sustainable energy carrier. The Panel's principal objective is to promote the safe operation, handling, and use of hydrogen and hydrogen systems across all installations and applications. The HSP contributes to this objective by:

- Participating in safety reviews
- Providing safety planning guidance
- Reviewing project designs and safety plans
- Sharing safety knowledge and best practices
- Presenting and recognizing safety as a priority
- Participating in incident investigations.

The Panel's approach is to focus on **engagement**, **learning**, and **discussion** rather than on audit or regulatory exercises, and to build on, rather than duplicate, the efforts of others such as the good work being done by codes and standards development organizations.

The Panel can assist project teams in developing safe approaches to design, operation, and maintenance of facilities that handle hydrogen. The effort is often most efficient and effective when the Panel is engaged early in the project. Pre-project reviews have the advantage of helping the project team ensure their designs are technologically sound and implement safety more efficiently. Early design reviews provide more detail to consider, and opportunities to make improvements before resources are spent on hardware for the installation. It may also be beneficial to re-engage with the Panel at later stages of the project to discuss significant changes in the risks or safety features as a result of changes from early design.

Appendix I – Acceptable ISV Methods

Background Information: Identification of safety vulnerabilities (ISV) can be done using any of several established industry methods. The ISV helps the team identify potential safety issues, discover ways to lower the probability of an occurrence, and minimize the associated consequences.

The ISV should address:

- The potential hazards of the operation
- Previous incidents and near misses
- Engineering and administrative controls applicable to the hazards and their interrelationships, e.g., the use of hydrogen detectors and emergency shutdown capability
- Mechanisms and consequences of failure of engineering and administrative controls
- A qualitative evaluation of a range of the possible safety and health effects resulting from failure of controls
- Facility location

The ISV should be performed by a team with sufficient expertise in all aspects of the work to be performed. At least one team member should have experience and knowledge specific to the set of processes, equipment, and facilities being evaluated. Also, one member of the team needs to be knowledgeable in the specific ISV method being used.

Method	Description	References
FMEA Failure Modes and Effects Analysis	The FMEA process has these elements ○ Identify top level hazards and events ○ Identify related equipment, components, and processes ○ Identify potential failure modes and effects ○ Identify designs that provide inherent safety ○ Identify potential prevention and mitigation corrective action	○ https://en.wikipedia.org/wiki/Failure_mode_and_effects_analysis ○ Government documents, including MIL-STD-882C and MILSTD-1629A ○ NASA Scientific and Technical Information http://www.sti.nasa.gov/ ○ 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.
"What If" Analysis	A speculative process where questions of the form "What if … (hardware, software, instrumentation, or operators) (fail, breach, break, lose functionality, reverse, etc.)..?" are formulated and reviewed.	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	Method 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 for 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.

Method	Description	References
Fault Tree Analysis	Fault Tree Analysis is a deductive (top-down) method used for identification and analysis of conditions and factors that can result in the occurrence of 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	This method is 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	A Probabilistic Risk Assessment (PRA) is an organized process for answering the following three questions: 1. What can go wrong? 2. How likely is it to happen? 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 II – Risk Binning Matrix[2]

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. 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

[2] *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 ≤ 10^{-2}/yr
EU	Extremely Unlikely	10^{-6}/yr < f ≤ 10^{-4}/yr
BEU	Beyond Extremely Unlikely	≤ 10^{-6}/yr

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

Appendix III – Hydrogen 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 III-1 illustrates the system considered by the Panel in developing the checklist. The general principles in the checklist can be applied to all types and sizes of hydrogen systems.

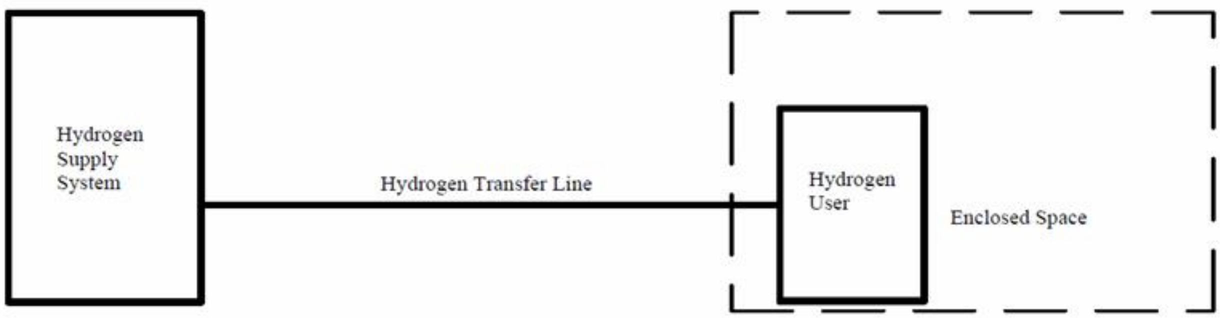


Figure III-1. *Outdoor Hydrogen Supply System for Indoor Use*

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 Tools Portal: https://h2tools.org**
- **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**

	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), valve 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 limit the 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 by 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 System	**Design systems to withstand worst-case conditions**	☐ Determine maximum allowable 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 withstanding the 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
	Protect systems	☐ Design systems to safely contain maximum allowable 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

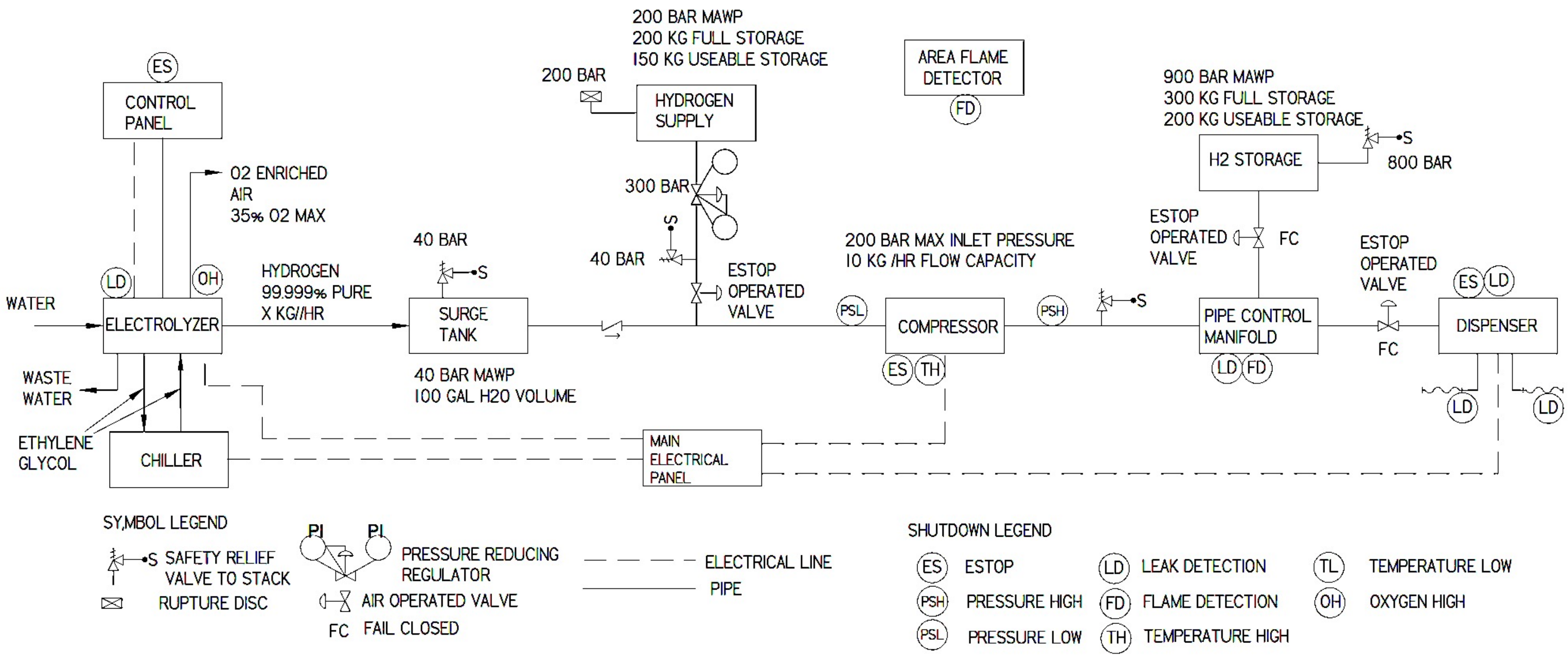
	Approach	Examples of Actions
	Provide hydrogen shutoff(s) for isolation	☐ Locate automatic fail-closed shutoff valves at critical points in the system (such as storage exit, entry to buildings, inlets to test cells, etc.) to put the system in a safe state when a failure occurs ☐ Consider redundant or 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 through a vent stack or into a laboratory ventilation system that assures proper dilution ☐ Direct discharges away from personnel and other hazards ☐ Secure/restrain discharge piping
Manage Discharges	**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
Manage Discharges	**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
	Approach	**Examples of Actions**
Detect and Mitigate	**Leak detection and mitigation**	☐ Provide detection and automatic shutdown/isolation if flammable mixtures are present, particularly in enclosed spaces ☐ Consider methods for manual or automatic in-process leak detection such as the ability for isolated systems to hold pressure ☐ Periodically check for leaks in the operating system
Detect and Mitigate	**Loss of forced ventilation indoors**	☐ Automatically shut off the supply of hydrogen when ventilation is not working
Detect and Mitigate	**Monitor the process and protect against faults**	☐ Provide alarms for actions required by people, e.g., evacuation ☐ Provide the capability to automatically detect and mitigate safety-critical situations ☐ Consider redundancy to detect and mitigate sensor or process control faults ☐ Provide the ability for the system to advance to a "safe state" if power failures or controller faults are experienced
Detect and Mitigate	**Fire detection and mitigation**	☐ Appropriate fire protection (extinguishers, sprinklers, etc.) ☐ Listed hydrogen specific flame detection ☐ Automatic shutdown and isolation if fire is detected
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 for maintenance such as lock-out/tag-out, hot work permits, and hydrogen line purging ☐ Review and approval of design and procedural changes

	Approach	Examples of Actions
	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

This checklist can be downloaded at https://h2tools.org/sites/default/files/HydrogenSafetyChecklist.pdf.

Appendix IV – Examples of Information for Selected Sections of the Safety Plan

Example Flow Diagram with Critical Shutdown Functions (H_2 Fueling Station Shown)



Example of a 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

Example Table of Procedures and Their Applicable Project Phases

Procedure	Design	Installation and 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 assist 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 17-member panel has over 500 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 325 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 at 509-371-7894 or by email at **hsp@h2tools.org**.

HYDROGEN
Safety Panel