



HYDROGEN  
**Safety Panel**

# **Safety Planning for Hydrogen and Fuel Cell Projects**

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# Safety Planning for Hydrogen and Fuel Cell Projects

## A. Introduction

This document was developed by the Hydrogen Safety Panel (HSP), an organization that 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 document provides information on safety planning for hydrogen and fuel cell projects. Section C identifies the necessary content and information needed for the safety plan and additional supporting documents are identified in Section D.

The project safety planning process is meant to help identify risks and avoid potential hydrogen-related incidents. Safe practices in the production, storage, distribution, and use of hydrogen are essential for the widespread acceptance of hydrogen and fuel cell technologies. A catastrophic failure in any project could damage the public's perception of hydrogen and fuel cells. This document aims to assist in generating a quality safety plan that will serve as a guide for the safe conduct of all work related to the development and operation of hydrogen and fuel cell equipment. A safety plan should be revisited periodically as part of an overall effort to give continuous and priority attention to the associated safety aspects.

Potential hazards, failure mechanisms, and related incidents associated with any work process or system should always be identified, analyzed, and eliminated or mitigated as part of sound safety planning. 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.

## B. Principles for Safety Planning

Best safety practices, incorporating a wealth of experience with new knowledge and insights gained, is an important aspect of continuous and priority attention given to safety planning. A thorough and integrated approach to project safety planning needs to involve all parties. For example, in the case of a system installation, the parties would include hydrogen/fuel cell/equipment suppliers, facility operators, and maintenance/repair providers.

As hydrogen and fuel cell technologies gain a greater commercial foothold, safe practices in the production, storage, distribution, and use of hydrogen are essential for widespread public acceptance. The following critical elements help ensure that safety is integrated into projects and system demonstrations.

## Early Identification 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,
- inspecting the installation,
- investigating and lessons learned reporting for incidents and near-misses, and
- work on 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, including 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 and alternatives are proposed, a sound technical basis 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 could occur as a result of unique zoning and planning ordinances.

## A Knowledgeable Emergency Response Team

A suitably trained emergency response force is an 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

A safety plan addresses potential threats and impacts to people, equipment, and the environment. 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, and operation. It is important to note that appropriate hazard and change communication should be described in the safety plan. As is often the case, work to develop a comprehensive safety plan may be conducted by multiple organization teams, coordinated by team leaders so as to integrate the approaches for assessing all safety vulnerabilities.

A safety plan should be prepared using a graded approach based on level of risk and complexity. 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. However, there may be times when a preliminary safety plan is developed as part of a predesign bid package. In this case elements such as risk analysis and mitigative features should be covered more generally with a focus on what risk analysis activities will be completed during the design phase after project award. 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
<b>Description of Work</b>	<ul style="list-style-type: none"> <li>Nature of the work being performed</li> </ul>
<b>Organizational Policies and Procedures</b>	<ul style="list-style-type: none"> <li>Application of safety-related policies and procedures to the work being performed</li> </ul>
<b>Hydrogen and Fuel Cell Experience</b>	<ul style="list-style-type: none"> <li>How previous organizational experience with hydrogen, fuel cell and related work is applied to this project</li> </ul>
<b>Safety Reviews</b>	<ul style="list-style-type: none"> <li>Applicable safety reviews beyond the ISV described below</li> </ul>
<b>Identification of Safety Vulnerabilities (ISV)</b>	<ul style="list-style-type: none"> <li>What is the ISV methodology applied to this project, such as FMEA, What If, HAZOP, Checklist, Fault Tree, Event Tree, Probabilistic Risk Assessment, or other method</li> <li>Who leads and stewards the use of the ISV methodology</li> <li>Significant accident scenarios identified</li> <li>Significant vulnerabilities identified</li> <li>Safety critical equipment</li> <li>Storage and handling of hazardous materials and related topics <ul style="list-style-type: none"> <li>ignition sources, explosion hazards</li> <li>materials interactions</li> <li>possible leakage and accumulation</li> <li>detection</li> </ul> </li> <li>Hydrogen handling systems <ul style="list-style-type: none"> <li>supply, storage, and distribution systems</li> <li>volumes, pressures, estimated use rates</li> </ul> </li> <li>Additional Documentation provided (see section below)</li> </ul>
<b>Risk Reduction Plan</b>	<ul style="list-style-type: none"> <li>Prevention and mitigation measures for significant vulnerabilities</li> </ul>
<b>Procedures</b>	<ul style="list-style-type: none"> <li>Procedures applicable for the location and performance of the work including sample handling and transport</li> <li>Operating steps that need to be written for the particular project: critical variables, their acceptable ranges, and responses to deviations from them</li> </ul>

Element	The Safety Plan Should Describe
<b>Equipment and Mechanical Integrity</b>	<ul style="list-style-type: none"> <li>• Initial testing and commissioning</li> <li>• Preventative maintenance plan</li> <li>• Calibration of sensors</li> <li>• Test/inspection frequency basis</li> <li>• Documentation</li> </ul>
<b>Management of Change Procedures</b>	<ul style="list-style-type: none"> <li>• 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</li> </ul>
<b>Project Safety Documentation</b>	<ul style="list-style-type: none"> <li>• How needed safety information is communicated and made available to all participants, including partners. Safety information includes the ISV documentation, procedures, references such as handbooks and standards, and safety review reports.</li> </ul>
<b>Personnel Training</b>	<ul style="list-style-type: none"> <li>• Required general safety training - initial and refresher</li> <li>• Hydrogen-specific and hazardous material training - initial and refresher</li> <li>• How the organization stewards training participation and verifies understanding</li> </ul>
<b>Safety Events and Lessons Learned</b>	<ul style="list-style-type: none"> <li>• The reporting procedure within the team</li> <li>• The system and/or procedure used to investigate events</li> <li>• How corrective measures will be implemented</li> <li>• How lessons learned from incidents and near-misses are documented and disseminated</li> </ul>
<b>Emergency Response</b>	<ul style="list-style-type: none"> <li>• The plan/procedures for responses to emergencies</li> <li>• Plans for communication and interaction with local emergency response officials</li> </ul>
<b>Self-Audits</b>	<ul style="list-style-type: none"> <li>• How the team will verify that safety related procedures and practices are being followed throughout the life of the project</li> </ul>
<b>Safety Plan Approval</b>	<ul style="list-style-type: none"> <li>• Safety plan review and approval process</li> </ul>
<b>Additional Documentation</b>	<ul style="list-style-type: none"> <li>• Layout of the system at the planned location</li> <li>• Flow diagram (see Appendix IV for an example)</li> <li>• Codes and standards discussion</li> <li>• Equipment component descriptions</li> <li>• Critical safety and shutdown table (see Appendix IV for an example)</li> </ul>
<b>Other Comments or Concerns</b>	<ul style="list-style-type: none"> <li>• Any information on topics not covered above</li> </ul>

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<sub>2</sub> 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. All intended project phases should be described. In describing the work, it is valuable to quantify the amount of hazardous materials generated, used, and stored. 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. Any relevant permits that apply to current and planned operations should be listed.

*The description of work for a hydrogen fueling station 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 are implemented for the work being performed. Project team member involvement is important in the development and implementation of comprehensive project safety plans.

**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

**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. In most cases, the safety reviews conducted for a project should 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 to make sure all of the risk reduction plans have been implemented and that all of the appropriate examination, inspection, and testing has been completed.
- **Other Safety Reviews.** Reviews that may be needed during the life of the project, including those required by organizational policies and procedures.

**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

**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:

- What risk associated with this system design, installation, and operation is most likely to result in an incident/accident?
- What hazard associated with this system design, installation, and operation 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, as shown in Appendix II.

**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 process or laboratory-scale 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*

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

**Sample Handling and Transport.** The plan should discuss any anticipated transport products and materials and identify the relevant policies and procedures that are in place to ensure their proper handling.

**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.** The plan should describe the method that will be used to review proposed changes to materials, technology, equipment, procedures, personnel, and facility operation for their effect on safety vulnerabilities. The MOC procedure should identify the appropriate project team members that must approve changes. All materials or equipment that is 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, that would require a documented management of change. Changes to operating procedures would also be handled as an MOC to help avoid unanticipated safety concerns. In particular, an MOC review is required for any change that affects the original hazard assessment or system safeguards.

*Background Information:*<sup>1</sup> *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 the 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.*

**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 team members.

*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*

<sup>1</sup> *Management of Change*, U.S. Chemical Safety and Hazard Investigation Board, Safety Bulletin No. 2001-04- SB, August 2001.

- *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**

*(<http://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, including communication and interaction with neighboring occupancies and local emergency response officials. [Note: The National Hydrogen and Fuel Cell Emergency Response Training Resource (<http://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.]

**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.

*Background Information: Verification is usually accomplished via a compliance audit that is 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.

## D. Additional 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:

Minimum Required	Desired if Available
Flow diagram showing equipment	Flow diagram showing components including equipment, and safety related devices such as block valves, instruments and relief devices. See Appendix IV for an example.
Preliminary functional description for equipment shown in the flow diagram	Design or functional description for each component in the diagram
Codes and standards compliance discussion, including information on alternative means and methods used to meet requirements	
Preliminary layout	Layout of the system including as applicable: <ul style="list-style-type: none"> <li>a) Site plan showing distances to property lines and other separation distances</li> <li>b) Vehicle access to/from the equipment (including delivery vehicle)</li> <li>c) Hydrogen vent system considerations, including the number of vent stacks, and pressure/flow design of each stack</li> <li>d) Electrical classification and ignition source control</li> <li>e) Ventilation requirements for any enclosed spaces</li> </ul>
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.	

*The Hydrogen Equipment Certification Guide (<https://h2tools.org/certification-guide/overview>) 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 (<http://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
<b>FMEA</b> Failure Modes and Effects Analysis	The FMEA process has these elements <ul style="list-style-type: none"> <li>○ Identify top level hazards and events</li> <li>○ Identify related equipment, components, and processes</li> <li>○ Identify potential failure modes and effects</li> <li>○ Identify designs that provide inherent safety</li> <li>○ Identify potential prevention and mitigation corrective action</li> </ul>	<ul style="list-style-type: none"> <li>○ <a href="https://en.wikipedia.org/wiki/Failure_mode_and_effects_analysis">https://en.wikipedia.org/wiki/Failure_mode_and_effects_analysis</a></li> <li>○ Government documents, including MIL-STD-882C and MILSTD-1629A</li> <li>○ NASA Scientific and Technical Information <a href="http://www.sti.nasa.gov/">http://www.sti.nasa.gov/</a></li> <li>○ A discussion and worked example can be found in <i>Guidelines for Hazard Evaluation Procedures, Second Edition with Worked Examples</i>, Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992.</li> </ul>
<b>“What If” Analysis</b>	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 <i>Guidelines for Hazard Evaluation Procedures, Second Edition with Worked Examples</i> , Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992.
<b>HAZOP</b> 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 <i>Guidelines for Hazard Evaluation Procedures, Second Edition with Worked Examples</i> , Center for Chemical Process Safety, American Institute of Chemical Engineers, 1992.
<b>Checklist Analysis</b>	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 <i>Guidelines for Hazard Evaluation Procedures</i> , 3rd Edition, Center for Chemical Process Safety, American Institute of Chemical Engineers, 2008. Risk-based decision-making guidelines, United States Coast Guard ( <a href="https://www.uscg.mil/hq/cg5/cg5211/risk.asp">https://www.uscg.mil/hq/cg5/cg5211/risk.asp</a> )



Method	Description	References
<b><u>Fault Tree Analysis</u></b>	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 <i>Guidelines for Hazard Evaluation Procedures</i> , 3rd Edition, Center for Chemical Process Safety, American Institute of Chemical Engineers, 2008.
<b><u>Event Tree Analysis</u></b>	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 <i>Guidelines for Hazard Evaluation Procedures</i> , 3rd Edition, Center for Chemical Process Safety, American Institute of Chemical Engineers, 2008.
<b><u>Probabilistic Risk Assessment</u></b>	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 <i>Guidelines for Chemical Process Quantitative Risk Analysis</i> , Center for Chemical Process Safety, American Institute of Chemical Engineers, 1999.
<b><u>Others</u></b>	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 <i>Guidelines for Hazard Evaluation Procedures</i> , 3rd Edition, Center for Chemical Process Safety, American Institute of Chemical Engineers, 2008.

## Appendix II – Risk Binning Matrix<sup>2</sup>

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	10	7	4	1
	Moderate		8	5	2
	Low		9	6	3
	Negligible	12	11		



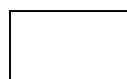
Higher risk



Lower risk



Moderate risk



Negligible risk

<sup>2</sup> 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.)

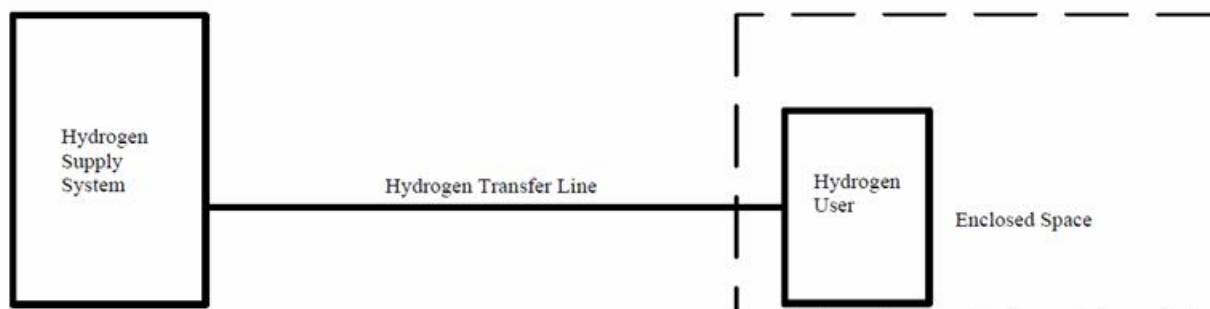
### Frequency criteria used for risk-binning

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

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	$\$100,000 < \text{damage} \leq \$50$ million Equipment destroyed Critical equipment damaged Production loss less than 1 week
Low (L)	Minor injuries No hospitalization	Damage $\leq \$100,000$ 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	<input type="checkbox"/> Identify risks such as flammability, toxicity, asphyxiates, reactive materials, etc. <input type="checkbox"/> Identify potential hazards from adjacent facilities and nearby activities <input type="checkbox"/> 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 <input type="checkbox"/> 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 <input type="checkbox"/> Consider excess flow valves/chokes to limit the size of hydrogen leaks <input type="checkbox"/> Define countermeasures to protect people and property <input type="checkbox"/> Follow applicable codes and standards
	Isolate hazards	<input type="checkbox"/> Store hydrogen outdoors as the preferred approach; store only small quantities indoors in well ventilated areas <input type="checkbox"/> Provide horizontal separation to prevent spreading hazards to/from other systems (especially safety systems that may be disabled), structures, and combustible materials <input type="checkbox"/> Avoid hazards caused by overhead trees, piping, power and control wiring, etc.
	Provide adequate access and lighting	Provide adequate access for activities including: <input type="checkbox"/> Operation, including deliveries <input type="checkbox"/> Maintenance <input type="checkbox"/> Emergency exit and response
	Approach	Examples of Actions
Keep the Hydrogen in the System	Design systems to withstand worst-case conditions	<input type="checkbox"/> Determine maximum allowable pressure considering abnormal operation, mistakes made by operators, etc., then design the system to contain or relieve the pressure <input type="checkbox"/> Contain: Design or select equipment, piping, and instrumentation that are capable of withstanding the maximum credible pressure using materials compatible with hydrogen service <input type="checkbox"/> Relieve: Provide relief devices that safely vent the hydrogen to prevent damaging overpressure conditions <input type="checkbox"/> Perform system pressure tests to verify integrity after initial construction, after maintenance, after bottle replacements, and before deliveries through transfer connections
	Protect systems	<input type="checkbox"/> Design systems to safely contain maximum allowable pressure or provide pressure relief devices to protect against burst <input type="checkbox"/> Mount vessels and bottled gas cylinders securely <input type="checkbox"/> Consider that systems must operate and be maintained in severe weather and may experience earthquakes and flood water exposures <input type="checkbox"/> De-mobilize vehicles and carts before delivery transfers or operation <input type="checkbox"/> Protect against vehicle or accidental impact and vandalism <input type="checkbox"/> Post warning signs
	Size the storage appropriately for the service	<input type="checkbox"/> Avoid excess number of deliveries/change-outs if too small <input type="checkbox"/> Avoid unnecessary risk of a large release from an oversized system

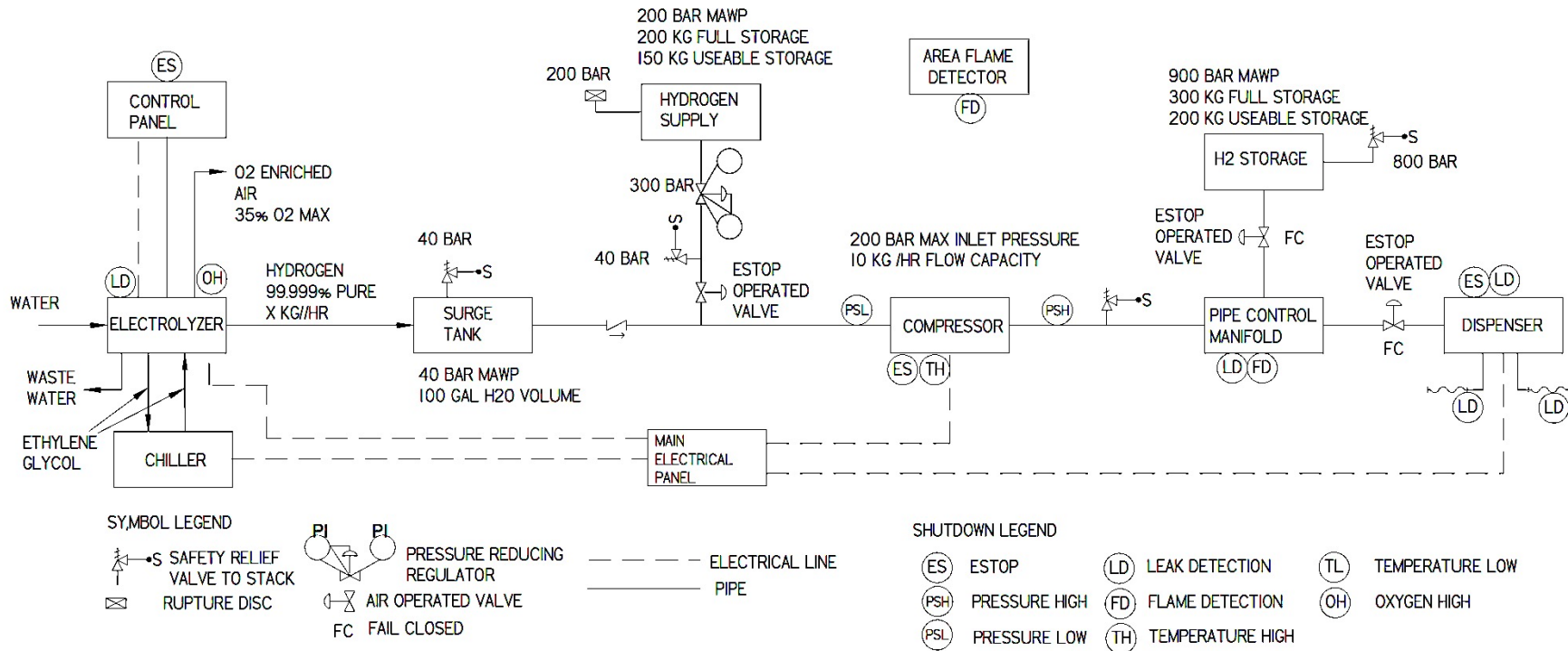
	Approach	Examples of Actions
	<b>Provide hydrogen shutoff(s) for isolation</b>	<input type="checkbox"/> Locate automatic fail-closed shutoff valves at critical points in the system (such as storage exit, entry to buildings, inlets to test cells, etc.) to put the system in a safe state when a failure occurs <input type="checkbox"/> Consider redundant or backup controls <input type="checkbox"/> Install manual valves for maintenance and emergencies
	<b>Prevent cross-contamination</b>	<input type="checkbox"/> Prevent back-flow to other gas systems with check valves, pressure differential, etc.
	Approach	Examples of Actions
<b>Manage Discharges</b>	<b>Safely discharge all process exhausts, relief valves, purges, and vents</b>	<input type="checkbox"/> Discharge hydrogen outdoors or into a laboratory ventilation system that assures proper dilution <input type="checkbox"/> Direct discharges away from personnel and other hazards <input type="checkbox"/> Secure/restrain discharge piping
	<b>Prevent build-up of combustible mixtures in enclosed spaces</b>	<input type="checkbox"/> 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 <input type="checkbox"/> Provide sufficient ventilation and/or space for dilution <input type="checkbox"/> Avoid build-up of hydrogen under ceilings/roofs and other partly enclosed spaces
	<b>Remove potential ignition sources from flammable spaces/zones</b>	<input type="checkbox"/> Proper bonding and grounding of equipment <input type="checkbox"/> No open flames <input type="checkbox"/> No arcing/sparking devices, e.g., properly classified electrical equipment
	Approach	Examples of Actions
<b>Detect and Mitigate</b>	<b>Leak detection and mitigation</b>	<input type="checkbox"/> Provide detection and automatic shutdown/isolation if flammable mixtures are present, particularly in enclosed spaces <input type="checkbox"/> Consider methods for manual or automatic in-process leak detection such as the ability for isolated systems to hold pressure <input type="checkbox"/> Periodically check for leaks in the operating system
	<b>Loss of forced ventilation indoors</b>	<input type="checkbox"/> Automatically shut off the supply of hydrogen when ventilation is not working
	<b>Monitor the process and protect against faults</b>	<input type="checkbox"/> Provide alarms for actions required by people, e.g., evacuation <input type="checkbox"/> Provide the capability to automatically detect and mitigate safety-critical situations <input type="checkbox"/> Consider redundancy to detect and mitigate sensor or process control faults <input type="checkbox"/> Provide the ability for the system to advance to a “safe state” if power failures or controller faults are experienced
	<b>Fire detection and mitigation</b>	<input type="checkbox"/> Appropriate fire protection (extinguishers, sprinklers, etc.) <input type="checkbox"/> Listed hydrogen specific flame detection <input type="checkbox"/> Automatic shutdown and isolation if fire is detected
<b>Manage Operations</b>	<b>Establish and document procedures</b>	<input type="checkbox"/> Responsibilities for each of the parties involved <input type="checkbox"/> Operating procedures <input type="checkbox"/> Emergency procedures <input type="checkbox"/> Preventive maintenance schedules for equipment services, sensor calibrations, leak checks, etc. <input type="checkbox"/> Safe work practices such as lock-out/tag-out, hot work permits, and hydrogen line purging <input type="checkbox"/> Review and approval of design and procedural changes

	Approach	Examples of Actions
	<b>Train personnel</b>	<input type="checkbox"/> MSDS awareness for hydrogen and other hazardous materials <input type="checkbox"/> Applicable procedures and work instructions for bottle change-out, deliveries, operation, maintenance, emergencies, and safety work practices
	<b>Monitor</b>	<input type="checkbox"/> Track incidents and near-misses, and establish corrective actions <input type="checkbox"/> 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<sub>2</sub> Fueling Station Shown)





Example of a Critical Safety Shutdown Table

Equipment/Alarms		Instrument Air Dispenser	Compressor Control Panel	Compressor Diaphragm H2 Storage	Hydrogen System Entry way 25 ft away from H2 System	Hydrogen Fill	Equipment Enclosure 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**

	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	•	•		•
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 Procedure		•		•

The **Hydrogen Safety Panel** 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](mailto:hsp@h2tools.org).



HYDROGEN  
**Safety Panel**