HYDROGEN
Safety Panel

Example Safety Plan for Hydrogen and Fuel Cell Projects

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ATTACHMENTS

A. Purpose

This document provides an example safety plan in Attachment A associated with hydrogen and fuel cells, where there is a significant flammability or explosive hazard from quantities, pressures, exposures, or other conditions. Hydrogen is unique among flammable gases in that small quantities may result in ignition or explosions. This example safety plan was developed by Pacific Northwest National Laboratories (PNNL) and its Hydrogen Safety Panel (HSP) members to assist entities working with hydrogen to ensure the protection of life, property, and the environment. It will also aid in understanding the expected planning that the U.S. Department of Energy (DOE) considers for proper hazard management of its funded hydrogen and fuel cell projects. Safer research, design, and operation will contribute to the continuing future of the hydrogen and fuel cell industries. While the example safety plan focuses upon hydrogen, the principles contained herein will advance the safety of any operation involving flammable gas hazards.

B. Application and Target Audience

This example safety plan is applicable to the design, construction, and operation of bulk hydrogen storage, hydrogen distribution systems, hydrogen fuel cell equipment, or any other hydrogen-related activity or research that could potentially result in a significant flammable gas incident. The target audience includes organizations (i.e., public, private, nonprofit), individuals (e.g., principle investigators, project leaders, technical contributors), and multi-party partnerships, who propose, develop, test, evaluate prototypes, deploy, operate, and decommission hydrogen and fuel cell systems.

C. Basis

This example safety plan implements the basic requirements from the PNNL document *Safety Planning for Hydrogen and Fuel Cell Projects* (PNNL-25279-3), prepared for the DOE. Entities are encouraged to amplify and provide additional information for their specific application to improve safety planning.

The information in the example safety plan is patterned from multiple plans reviewed by the HSP that were concluded to be high quality. While the sections are based on several real-world plans, all mention of company-specific information has been removed to protect companies' anonymity; any similarity to companies, schools, locations, and work in progress or development is strictly coincidental. Because the input may be from varying technologies and projects, the wording in each section may not correspond exactly to other sections. By following the general concepts in each section, entities can adapt the example for their specific project safety plan.

D. Format

The example safety plan includes scope by two entities partnering on a hydrogen project: basic research by a university laboratory; and development of a subsequent prototype by an experienced equipment firm. The example safety plan only provides data from both partners in three key sections of the document: Description of Work, Identification of Safety Vulnerabilities (ISV), and Risk Planning. This maintains document brevity while providing a project leader a perspective on how to integrate multiple entities.

The layout of the example safety plan is a book/document format. Entities may organize their information similarly or in a table matching the template Annex "A" of PNNL-25279-3. An often overlooked page is the cover. The example cover establishes the unique configuration management descriptors for the project, lists the project managers/investigators, and most importantly, identifies the approval authority.

Two features are used to assist the reader in the example plan. First some portion of the text in the example plan is grey-highlighted. This indicates key data that HSP reviewers are focused upon. Secondly, text boxes are added to clarify options or give perspectives from the many years of HSP reviews.

Example text box.

E. General Concepts

Table 1 identifies three major scope concepts seen in hydrogen safety plans with best practices. Key recommendations are bolded.

Table 1. General Considerations for Hydrogen Safety Plan Preparation

Scope	Direction
1. Project involves multiple partners	**Entities involving multiple business partners should prepare a single safety plan document covering all activities involving hydrogen hazards for the total project.** It may include different plans within a single document, or compiled information organized by template section. A single plan allows for a more thorough review. More importantly a single plan indicates a high-level of safety integration by the project leader; understanding the safety planning of all partners supports improvement of specific safety applications and individual entity safety cultures. Safety plan information for partners that do not involve hydrogen are not normally included. DOE national laboratories safety plans are often only referenced.
2. Project is in early phase	**A description of safety planning for all template sections, rather than solely a future commitment should be documented, regardless of the project phase or timing.** The project phase or timing of the safety plan may not allow the completion of some information, and future commitment as a description is acceptable if additional planning is described. Many hydrogen safety plans are prepared prior to completion of a formal hazard analysis. Two types of data are critical in allowing an adequate safety review in this circumstance: 1.) project planning information such as the proposed methodology, the reason for its usage, and schedule within the project, and 2.) a preliminary discussion of hazards that indicate a knowledgeable safety culture. The example safety plan has an ISV section that includes both a proposed review by the research university, with the added planning data described above, and a completed hazard analysis performed by the equipment firm.

Table 1. General Considerations for Hydrogen Safety Plan Preparation

Scope	Direction
3. Project repeats or continues past scope	**Text should focus on unique applications of safety planning relevant to the project, even if the entity has prepared prior safety plans.** It is acceptable to repeat information included in previous safety plan versions by the same entity. However, if a safety plan is simply a "cut and paste" from previous plans, without addressing review comments or unique project hazards, then it demonstrates a need for a significant improvement in the entity safety culture.

F. Hazard Analysis

The most critical sections of the safety plan is the ISV, describing the project hazard analysis, followed by preventive/mitigative measures in the Risk Planning section. Safety program management and risk planning are dependent upon a high-quality evaluation of the hydrogen hazards.

The highest standard for a quality safety plan ISV is that it includes the **results** of a formal Failure Mode and Effects Analysis (FMEA). The FMEA should be completed by a team of project experts, examining all key system nodes and operational/testing protocols, referenced to an attached diagram. There are other hazard analysis formats that may be used depending upon the scope of activities. Attachment B provides a table and references of the multiple methods for performing a hazard analysis, from PNNL-25279-3.

G. Acknowledgements

The HSP appreciates the quality of over 500 safety plans it has reviewed during its 17+ years of reviewing experience. It is honored to be involved with the multiple entities and their creativity and technological innovation.

Special acknowledgement is provided to the DOE Hydrogen and Fuel Cells Technology Office (Internet link here), whose leadership and guidance for the hydrogen safety program has been exemplary and responsible for its high quality.

H. References

PNNL-25279-3, *Safety Planning for Hydrogen and Fuel Cell Projects*, Revision 3, January 2020, Pacific Northwest National Laboratory, Richland, WA (Link to the document on the https://H2tools.org site, here)

Attachment A – Example Safety Plan

Evaluation of a Protonic Ceramic Unitized Electrolyzer for an Organic Catalyst Fuel Cell Stack

Document #: UEU-2020-417, Revision 0

Date: February 30, 2020

Project #: 973624-2

DOE Contract: DE-EE000000

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The (fictional) names here are used for reference and contact. The Approval line documents formal approval authority and status of document.

Approvals:

_______________________________________ _____________

Dr. I.M. Second, UEU EHS Department Head Date

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> *The entity should consider adding these type of editing tables if the plan is lengthy, complex (e.g., has multiple partner sections), or uses unique acronyms/units.*

Table of Acronyms and Units

cf	cubic feet
SLPM	standard liters per minute
psig	pounds per square inch gauge

1.0 General Project Scope

This revision 0 safety plan for the project, "Evaluation of Protonic Ceramic Unitized Electrolyzer for an Organic Catalyst Fuel Cell Stack" is submitted under DE-EE000000. The project comprises a partnership between University of Eastern Utopia (UEU) and Some Amazing Technologies, Inc. (SAT). The UEU will provide project management and technical leadership while completing experiments to obtain data for design of a protonic ceramic unitized electrolyzer and organic fuel cell catalysts, at its Utopia, MZ campus. The SAT firm will scale up the data to design, build, and test a prototype system; and develop a draft full-scale specification, at its headquarters and test facility in Other City, LZ.

> *While this section is not listed in the template many entities use it to provide a general project description. The critical information provided here is entity roles and project goal; which could alternatively be described below in the Description of Work.*

The overall goal of the project is to obtain test data for establishing a final design of a more efficient protonic ceramic unitized electrolyzer and fuel cell stack, as documented in laboratory and prototype test reports and final design specification. Design, fabrication, construction, and operation of a full-scale manufacturing plant will occur through a different project.

Laboratory testing is scheduled to begin September 2020, and prototype design effort in December 2020. Laboratory testing will involve small volume and flows of hydrogen and other gases, while prototype testing will utilize SAT's liquid hydrogen storage system and larger volume/flows of hydrogen gas.

This safety plan follows the outline of PNNL's safety plan template with UEU's and SAT's effort detailed specifically in each template section for their phase of the project.

2.0 Description of Work

2.1 UEU Research

This example plan only describes the two entities in a few sections for brevity: Description of Work, Identification of Safety Vulnerabilities, and Risk Planning.

Laboratory-scale effort will be conducted at UEU's Easton Hall research laboratory within a ventilated and third party inspected walk-in fume hood. The work will involve the consumption of hydrogen and oxygen gases, and venting of the same gases during purging. During fuel cell testing, up to 0.5 SLPM of hydrogen gas and up to 0.3 SLPM of oxygen gas at 15 psig will be allowed to flow through the fuel cell from commercial high-pressure cylinders. A maximum of two cylinders will be located in the standard chain-secured cylinder rack outside of the fume hood, within the laboratory; one each of hydrogen and oxygen. The hydrogen cylinder will contain about 200 cf of hydrogen gas at 2000 psig, equipped with a CGA350 two-stage pressure reducing regulator. Testing will occur during day shift on intermittent days during the first three weeks of September, by the principal investigator and two students. The system will be shut down, when testing for the day is completed, and purged from the primary cylinder connection with nitrogen from the university-supplied central system, utilizing manually connected nitrogen supply hoses and isolation valves. Refer to Appendix A for the test system laboratory diagram showing flow, exhaust, and control systems. Refer to Appendix B for a corresponding process parameter table summarizing process safety limits/shutdown values for temperature, flow, pressure, and power.

2.2 SAT Prototype Evaluation

Prototypic testing will construct a fuel cell stack in the primary testing warehouse at SAT headquarters, fed from SAT's proprietary liquid hydrogen system maintained outside of the warehouse. The fuel cell stack will be process up to a maximum 4 SLP of both hydrogen and oxygen gases, at pressures ranging from 20 psig to 45 psig. Oxygen will be supplied through a cylinder bank maintained at the north end of the warehouse, containing up to ten staged industrial pressurized oxygen cylinders from Gas Products Company. The fuel cell stack will be located in an isolated walled area of the warehouse, containing its own exhaust fan system, hydrogen gas sensors, and fire/smoke detection system. Automatic (fail to close) valves on both the hydrogen and oxygen gas supply into the warehouse are interlocked to close upon detection of 0.1% hydrogen in the warehouse airspace, from activation of the fire/smoke sensors, or shut down of the exhaust system. Oxygen and hydrogen piping enter the warehouse through the wall of the enclosed test area, and are not contained in any other portion of the warehouse. Testing will be conducted at all hours of the day over a 3-month period. Pipe purging from nitrogen cylinders will occur prior to testing, after completion of testing, and during any incidents or equipment failures. Refer to Appendix C for the prototype system process flow piping and fuel cell stack apparatus, warehouse area diagram including liquid hydrogen system, and safety controls. Refer to Appendix D for a corresponding process parameter table summarizing process safety limits/shutdown values for temperature, flow, pressure, and power.

This high level of detail best supports the application of safety described in the ISV or Risk Planning section.

3.0 Organization Policies and Procedures

The most relevant safety-related program policies and procedures are described in the UEU Laboratory Safety Manual, which are located at the University ES&H Foster Building and accessible at this *link*. New projects undergo a peer review process where potential hazards are recognized, and controls or plans are set in place to eliminate or mitigate the hazards. After peer review, the

Building Inspector and Fire Marshall's offices hold their own review. The project must pass review to begin. After approval, a certificate of use is issued from the Building Inspector's office.

Changes to the process or equipment require safety auditing and are logged in the laboratory logbook. Laboratory test personnel are retrained in the correct use and operating procedures. Safety incidents are reviewed by cognizant safety personnel and reported to project funding agents.

The project Principal Investigator (PI) reviews and approves the project safety plan.

4.0 Hydrogen and Fuel Cell Experience

The SAT has been designing, testing, and manufacturing fuel cell stacks for 10 years. The SAT project manager (PM) assigned to this project has been with the company since its founding, and has led the research and development organization for 7 years, with a total career experience of 30+ years in directly testing fuel cell and electrolyzer systems, from small, low-pressure cells (1 cm^2, ambient) to large, high-pressure stacks (1,100 cm^2, 4500 psi). This large experience with different sizes of fuel cell stacks will assist the development and conductance of the prototype system from research data, and ensure proper safety during scale-up.

The Project Manager (PM) is a Project Management Institute certified project manager, and holds multiple industrial and safety certifications. A resume is available upon request. The PM also makes sure that design, construction, and test personnel have the required safety training and experience to conduct the work.

5.0 Identification of Safety Vulnerabilities (ISV)

5.1 UEU Research

The UEU discussion is an example of a planned/future ISV.

The ISV will be completed prior to initiation of test activities. It will be performed with a team of laboratory personnel and members of the university Environmental Health and Safety (EHS) department. The PI will lead the development of this safety analysis, and a separate Job Safety Analysis (JSA), and ensuing Risk Assessment/Ranking/Plan. EHS expertise leads the project team through the processes of identifying, categorizing, and ranking hazards and developing mitigation solutions. All hazard analysis documentation will be approved by the PI, Project Lead, and EHS manager.

Tasks are broken down during the JSA into their key steps. Each step is evaluated, and equipment and materials needed are identified. Possible hazards associated with each step are then brainstormed followed by the identification of needed personnel protective equipment. The JSA will also identify licenses, qualifications, or work permits that may be necessary. The consequences of failures in equipment or material will be carried forward into the general hazard analysis.

The hazard analysis will be conducted using a What-if methodology, as prescribed in UEU EHS procedure XXX. Hazards are identified for all systems, including possible failures of the equipment and support systems (e.g., a general power failure). Engineering and administrative controls needed to prevent or mitigate hazards are identified. Implementation is prioritized during risk ranking, which evaluates consequence, and frequency/likelihood of occurrence.

Safety documentation results are maintained in the UEU Portal document control system, accessible by the entire project team.

Similar hazards to be evaluated from prior safety reviews and experimentation include the following:

- Hydrogen distribution system leakage
- Flammable gas buildup in the fume hood and exhaust system
- Quality control of hydrogen and oxygen cylinder receipt and management
- Pressure regulator failure
- Control system instrumentation failure
- Power failure
- Operator error in fume hood/exhaust system operation

5.2 SAT Prototype Evaluation

The SAT discussion is an example of a completed ISV.

The SAT is experienced in conducting safety analyses of its operations. The primary methodology used by SAT is a Hazard and Operability Analysis (HAZOP), managed by company procedure XYZ and training. The following is an example of the stages SAT uses for completing its identification of safety vulnerabilities:

1. Early Project ISV. Early project safety vulnerability identification begins during the negotiation stage of project funding. The project team meets with SAT's Environmental Health and Safety (EHS) organization and performs a high-level safety overview of the entire project. This allows EHS an opportunity to develop a path forward for safety features and training needed to ensure the team and building occupants are kept safe during the project. Collection of the ISV's of similar projects are reviewed for applicability.
2. Initial Design Stage ISV. Design stage safety vulnerability identification begins upon award of project funding. At this time members of the project team begin writing all necessary operating procedures and work through the general project system to identify administrative and engineering controls needed to eliminate or mitigate hazards. The hazard and operability study (HAZOP) is developed and issued as Revision 0, using a multidiscipline project team and EHS, led by the Project Manager.
3. Final Design Stage ISV. Research data from UEU, along with final calculations are used to complete the design details, including piping and instrument diagrams, process flow diagrams, alarms and interlocks logic, and architectural/electrical/structural drawings. Lessons learned from SAT prior designs and operations, and UEU research, along with changes from initial design are used to complete a revision of the HAZOP.

SAT has progressed through issuing its Revision 0 HAZOPS, and it is attached as Appendix XYZ. Key hazards are summarized below in the SAT Risk Reduction Plan section, along with the preventive and mitigative measures. Primary identified risks are: hydrogen gas leaks resulting in flammable gas mixture and combustion, contact with corrosives, and accidental contact with hot surfaces and pinch points by workers.

6.0 Risk Reduction Plan

Discussing general risk prevention and mitigation measures are valuable to better understand the entity's approach.

Flammability and explosion are the primary hazards associated with the use of gaseous hydrogen, and the wide flammability range and the low energy required for ignition dictate special handling to prevent mixing with air. Ignition sources such as sparks from electrical equipment and sources of static electricity, open flames, and extremely hot objects must be removed from the vicinity of gaseous hydrogen sources to preclude inadvertent ignition. Vent systems are designed to assure the hydrogen is exhausted to a safe location, and are designed to prevent backflow. Engineering controls are prioritized above administrative controls; above personnel protective equipment.

6.1 UEU
As stated above UEU has not completed it ISV. However, the following risk planning measures are typical of prior research and understood by project leadership and safety personnel, and will be incorporated into the final hazard analysis and risk reduction protocols.

- Hydrogen for this project will come from regulated commercial hydrogen gas cylinder. Risks are mitigated by using a single cylinder, chained to a cylinder rack located within a separate walk-in ventilated fume hood in the laboratory. The amount of hydrogen in each laboratory follows the flammable gas quantity limitations referenced in NFPA 45.
- All hydrogen connections from the cylinder are stainless steel, with fittings leak checked prior to every use. Hydrogen delivery piping includes a hydrogen-certified pressure regulator.
- The cylinder rack also contains a single cylinder of pressurized nitrogen used to purge the piping and fuel cell system after testing is completed each day, with purge systems being manually connected/disconnected to the hydrogen piping as needed. Only trained and qualified personnel can handle compressed gases.
- The electrolyzer will be operated within its own separate ventilated hood. The generation of hydrogen by electrolyzers will not be higher than 1% of the ventilation capacity of the exhaust in the room in which it is located.
- The laboratories are all designed for hydrogen use with appropriate air flow and hydrogen monitors in each room. The inadvertent shutdown of any test-related fume hood vent fans will alarm within the laboratory, and stop hydrogen flow to the electrolyzer through usage of an electrically-operated fail-to-close interlock valve, rated for hydrogen service.
- Fume and vent hoods are managed for proper sash closure to operating procedure limits, and vent to atmosphere above the laboratory building through independent vent stacks.

6.2 SAT
Key hazards are noted below in Table 1 from the HAZOPS results, along with planning measures to reduce the hazard risk. Full details are noted in the attached HAZOP report, in Appendix XYZ.

Table 1 SAT HAZOPS and Risk Planning Table Results

Parameter	Condition	Consequence(s)	Plan	Reference
Flow - A	*High H2 flow into building from liquid gas line*	*Electrolyzer failure and added flammable gas burden to vet system*	• *Piping sized to XYZ* • *Flow restrictive device XYZ* • *High flow alarm XYZ* • *Flow indicators XYZ*	*Drawings XYZ*
Flow - B	*H2 leak*	*Flammable gas mixture in uncontrolled area*	• *Piping system, and fittings 304L SS* • *Valves and instruments rated for H2 at 150% design flow and pressure* • *Purge protocol* • *H2 and O2 sensors with alarms and interlocks*	*Drawings XYZ and procedure XYZ*
Pressure	*High H2 pressure into test setup from supply*	*Electrolyzer failure, piping/fitting failure, valve/instrument failure*	• *Dual pressure regulator system* • *Pressure relief valves system vented to XYZ*	*Drawings XYZ*
Temperature	*Freezing exposure to personnel at liquid hydrogen system*	*Thermal exposure and burn*	• *Insulation* • *Warning signs* • *Hazard in procedure XXX*	*Drawings XYZ and procedure XYZ*
Purging	*Not purged*	*Unknown flammable gas mixture and use of wrong spark-*	• *Safety startup and shutdown checklist* • *Nitrogen purge gas*	*Drawings XYZ and procedure XYZ*

		producing tools	*totalizer*	
Startup	*Incomplete system check*	*Flammable gas mixture in uncontrolled area*	• *Safety startup checklist*	*Procedure XYZ*
Primary Power	*Failure*	*Flammable gas mixture in uncontrolled area*	• *Alarms and interlocks with H2 supply*	*Drawings XYZ*
Incident	*Unseen hydrogen flame*	*Trapped personnel, exposure to H2 flame*	• *Fire rated doors interlocked with alarm system* • *Hand-held I/R* • *Drills*	*Drawings XYZ and procedure XYZ*

7.0 Code and Standards

The facility is built to the following codes and standards, and verified through approved design documents, and occupancy permits, both on file at the university main business office.

- ASME B31.3, Process Piping Code
- ASME Boiler and Pressure Vessel Code (BPVC)
- NFPA 70, National Electric Code
- NFPA 496, Standard for Purged and Pressurized Enclosures for Electrical Equipment
- NFPA 497M, Classification of gases, vapors, dusts for electrical equipment in hazardous (classified) locations
- NFPA 55, Compressed Gases and Cryogenic Fluids Code
- NFPA 2; 2016 Edition, Hydrogen Technologies Code
- SAE J2600 (2012), Compressed Hydrogen Surface Vehicle Fueling Connection Devices
- SAE J2601 (2016), Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles
- SAE J2799 (2014),
- ISA 12. 12.01:2016 Ed.7
- UL 1203; 2013 Ed.5
- UL 913, Standard for Intrinsically Safe Apparatus and Associated Apparatus
- UL 508A, Standard for Industrial Control Panels
- NFPA 79, Electrical Standard for Industrial Machinery
- Title 24 of CA Electric Code
- NFPA 68, Standard on Explosion Protection by Deflagration Venting
- NFPA 69, Standard on Explosion Prevention System

8.0 Procedures

Sections of the SOPs may be copied and included, but usually a general description and listing is sufficient.

Operating steps for the testing scope are spelled out in Standard Operating Procedures (SOPs) #ABC and #XYZ. In addition, each SOP includes process safety limits, process safety shutdowns, quality/safety Hold Points, and specific engineering and administrative controls. Employees sign off on applicable operating steps within a paper copy or a formal logbook. Some SOPs reference specific safety procedures, such as #DEF, *Setup of New Hydrogen Cylinders*, or are stand-alone general safety procedures. A listing of all involved procedures and the links to their access on the main procedure website are noted in Appendix XYZ.

All SOPs are reviewed by a member of the Environmental Health and Safety (EHS) group. EHS provides feedback for improvements and clarity. Procedures are the primary tool of test personnel and are reviewed by the Project Leader and test team prior to startup. Users of procedures undergo a formal training of each procedure, amplified below in the Training section. Redline changes and formal revisions are reviewed and signed off by test personnel when needed or during the daily kickoff safety meeting led by the Project Leader.

Every employee is encouraged to stop work if they encounter difficulties with procedures. The Stop Work is resolved with the Project Leader and other technical support personnel prior to reinitiating testing scope. The Stop Work program is further described in the company program procedure XYZ.

9.0 Equipment and Mechanical Integrity

Validation of system materials hydrogen compatibility will follow the rules, regulations and codes detailed in Hydrogen Technology Safety Guide published by NREL. Tubing and fittings used will be suitable for hydrogen service and for the pressures and temperatures the system is designed to operate at in accordance with manufacturers' specifications as described by NFPA 2 and ASME B31.12. Certificates of compliance will be acquired from manufacturers upon delivery of all safety related devices. All employees are trained in the proper process for installing process piping and associated fittings.
A preventative maintenance plan will be implemented for all systems. Routine maintenance will be established in accordance with manufacturers' guidelines and frequency of system use. In addition, in the event of extensive lapse in system use a fixed interval of time will be established for ensure proper maintenance is performed prior to startup. Records will be kept that will require name, date and detailed results of the maintenance test.

Calibration and testing of safety related devices will be performed periodically in accordance of manufacturers' guidelines considering the frequency of use. A log of calibration and inspection details is maintained. After each calibration, the log is updated to include equipment ID number, calibration-performed date, results, next calibration due date, and initials of the person who performed the calibration.

The system will be tested and inspected based on frequency of use, but not to exceed manufacturers' recommendations. Prior to any tests performed, a helium leak test will be conducted to ensure all fittings remain gas-tight. The system will be visually inspected prior to pressurization. Upon passing inspection the system will be accepted. Pressure relief devices are inspected every 3 years.

Mechanics and test personnel authorized to repair and adjust equipment are certified to industry standards, and receive specialized training on unique equipment from either the Project Leader, the Training Department, or manufacturer representatives.

10.0 Management of Change (MOC) Procedures

In the event a change needs to be made at any time (during initial design, commissioning, startup operation or maintenance) to materials, equipment, technology, procedures, or personnel, the project team will consult with appropriate subject matter experts, and review the proposed change for potential hazards and needed mitigation measures. The team will then submit a change request form to the project management office for approval. The request must identify the needed change, the purpose of the change, and any potential hazards and mitigation techniques involving the change. The project management office will review the request and approve or deny based on their investigation of the change impact on the project.

Changes are discussed in the daily safety briefings prior to start of operation, and are disseminated formally by email to all test personnel. If the change involves a formal revision to a procedure then all affected test personnel will review and sign off acknowledgment of the change. All project documents are updated and stored in the document management system when changes are made. The Project Leader is responsible to ensure that the most current record of the affected document is available and in use by test personnel.

The entity should give the MOC section special attention. Many hydrogen-related incidents result from an equipment or procedure change that was not communicated to the project team.

11.0 Safety Reviews

Safety reviews are conducted at various times during the project by subject matter experts, project team personnel and members of the Environmental Health and Safety (EHS) organization. Safety review records are maintained in project files. Specific reviews include the following formal effort.

Design
Completion of the design involves several formal and informal safety reviews, including a Process Hazards Analysis, and HAZOP. Records of this review are included with the original design document set.

Pre-Startup Safety Review
Prior to the beginning of any operation a safety review is conducted to ensure:

- The system is installed as designed
- All identified safety features, including engineered and administrative controls are in place
- Training has been implemented
- Equipment has been inspected and tested.

Daily Briefings
Safety is discussed as a key topic in the daily project briefing.

Additional safety reviews are conducted as needed by the project (e.g., in response to a Stop Work request). These include safety reviews after changes to equipment, chemicals or staff; and at the creation of new work scope. EHS conducts periodic lab walk downs to ensure all safety guidelines are adhered to and action items are being tracked to closure. Principle Investigators are required to attend regular safety meetings in addition to the project meetings. Project meetings and safety meetings may be held together.

There is an annual audit/inspection of laboratory facilities by EHS to identify any missing or outdated safety equipment, and general safe condition of the testing areas.

12.0 Project Safety Documentation

Safety procedures that pertain only to the project are kept in the project specific lab notebook. General safety requirements are maintained in notebooks located within the lab and are also posted on the Safety and Training web site. The Project Manager and Environmental Health and Safety (EHS) organization are responsible for periodically reviewing and maintaining these documents. Project personnel have access to both the written and digital formats from within the laboratory. The digital copies can be accessed from any approved device, including but not limited to cellular devices, tablets, and computers. Project partners are afforded access to digital copies of all safety information.

The Principle Investigator and Project Manager are responsible for the safe keeping of the notebook and controlling the notebook at required review meetings. The Project Laboratory Notebook contains the following:

- The Statement of Project Objectives
- Standard Operating Procedures
- Safety Evaluation Workbook
- Emergency Procedures
- Safety Plan
- Training documentation
- Safety Review Reports, and
- Change log.

This safety plan is updated as conditions change or new hazards are identified, and the changes are communicated to all team members.

13.0 Personnel Training

All personnel who work with these systems are trained and have working knowledge of all hazards that pertain to a project prior to beginning work. New and refresher safety training needs are identified by the Project Manager and the Training Department. Subject matter experts, including equipment manufacturers, support development of training resources, conductance of training classes, and assessment of knowledge. Training records are maintained by the Training Department and are available to the Project Leader. Company training involves the following phased scope.

Initial
All employees require completion of a general training to company safety programs, including general facility hazards, hazards of flammable gases, pressurized cylinder handling, fire incident first response, emergency response, response to alarms, OSHA requirements, lock and tag, chemical waste management, 20 or 40-hour hazardous worker certification, and Stop Work. This training is conducted immediately upon a new hire prior to start of work.

Periodic
Retraining is conducted annually and biannually for certified worker training per OSHA requirements, and after major revisions to company operations or national safety programs. Emergency drills are conducted routinely (e.g., fire drills every calendar quarter) to maintain personnel proficiency and identify impacts of changing conditions.

Project-Specific
Only special-trained personnel are allowed both access and operational authority to the hydrogen test facility. The following are examples of unique project information and procedures that are required for this special training, including operators and maintenance personnel.

- Safety Data Sheets
- Fighting hydrogen fires
- Electrolyzer operation, calibration, and maintenance
- Test facility emergency procedures, alarms, and interlocks
- Project-specific operating procedures
- Project Safety Plan (this document)
- Other equipment user manuals
- Startup/shutdown procedures
- Preventive maintenance procedures (e.g., safety device checks, cleaning, lubrication, checking for deterioration, and performing instrument calibration)
- Lock and tag for authorized workers

Project-specific procedures and documentation are located in the safety documentation cabinet at the worksite and are accessible to all employees on the company local internet. The Project Leader is responsible for ensuring all employees working on the project have completed project-specific training, and any refresher training.

Communicating training documentation and resource changes are discussed in meetings, posted, and emailed to employees. Once a safety plan has been finalized it is verbally communicated to all team members in the safety kick-off meeting prior to the start of work. Safety knowledge is refreshed in the monthly safety meetings or as necessary to accommodate new policies and procedures that may be implemented because of changes.

14.0 Safety Events and Lessons Learned

Incidents, injuries, and near misses are reported to the Project Leader and Environment Health and Safety (EHS), after initiation of first response effort (e.g., pulling fire alarm). When required by contract or law, EHS reports to the appropriate authority within required timeframes. All incidents are also reported to DOE. Records are kept pursuant to legal requirements and Occupational Safety and Health Administration (OSHA) rules. At a minimum, a company incident report is documented.

An independent team under EHS will initiate an investigation. This includes first placing the site in a safe condition, securing evidence, producing a formal description of the injury and incident including descriptions from eye witnesses, noting pertinent background events that led up to the incident, identifying the root cause, producing recommended corrective actions, and documenting corrective actions taken; with pictures and diagrams. The HSP may be called upon to support analyses and corrective actions.

All communications to the public will occur through our Communications department with support of Legal and the Project Manager. During the investigation, safety meetings will be held to keep employees up to date on findings, during these meetings information will be passed along to employees verbally. The documented findings will be digitized and uploaded to the lessons learned portion of the company safety and training site. If it is discovered additional training is required, employees must complete the training prior to returning to work. A full investigation report will be completed and provided to the DOE Program Manager. The incident, if related to hydrogen or flammable gas usage, will be will be reported through the Lessons Learned website (https://h2tools.org/lessons).

A review of documented incidents on the h2tools.org website was conducted and two relevant incidents were found for similar scope to the project. They were incidents #ABC and #XYZ. As a result of reviewing these incidents the design was modified to install a separate, manually connected/disconnected purge line to the hydrogen piping system, and procedures were updated to add a signed-off Hold Point for line purging prior to hydrogen flow activation.

A review of the existing Lessons Learned database indicates a robust safety culture.

15.0 Emergency Response

The company Emergency Action Plan program complies with the OSHA Emergency Action Plan Standard, 29.CFR.1903.38. The objective is to prepare employees for dealing with emergency situations. The plan is designed to minimize injury, loss of human life, and company resources by training employees, procuring and maintaining necessary equipment, and assigning responsibilities.

This plan applies to all emergencies that may reasonably be expected to occur, and may be accessed on the company website at this *link*.

The following key activities from the Emergency Action Plan are summarized below to address emergencies that may occur during project effort with hydrogen gas.

- Verifying all portable safety equipment and personnel protective equipment are in place, clean, and operable, prior to start of hydrogen and flammable gas flows.
- Verifying all flammable gas-related alarms and interlocks are operable.
- Shift office is notified of start and stop of all hydrogen and flammable gas flows.
- Personnel accountability is maintained through use of electronic activated keycards for test room access.
- Signage is posted for operational and supervisory personnel emergency numbers available during the test, including local first responders (for numbers in addition to 911).
- Emergency routes and evacuation sites are identified and personnel trained to access.
- Operational and supervisory personnel are current with fire, evacuation, and take cover drills.

16.0 Supporting Documentation

Appendix A UEU Flow Diagram with Critical Instrumentation
Appendix B UEU Critical Instrument Safety Shutdown Parameters
Appendix C SAT Flow Diagram with Critical Instrumentation (not included for brevity)
Appendix D SAT Critical Instrument Safety Shutdown Parameters (not included for brevity)

17.0 Safety Plan Approval

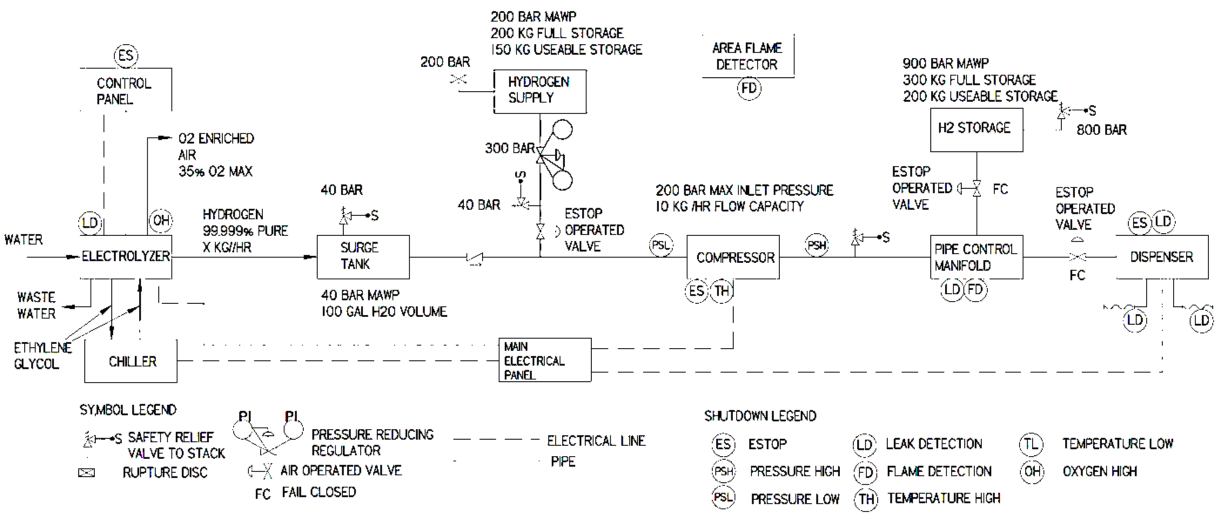
This draft safety plan will be finalized by the Project Manager and his team with the following effort.

1. Incorporation of revisions from HSP review
2. Incorporation of final review comments from UEU and SAT safety teams
3. Final review by UEU EHS, Training, Legal, and management
4. Obtaining all interim approvals as noted on the Cover Sheet
5. Final approval by Dr. I. M. Second of the UEU EHS department, as noted on the cover

The final approved safety plan is placed in Project Safety Notebook. A pdf-file type scan of the approved document, and a native Word® file of the final document are uploaded to SharePoint safety site. Following issuance of this safety plan, revision, update, or production of new SOPs will be completed, incorporating safety plan direction.

Attachment A – Example Safety Plan

Appendix A - Flow Diagram with Critical Instrumentation



Appendix B - Critical Safety Shutdown Parameters

Description	Shutdown Type	Hard Wired or PLC	Shutdown Setpoint	Time Delay	System Action
Emergency Stop Button Local	Emergency	Hardwired	Depressed		Shutdown and trips feed breaker
Emergency Stop Button Remote	Emergency	Hardwired	Depressed		Shutdown and trips feed breaker
Hydrogen Separator Low Seal Water Level (Tank A3 Empty)	Critical Safety	Hardwired	L1		Shuts SV 10
Low Circulation Water to EM1 (Cell Stack A)	Operational	Hardwired			Removes power from power supply
Enclosure Fan Failure	Critical Safety	Hardwired			Shutdown and trips feed breaker
System Pressure High	Critical Safety	PLC	260 psig		Alarm
System Pressure Low	Critical Safety	PLC	230 psig	10 seconds	Alarm
System Pressurization Timeout	Critical Safety	PLC		200 seconds	Alarm
System High Temperature Shutdown	Critical Safety	PLC	60 deg C (140 deg F)		Shutdown and trips feed breaker
E-Stop Circuit Failure	Critical Safety	PLC			Alarm
CG 12 in Oxygen High	Critical Safety	PLC		25% LFL	Shutdown and trips feed breaker
CG 13 in Enclosure High	Critical Safety	PLC		25% LFL	Shutdown and trips feed breaker
Safety Interlock Error	Critical Safety	PLC			Alarm

*** End of Safety Plan***

Attachment B – Example Hazard Analysis Methodologies

Source: PNNL-25279-3, *Safety Planning for Hydrogen and Fuel Cell Projects*, Revision 3, January 2020, Pacific Northwest National Laboratory, Richland, WA (Link to the document on the https://H2tools.org site, here)

Hazard Analysis Methodologies		
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. Risk-based decision-making guidelines, United States Coast Guard (https://www.uscg.mil/hq/cg5/cg5211/risk.asp)
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.

Attachment B – Example Hazard Analysis Methodologies

Hazard Analysis Methodologies		
Method	**Description**	**References**
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.

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 more than 380 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 us at **hsp@h2tools.org**.

HYDROGEN
Safety Panel