Standard Operating Procedure for Use of Hydrogen Gas and its mixtures

|  |  |
| --- | --- |
| Department: | Choose a department.Enter department here if not listed. |
| Principal Investigator: | PI name. |
| Group Safety Coordinator/Lab Manager: | Name of safety contact. |
| SOP written by: | College of Engineering Office of Safetyengrsafety@illinois.edu |
| Date SOP was approved by PI/lab supervisor: | 1/5/2017 |
| Lab Phone: | Enter the lab phone number |
| PI’s Phone: | Enter the PI office or mobile phone number |
| Location(s) covered by this SOP: | Enter the building and room number |
| Emergency contact information for this location: | Enter contact information of lab personnel to be notified in case of emergency. |

|  |  |  |  |
| --- | --- | --- | --- |
| Type of SOP: (check one) | [x] Hazardous material(SOP describes a specific hazardous chemical) | [ ] Hazardous class(SOP describes a group of hazardous materials ) | [ ] Hazardous Process(SOP describes a hazardous process or equipment) |

**NOTE**: This SOP is intended as an initial resource and as a general reference regarding the topic discussed. It is not a substitute for hands-on training and supervision by experienced laboratory personnel. The Principal Investigator must review and approve of all information in this document for the SOP to be valid and useable.

*This SOP is not complete until: 1) Clear and detailed instructions are written that will ensure safe handling of the material or safe performance of the procedure, and 2) SOP has been approved and dated by the PI or laboratory supervisor.*

Print a hardcopy and insert into your *Laboratory Safety Manual* and *Chemical Hygiene Plan*.

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# Purpose

This SOP aims to provide the reader with the fundamental awareness of the hazards associated with the handling and storage of gaseous hydrogen (H2).

*This SOP does not cover the use of liquid hydrogen.*

# Key Points

Hydrogen (H2) is an extremely flammable, colorless and odorless compressed gas that is used in some research laboratories. It has virtually no toxic effects on the human body, but it can displace air causing asphyxiation if enough is released in an enclosed room. However, the most imminent danger when dealing with hydrogen is that is has a wide explosive/ flammability range (4%-74% in air). This means that even a small leak can cause a hazardous fire or explosion.

If not handled and stored properly, hydrogen gas can pose a serious threat to the health and safety of laboratory personnel & emergency responders and also to the property. It poses an immediate fire and explosive hazard when concentrations exceed 4% and can be ignitable by static electricity. It is much lighter than air and burns with an invisible flame. The storage and use of hydrogen poses unique challenges due to its ease of leaking as a gaseous fuel, low-energy ignition, wide range of combustible fuel-air mixtures, buoyancy, and its ability to embrittle metals that must be accounted for to ensure safe operation.

Hydrogen gas forms explosive mixtures with air at concentrations of 4–74% and forms explosive mixtures with chlorine at concentrations of 5–95%. Mixtures of hydrogen with air and other oxidizing gases spontaneously explode by spark, heat or sunlight.

The detection of a burning hydrogen leak may require a flame detector; such leaks can be very dangerous. Hydrogen reacts with every oxidizing element. Therefore, hydrogen gas leaking into external air may spontaneously ignite. Moreover, hydrogen fire, while being extremely hot, is almost invisible, and thus can lead to accidental burns.

Because the use and storage of hydrogen impacts building code requirements, the approval for the use of hydrogen in a lab may require involvement of the home department, building manager or other campus agencies.

# Important considerations

## **Prior approval from PI required?** YES

 If the answer above is Yes, consent must be obtained from the PI before performing the experiment or procedure. Describe the approval process here.

## Consultation of other reference material, documents or knowledgeable persons

Lab personnel involved with hydrogen gas systems should educate themselves on the hazards of hydrogen. The References section list some resource material among which is Hydrogen Gas Safety: Self-study, Document No. ESH13-401-sb-8/00, Los Alamos National Laboratory, Los Alamos NM, 2000.

Those attempting to perform a *hydrogenation* reaction should head to the School of Chemical Sciences’ [High Pressure/Hydrogenation Lab](http://scs.illinois.edu/hpl/) for expert advice and access to a facility designed for such experiments.

## Pre-requisite training or skill

Knowledge of use, storage and handling of compressed gases is a minimum requirement. Pacific Northwest National Laboratory’s Hydrogen Tools website features an [online safety-training module for hydrogen researchers](Hydrogen%20Safety%20Training%20for%20Researchers).

# Hazard Awareness

## Introduction

A **hazard** is a condition or circumstance that presents a potential for injury, illness or property damage. Hazards vary in nature and can be chemical, biological, physical (includes electrical, radiation, temperature extremes, pressure or vacuum, noise, mechanical), and ergonomic. The negative outcomes associated with hazards include exposure, poisoning, illness, shocks, burns, fires, slips and falls, spills, explosions, and perhaps even fatalities. It is important that you become aware of hazards inherent in the procedures undertaken or materials used in experiments. A comprehensive **hazard identification** and **risk assessment** should have been performed on this lab experiment to identify hazards and determine their risk of consequence from the hazards. Only by identifying hazards can solutions and strategies be developed to address the hazards and control them or minimize the **risk** (likelihood of adverse events or negative outcomes associated with the hazards). In addition, there are **laws** that apply to many workplace settings, including academic research laboratories, that require the assurance of a safe workplace, as well as **regulations** that set and enforce standards that need to be complied with to ensure a safe and healthful workplace.

For the SOP author: Perform a comprehensive **hazard identification** and **risk assessment** (see section on **Tools and resources**) on the chemical or process to identify hazards and determine their risks. You may keep the documentation of the hazard identification/risk assessment separate from the SOP, but list and discuss the hazards and risks below. It is important that researchers are made aware of hazards inherent in the procedures to be undertaken or materials to be used in experiments. The means to control the hazards should be made known to the researcher, so that he or she can apply them. Applicable laws or regulations should be cited and the means to comply with them should be stated.

## **Hazards and pertinent regulati**ons

Hydrogen (H2) is a highly flammable gas. Hydrogen gas (dihydrogen or molecular hydrogen) is highly flammable and will burn in air at a very wide range of concentrations between 4% and 75% by volume.

Hydrogen is very light and quickly rises if released, and also has the unique characteristic of making certain metals brittle after prolonged use. So, use caution when working with metal tools and devices.

When hydrogen is in air it can ignite with extremely low energy input. For instance, hydrogen only needs 10% of the energy (0.02 millijoules or 20 microjoules) required to ignite a gasoline-air mixture. Even a static spark from a person or clothing can ignite hydrogen gas. Hydrogen needs only a minimum of 10% oxygen or a maximum of 41% of oxygen in air to ignite. Also, because the flame is almost invisible in daylight, finding and fighting a hydrogen fire can be difficult.

Hydrogen gas forms explosive mixtures with air at concentrations of 4–74% and forms explosive mixtures with chlorine at concentrations of 5–95%. The mixtures spontaneously explode by spark, heat or sunlight. The detection of a burning hydrogen leak may require a flame detector; such leaks can be very dangerous. Hydrogen reacts with every oxidizing element.

The storage and handling of hydrogen gas cylinders must comply with building and fire code requirements. The authority having jurisdiction (AHJ) on campus is [Campus Code Compliance and Fire Safety](http://fs.illinois.edu/services/more-services/code-compliance-fire-safety), which manages building and fire code compliance.

**Always consult with Campus Code Compliance and Fire Safety first when planning the use of hydrogen.** There are facility requirements based on the intended quantities of use. Contact CCC&FS for an evaluation before purchasing any quantity of hydrogen.

**National Electrical Code (NEC)**

The National Electrical Code (NEC) or NFPA 70, is a standard for the safe installation of electrical wiring and equipment in the United States. Because of the presence of flammable gas such as hydrogen in proximity to electrical equipment increases the risk of fire or explosion and renders the premise or building as a hazardous location, researchers must understand how the use of hydrogen will impact the electrical code requirements.

*Hazardous locations are areas where flammable liquids, gases or vapors or combustible dusts exist in sufficient quantities to produce an explosion or fire. In hazardous locations, specially designed equipment and special installation techniques must be used to protect against the explosive and flammable potential of these substances.*

In North America, a ***“Class, Zone or Division”*** System has been used for decades as the basis for area classification of hazardous (classified) locations. Because the hazards and methods of protecting electricalequipment against these hazards differ for different materials, hazardous locations are divided into three Classes, and two Divisions. Where flammable gases are involved, the location is designated as Class I. The NEC then subdivides class 1 into Zones. The subdivision of Class I, locations into “*Divisions*” or “*Zones*” is based on the probability that an *explosive gas atmosphere* may be present in a location. Note that for hydrogen, this means a mixture with oxygen or air above the LEL. The frequency of occurrence determines the level of hazard for a location. Simply stated, the longer the material is present, the greater the risk. Table 1 below summarizes the Class I Division/Zone system.

Table 1: Class I Divisions and Zones

|  |  |  |
| --- | --- | --- |
| **Zone 0** | **Zone 1** | **Zone 2** |
| Where ignitable concentrations of flammable gases, vapors, or liquids are present continuouslyor for long periods of time under normal operating conditions. | Where ignitable concentrations of flammable gases, vapors, or liquids:• Are likely to exist under normal operating conditions• May exist frequently because of repair, maintenance operations, or leakage | Where ignitable concentrations of flammable gases, vapors, or liquids:• Are not likely to exist under normal operating conditions• Occur for only a short period of time• Become hazardous only in case of an accident or some unusual operating condition |
| **Division 1** | **Division 2** |
| Where ignitable concentrations of flammable gases,vapors, or liquids:• Are likely to exist under normal operating conditions• Exist frequently because of maintenance/repair work or frequent equipment failure | Where ignitable concentrations of flammable gases, vapors, or liquids:• Are not likely to exist under normal operating conditions• Are normally in closed containers where the hazard can only escape through accidental rupture or breakdown of such containers or in case of abnormal operation of equipment |

Electrical equipment belonging for a classified location must have sufficient protections methods for that Zone or Division. Table 2, below, summarizes the applicable protection methods per Zone/Division. In general, the lower the probability of explosive mixtures, the fewer (and less stringent) the electrical code requirements will be. For instance, if the presence of explosive hydrogen mixture will only occur in an abnormal condition (e.g. in those situations where ignitable concentrations are normally prevented by mechanical ventilation and which might become hazardous through failure of ventilation equipment), the location falls under Class I, Zone 2 or Division 2. Should this be the case, electrical apparatus must utilize the protection techniques for Division 2, such as Protections “n”, or higher. Compare this with the protection methods needed for situations where ignitable mixtures are continuously present, which would require intrinsically safe or explosion-proof rated equipment. Wiring and conduits must also conform to permitted methods for that classification in accordance with the NEC.

Table 2. Class 1 Protection Methods

|  |  |  |
| --- | --- | --- |
| **Zone 0** | **Zone 1** | **Zone 2** |
| Intrinsicallysafe (2 fault)• Intrinsicallysafe, “ia”(2 fault)Class I,Division 1(U.S. only) | • Encapsulation, “m”• Flame-proof, “d”• Increased safety, “e”• Intrinsically safe, “ib” (1 fault)• Oil Immersion, “o”• Powder-filled, “q”• Purged/Pressurized, “p”• Any Class I, Zone 0 method• Any Class I, Division I method (U.S. only) | • Energy limited, “nC”• Hermetically sealed, “nC’• Nonincendive, “nC”• Non-sparking, “nA”• Restricted breathing, “nR”• Sealed device, “nC”• Any Class I, Zone 0 or 1 method• Any Class I, Division 1 or 2 method (U.S. only) |
| **Division 1** | **Division 2** |
| • Explosion-proof• Intrinsically safe (2 fault)• Purged/Pressurized (Type X or Y) | • Hermetically sealed• Nonincendive• Non-sparking• Oil immersion• Sealed device• Purged/Pressurized (Type Z)• Any Class I, Zone 1 or 2 method (U.S. only)• Any Class I, Division 1 method |

*Because electrical equipment is a potential source of ignition, it must be properly selected, installed and operated to provide protection against explosion in hazardous locations.*

**Always consult with Campus Code Compliance and Fire Safety first when planning the use of hydrogen.**

## Experimental Risk Assessment

The goals of Safety Planning are to identify hazards, evaluate risks by considering the likelihood and severity/consequence of an incident associated with the hazards, and to minimize the risks associated with a project. To achieve these goals, various hazard analysis and risk assessment techniques are used, in conjunction with safety reviews by Campus agencies. The two main questions to consider in a hydrogen risk assessment are:

**What hydrogen hazard has the potential to result in the worst consequence?**

This could include uncontrolled hydrogen release from equipment failure (resulting in concentration greater than the lower flammability limit); flammable mixture exposed to ignition source (resulting in fire or explosion); excess pressure buildup inside equipment (resulting in loss of containment and fire or explosion); unexpected rapid reaction with energetic materials that can’t be controlled; etc.

**What hydrogen hazard is the most likely to occur?**

This could include hydrogen leaks, minor burns, exposure of energetic/reactive materials to air or water, etc.

Once the hazards are identified, their risks should be categorized in terms of potential impact (consequence) and probability of occurrence (frequency). For example, a very-low-probability risk might be one that is not likely to occur in the 50-year expected operating lifetime of the process, and a low-probability risk might be one that is likely to occur just once in the process lifetime. A medium probability risk might be likely to occur a few times in the process lifetime, a high-probability risk might be likely to occur once a year or whenever an operator is working in a highly stressed condition without immediate oversight, and a very-high-probability risk might be likely to occur during every equipment maintenance/repair outage or at least a few times each year. The impact categorization scheme might be in terms of the severity of a potential personnel injury and/or the extent of equipment damage and lost production.

After the risks are categorized, hazard controls should be developed to eliminate or reduce the probability, consequences or both. The highest risks should receive the most attention.

The [Reference](#_Tools_and_resources) section lists hydrogen safety planning resources.

## Means to control the hazards

For each hazard listed, briefly describe the means to control the hazard of minimize the risk associated with the hazards. Details of specific work practices, administrative or engineering controls and PPE should be deferred to the later section of **Safe Work Practices**.

## Examples of hazardous materials or processes

Give examples of hazardous materials or procedures relevant to your lab and this SOP.

# Safe Work Practices: Engineering Controls, Administrative Controls, and PPE

## Introduction to engineering controls, administrative controls, and PPE

**Safe work practices** describe known safe and prudent policies and practices to adhere to in performing the experiment or procedure or in handling the materials. Some chemicals are acutely toxic or carcinogenic and require a **designated area** for work with these chemicals. A designated area may be the entire laboratory, an area of the lab, or a containment device such as a fume hood. Safe work practices may require the use of **engineering controls, administrative controls** and **personal protective equipment** (PPE). **Engineering controls** are methods that are part of the equipment or process to reduce or eliminate the hazard to the researcher. **Administrative controls** are changes to work procedures with the goal of reducing the duration, frequency and severity of exposure to hazardous materials or situations. **Personal protective equipment** or PPE refers to protective clothing, attire or garments designed to protect the wearer’s body from injury or exposure. In general, if the hazard cannot be eliminated or substituted out, engineering controls are favored over administrative controls and PPE, because well-designed engineering controls can be highly effective while not requiring effort on the part of the researcher to follow certain work policies or remembering to wear the correct protective equipment.

For the SOP author: Describe relevant safe work practices, designated areas (if present), engineering and administrative controls and select the PPE that are needed to protect the experimenter from hazards.

## Recommended work practices

* Compressed gas cylinders be double chained to a stable structure such as a wall. The first chain must be one third from the bottom of the cylinder and the second chain should be one third from the top of the cylinder. Do not use Nylon straps to secure compressed gas cylinders. Do not use table/bench clamps for securing the cylinders. Replace the straps with chains. Secure cylinders of equal sizes together to avoid chaining problems.
* If compressed gas cylinder holding metal rack is used to restrain the cylinders, the rack must be bolted to the floor and the chains or rods must be at 1/3rd from the bottom and 1/3rd from the top of the cylinders. A clam shell (a cylindrical metal casing bolted to the floor) can be used to secure cylinders that need to be stored and used next to the experimental set-up.
* Always use Stainless Steel (SS) tubing to convey hydrogen gas. Non-metal tubing is unsafe because hydrogen will permeate to the exterior surface, and elevated temperature increases the rate of permeation. If plastic tubing must be used, use one that is rated for hydrogen by the manufacturer.
* Remove the regulator and place the safety cap on, when the cylinder is not in constant use.
* Perform an inert gas leak test before using the piping or connected equipment. For indoor installations, it is a good idea to perform an additional leak check of the downstream connections using a hand-held detector after hydrogen has been introduced into the system.
* The installation of a hydrogen gas leak detector is recommended.
* Prevent hydrogen leaks by meticulously connecting gas regulator and tubing.
* Keep constant vigilance to immediately detect accidental leaks.
* Prevent accumulations of leaked hydrogen using plentiful ventilation.
* There should be no open flames or smoking in areas where hydrogen is used. Eliminate likely ignition sources, and suspect unknown ignition sources. Sources of ignition could be electrical (e.g. static discharge, opening or closing of switch or pushbutton contacts), mechanical (e.g. impact, friction, metal fracture) or thermal (e.g. open flame, hot element)
* Work in an area with plenty of ventilation. If possible, work in a fume hood or use a canopy hood as fugitive vapors, if not captured, may collect near the ceiling.
* Store hydrogen gas cylinders away from electrical panels, emergency eyewash & safety shower, and points of egress (exits).
* Always assume hydrogen is present, and verify the system has been purged to less than 1 percent when performing system maintenance on a hydrogen system. Inert gases such as Nitrogen & Argon can be used for purging.
* All volumes containing hydrogen should be evacuated or purged with nitrogen or other inert gas before and after use.
* Always assume oxygen is present, and verify the system has been purged to the appropriate level when reintroducing hydrogen into a system.
* Have lab buddy system when working with highly flammable gases such as Hydrogen, Ethane, Methane, Acetylene etc.
* All users must have had hands-on training to work with highly flammable gases. The training must be documented.
* Lab personnel handling highly flammable gases must have easy access to an Emergency Eyewash & Safety Shower within 10 seconds (i.e., travel distance no greater than 100 feet).
* Remove electrical equipment or electronic devices from the vicinity of hydrogen gas unless the device is certified "intrinsically safe". Even invisible small sparks from electronic devices could ignite hydrogen.
* Use non-sparking tools in the vicinity of hydrogen gas.

## Designated area to work with the material or process

A leak detection system may be required for locations where hydrogen cylinders will be used. In general, a hydrogen detector would be typically mounted over each hydrogen cylinder a certain distance from the ceiling.

Hydrogen should be used in well-ventilated areas to prevent accumulations of leaked gas, or under a properly function gas cabinet. While the use of hydrogen in fume hood may seem like a good idea, the fume hood fans may not be explosion-proof or intrinsically safe. Therefore, discharging over 4% H2 in a fume hood can result in an explosion on the roof stack. One should check with the building manager. Also, keep in mind that fume hoods are not designed to contain an explosion.

## **Necessary engineering or administrative controls**

• Hydrogen should be used in well-ventilated areas to prevent accumulations of leaked gas.

* Any near miss incidents such as leaks or evidence of unintended combustion such as flames, unusual hot spots, smells or popping sounds must be reported and investigated as they could point to deteriorating safety conditions.
* Have a lab buddy system in place when working with highly flammable gases such as hydrogen.

Where appropriate, use the following components in the gas supply system:

* Isolation valves to shut off flow when necessary.
* Check valves to prevent reverse flow that could contaminate the hydrogen gas system.
* A regulator is not a safety device. Without additional protection, downstream components can be exposed to pressures exceeding the set pressure up to the full bottle pressure. If items downstream of the regulator are not rated for full bottle pressure, it is recommended that protection be added to the system. Use pressure relief devices (PRDs) to prevent system pressure from exceeding 10% of the maximum allowable working pressure. The discharge of pressure-relief devices should be vented outdoors and not into areas where hydrogen may accumulate.
* Use flashback arrestors where hydrogen and oxidizing gases are connected to a common piece of equipment or where low and high-pressure gases are connected to a common set of piping.



## **Required Personal Protective Equipment.**

Hand Protection: Chemical-resistant gloves must be worn; nitrile gloves are recommended. Wearing two pairs of nitrile gloves is recommended. NOTE: Consult with your preferred glove manufacturer to ensure that the gloves you plan on using are compatible with the specific chemical being used.

Eye Protection: ANSI approved properly fitting safety glasses or chemical splash goggles are required. A face shield may also be appropriate depending on the specific application.

Skin and Body Protection: Flame resistant laboratory coats must be worn and be appropriately sized for the individual and buttoned to their full length. Personnel must also wear full length pants, or equivalent, and close-toed shoes. Full length pants and close-toed shoes must be worn at all times by all individuals that are occupying the laboratory area. The area of skin between the shoe and ankle must not be exposed.

# Detailed procedures or techniques

## Introduction

Successful experiments require adherence to correct procedure, correct sequence of operation, observation of experimental parameters and possibly making adjustments to certain variables to ensure safe operation. After completion of the experiment, all waste material should be collected in properly labeled containers.

For the SOP author: Describe detailed procedures for performing the experiment or handling the materials in the step-by-step procedures section below. Whenever possible, point out critical steps, and describe any observations or indicators that the experiment is proceeding in a satisfactory manner. Describe any criteria that would indicate that something is amiss, as well as actions to be taken in those cases to avoid mishap. Upon conclusion of the experiment, describe the procedures to properly deal with any waste generated. If a waste stream has already been established with a UI#, include that to aid the researcher in collection container labelling, waste segregation and disposal.

## Step-by-step procedures

Describe in detail the proper procedures or techniques.

## Waste disposal procedure.

Describe the proper waste disposal procedures, including proper labeling and storage of waste containers awaiting pickup. If necessary, consult: [Division of Research Safety Waste Disposal Guide](https://www.drs.illinois.edu/site-documents/WasteDisposalGuide.pdf) and [Division of Research Safety Chemical Waste Quick Start Guide](https://www.drs.illinois.edu/Waste/ChemicalWasteQuickStartGuide)

# **Emergency response**

## Introduction to emergency response

Fire and explosion are the most obvious hazards associated with hydrogen gas. Prevention is key, as there is likely no safe or effective containment of a hydrogen explosion in the laboratory.

## Necessary emergency equipment

When preparing to work with flammable gas, emergency equipment must be present and in good working condition, and the researcher must be familiar with their operation. **Be aware of the location of emergency equipment at all times**!

* Fire Extinguisher.
* Fire alarm – identify where pull stations are.
* Emergency eye-wash – needs to be tested weekly. Make sure eye wash station access is unobstructed.
* Emergency shower – use the chemical fume hood that is closest to the shower if possible. Make sure emergency shower access is unobstructed.
* Ventilation (to help expel flammable vapors out of lab space) – if provided, an *intrinsically-safe* forced ventilation system can be turned on to prevent accumulation of hydrogen in case of a release. All researchers should be trained on its use.
* Hydrogen leak alarm – A hydrogen detector would be typically mounted over each hydrogen cylinder a certain distance from the ceiling. Researchers need to be trained on the actions in response to an alarm.
* Emergency shutoff systems – should a fire or a leak be detected, isolation and shutoff systems will need to be activated.
* Sprinklers, if available, need a minimum of 18” vertical clearance from the sprinkler head to the nearest object below the sprinkler head. Do not stack objects near sprinkler heads.

## What to do if there is a material release or a fault in the process.

If a hydrogen leak is detected, the steps to take should be described in detail in this section. There will likely be different response to a small leak versus a larger leak, or a leak that has ignited. Discovery of a hydrogen leak or sounding of the hydrogen alarm, personnel will typically take the following steps.

1. Evacuate the immediate area of all nonessential personnel.
2. Shut off hydrogen at the source, and vent hydrogen to a safe outside location.
3. Increase indoor ventilation with intrinsically-safe or explosion-proof exhaust fans, if available.
4. Call 911.

It may be difficult to detect a small, local hydrogen fire. However, if fire is present perform the following:

1. Shut off hydrogen source.
2. Let the fire burn itself out. (If the flame is snuffed out, leaking hydrogen gas may reignite and cause greater damage)
3. Call 911.

## What to do if there is an exposure or injury

If clothing catches fire, use the emergency shower immediately.

# Storage

## Introduction to proper storage of hazardous materials

The storage of chemicals goes beyond simply placing bottles on shelves for easy retrieval. Proper storage involves careful separation of incompatible chemicals, examination of containers for integrity, use of appropriately-sized secondary containment and management of time-sensitive or temperature-sensitive chemicals. Improper storage has led to unsafe conditions and incidents, and must be avoided.

For the SOP author: Identify and recognize incompatibilities and describe ways to safely store chemicals involved in this SOP.

## Special storage requirements

* Hydrogen cylinders must be stored with valve’s protective cap in place. If the cap has been removed, the cylinder must be stored upright and secured with non-combustible straps or chains.
* Compressed gas cylinders be double chained to a stable structure such as a wall. The first chain must be one third from the bottom of the cylinder and the second chain should be one third from the top of the cylinder. Do not use Nylon straps to secure compressed gas cylinders. Do not use table/bench clamps for securing the cylinders. Replace the straps with chains. Secure cylinders of equal sizes together to avoid chaining problems.
* If compressed gas cylinder holding metal rack is used to restrain the cylinders, the rack must be bolted to the floor and the chains or rods must be at 1/3rd from the bottom and 1/3rd from the top of the cylinders. A clam shell (a cylindrical metal casing bolted to the floor) can be used to secure cylinders that need to be stored and used next to the experimental set-up.
* Hydrogen cylinders must be stored more than 10 feet away from ordinary combustibles.
* Hydrogen cylinders must be stored more than 20 feet away from cylinders of oxygen or other oxidizers, e.g., bromine, chlorine, fluorine or be separated by a noncombustible wall extending not less than 18” above and to the sides of the stored material.
* Never open the cylinder valve before making sure all your connections are secure and have been purged and leak tested, as the static discharge from flowing gas may cause hydrogen to be ignited.
* Never use adapters to adapt a regulator intended for one gas to be used for another gas.
* Be aware of leaks! Hydrogen has a low viscosity which makes it to have a high leakage rate. A leak as small as 4 micrograms/second can support combustion.
* Due to hydrogen’s low molecular weight, this gas will diffuse rapidly in a room and will collect near the ceiling. It is important to use and store hydrogen only in well-ventilated locations.
* All electronic equipment used near hydrogen gas must be electrically grounded and bonded. Metal vessels and piping systems that contain hydrogen should also be grounded and bonded.
* Check that the pressurized system does not leak hydrogen with leak detection solution or pressure sensing.
* Close the cylinder valve when not in use. Do not leave the piping pressurized with hydrogen gas if not in use. Purge and backfill with inert gas.

Hydrogen is incompatible with many materials and situations, some of which are listed below. Storage in proximity with the following materials or under the following situations should be avoided:

* It ignites easily with oxygen, could explode when heated.
* It reacts violently or explosively or forms heat- and/or-shock sensitive explosive mixtures with oxidizers, halogens, halogen compounds, acetylene, bromine pentafluoride, chlorine oxides, fluorine perchloride, oxides of nitrogen, and so on. Check SDS for list of incompatibles.
* Hydrogen forms explosive mixtures with chlorine at concentrations of 5–95%. These mixtures may explode on exposure to light.
* Mixtures with oxygen may explode in presence of platinum catalyst.
* It forms hydrides when heated with alkalis, alkaline earth, and some other elements.

## Quantity limits and other storage considerations

Always consult with Campus Code Compliance and Fire Safety first when planning the use of hydrogen. There are facility requirements based on the intended quantities of use. There must be no more than 1000 cubic feet of flammable gases per usage area unless there are adequate engineering controls. Contact CCC&FS for an evaluation if there will be more than one large cylinder used in a room and one in storage. A standard large cylinder contains about 260 cubic feet of hydrogen. If there are inadequate engineering controls, CCC&FS may restrict the volume of hydrogen gas, or request that they be stored in an exhausted location and require hydrogen monitoring and alarms, or other safety controls. There may be other requirements wherever hydrogen is used. These requirements may include, but not be limited to:

* Hydrogen gas detection systems
* Automatic sprinkler systems
* Mechanical ventilation systems
* Ventilated gas cabinets
* Separate storage and use areas
* Warning signs and placards

# Reference

## Definition of terms

**Intrinsic safety -** One of the protection techniques allowed in hazardous locations defined by the NEC. Devices are rated as intrinsically safe if explosive gases, vapors, dust or fibers from the surrounding environment cannot penetrate the device, which could potentially serve as a source of ignition. *Intrinsically safe* devices have been tested at a 3rd party laboratory and proven to be safe for use in even the highest electrical classification of Class 1, Group A, Division 1 hazard category; therefore, they can be used for all hazardous environments requiring explosion proof conditions. In the US intrinsically safe testing and certification can be done by Factory Mutual (FM) or Underwriters Laboratories (UL). Intrinsic safety equipment designated “ia” for use in Zone 0, “ib” for use in Zone 1, and “ic” for use in Zone 2 locations, respectively.

**Type of Protection “n”** – One of the protection techniques allowed in hazardous locations defined by the NEC. Type of protection where electrical equipment, in normal operation, is not capable of igniting a surrounding explosive gas atmosphere and a fault of said equipment capable of causing ignition is not likely to occur. This equipment is suitable for Class I, Zone 2 locations. Type of protection “n” is further subdivided in nA, nC, nR.

**Nonincendive Equipment** - One of the protection techniques allowed in hazardous locations defined by the NEC. Equipment having electrical/electronic circuitry that is incapable, under normal operating conditions, of causing ignition of a specified flammable gas-air, vapor-air, or dust-air mixture due to arcing or thermal means. Nonincendive equipment is a combination of Nonincendive circuits and nonincendive components, each adhering to its own specific requirements.

**Hermetically sealed** – One of the protection techniques allowed in hazardous locations defined by the NEC. Equipment sealed against the entrance of external atmosphere where the seal is made by fusion, for example, soldering, brazing, welding, or the fusion of glass to metal.

**Explosion proof** – One of the protection techniques allowed in hazardous locations defined by the NEC. Electrical equipment enclosed in a case that is capable of withstanding an explosion of gas or vapor that may occur within it, and capable of preventing the ignition of a surrounding flammable atmosphere.

**Hazardous location** – As defined in the National Electrical Code, hazardous locations are areas where flammable liquids, gases or vapors or combustible dusts exist in sufficient quantities to produce an explosion or fire. In hazardous locations, specially designed equipment and special installation techniques must be used to protect against the explosive and flammable potential of these substances.

**Authority having jurisdiction** - An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure. On campus that office is [Campus Code Compliance and Fire Safety](http://fs.illinois.edu/services/more-services/code-compliance-fire-safety), which manages building and fire code compliance.

**Non-sparking tool** - Commonly used hand tools are often manufactured of steel alloys, which create sparks when struck or impacted on other materials such as steel or concrete. These sparks can cause ignite flammable materials. "Non-sparking", "spark reduced", "spark-resistant" or "spark-proof" tools are names given to tools made of metals such as brass, bronze, Monel metal (copper-nickel alloy), copper-aluminum alloys (aluminum bronze), or copper-beryllium alloys (beryllium bronze). Non-sparking tools provide protection against fires and explosions in environments where there is a concern about sparks igniting flammable solvents, vapors, liquids, dusts or residues. There are many standards and recommendations that have been published by OSHA (Occupational Health and Safety Administration) and NFPA (National Fire Protection Association) that advise the use of non-sparking tools in hazardous environments.

## Tools and resources

***Tools for Performing a Lab Risk Assessment***

Safety planning tools and checklists specific to hydrogen use can be found in the [Hydrogen Tools](https://h2tools.org/) website:

* [Hydrogen Tools: Safety Planning](https://h2tools.org/bestpractices/safety_planning)
* *Identifying Safety Vulnerabilities:* H2 Safety Snapshot [Vol 2, Issue 2, July 2011](https://h2tools.org/sites/default/files/h2_snapshot_v2i2.pdf).
* [Hydrogen Safety Checklist](https://h2tools.org/sites/default/files/HydrogenSafetyChecklist.pdf)

Hazard recognition and identification is the first step to creating a risk assessment for your laboratory procedure. The following links provide guidance in identifying hazards and assessing the risks from the hazards.

[American Chemical Society: Hazard Assessment in Research Laboratories](https://www.acs.org/content/acs/en/about/governance/committees/chemicalsafety/hazard-assessment.html)

[Division of Research Safety: Standard Operating Procedures](https://www.drs.illinois.edu/Programs/StandardOperatingProcedures)

***Tools for selection of hazard controls***

Once the hazards have been identified, control measures aim to eliminate or mitigate (lessen) the risk from each hazard. Consult: [American Chemical Society: Control Measures](https://www.acs.org/content/acs/en/about/governance/committees/chemicalsafety/hazard-assessment/fundamentals/control-measures.html)

Chemical fume hoods are an important engineering control as they provide protection from vapors, splashes and impacts from chemicals and their reactions. Consult: [Division of Research Safety: Fume Hoods](https://www.drs.illinois.edu/SafetyLibrary/ChemicalFumeHoods)

PPE should be considered as the last line of defense against exposure to hazardous materials. If used, they should be selected correctly to protect against the hazardous material and must fit the wearer. Each person using PPE must understand when PPE is needed, what PPE is needed, how to properly wear, adjust, and remove PPE, as well as how to clean or maintain or dispose of PPE. Personnel must understand the limitations of PPE. Consult: [Division of Research Safety: Personal Protective Equipment](https://www.drs.illinois.edu/SafetyLibrary/PersonalProtectiveEquipment)

***Change management***

The SOP needs to be reviewed on an annual basis and whenever events or conditions arise that trigger a review, such as:

1. An incident or significant near miss or close call.
2. Modifications to equipment other than replacement in kind.
3. Use of a commercial product for a purpose for which it was not designed.
4. Increased risk beyond what is covered in the SOP.
5. New experiment, equipment, or control software.
6. A change/improvement in an SOP or other program document is made.
7. New materials are introduced to an experiment that were not accounted for in the SOP.
8. Changes in essential personnel.

It also helps to maintain a *change management document* that lists sections or items in the SOP that need to be checked in every review, such as: web links, names of resource persons, or other information that might become outdated.

***Reference material***

[Basquin, S. and Smith, K. *Hydrogen Gas Safety: Self-study*, Document No. ESH13-401-sb-8/00, Los Alamos National Laboratory, Los Alamos NM, 2000](http://miningquiz.com/pdf/Mine_Gases/hydrogengassafety.pdf).

Hydrogen Tools.Org: [Best Practices](https://h2tools.org/bestpractices/), [Safety Resources](https://h2tools.org/hsp/safety-resources), [Online Hydrogen Safety Training](https://h2tools.org/content/doe-hydrogen-safety-training-researchers), [Lessons Learned database](https://h2tools.org/lessons) and [Hydrogen Safety Checklist](https://h2tools.org/sites/default/files/HydrogenSafetyChecklist.pdf).

The reports of the UC Center for Laboratory Safety concerning the University of Hawaii Hydrogen/Oxygen Explosion of March 16, 2016 offers insights on how the incident could have been prevented. [Report 1](http://www.hawaii.edu/news/wp-content/themes/davinci-20-child/docs/report-1-university-of-hawaii.pdf) and [Report 2](http://www.hawaii.edu/news/wp-content/uploads/2016/07/Report-2-University-of-Hawaii.pdf).

[Prudent Practices in the Laboratory. Handling and Management of Chemical Hazards. NRC (National Research Council). National Academy Press: Washington, DC, 2011.](http://www.nap.edu/catalog/12654/prudent-practices-in-the-laboratory-handling-and-management-of-chemical)

[Identifying and Evaluating Hazards in Research Laboratories. ACS (American Chemical Society) 2015.](http://www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/identifying-and-evaluating-hazards-in-research-laboratories.pdf)

# Record of changes made to this SOP

Describe the changes made to this document since its creation. Identify the personnel who made the edits or revisions and when the change was made.

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| **Date of change** | **Changed by** | **Description of change** |
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Standard Operating Procedure for Use of Hydrogen Gas and its mixtures

# Training record

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