# Standard Operating Procedure

**Chemical name and concentration:** Hydrogen from gas generator, 99.9%

*This is an SOP template. It is not complete until:*

1. *Apparatus design and implementation has been reviewed and approved by each of the following:*
   1. *ASU EHS (this includes the ASU Fire Marshall review)*
   2. *ASU FDM FM KE Hazardous Materials Operations Team*
   3. *FSE DO Infrastructure and Safety Team (IaST)*
2. *Lab specific information is entered into the box below.*
3. *Lab specific engineering controls, apparatus, and procedure are added to the relevant sections.*
4. *SOP has been reviewed, signed, and dated by the PI and relevant lab personnel.*
5. *All italicized/red text has been removed/replaced with information specific to the chemical process and the lab.*
6. *All office phone numbers provided must forward to a working and answerable phone.*

|  |  |  |  |
| --- | --- | --- | --- |
| **FSE School and Department:** | Click here to enter text. | | |
| **SOP preparation date:** | Click here to enter a date. | **SOP approval date:** | Click here to enter a date. |
| **Principal investigator:** | Click here to enter text. | Office phone: |  |
| **Lab manager name:** | Click here to enter text. | Office phone: |  |
| **Laboratory phone:** | Click here to enter text. | **Office phone:** |  |
| **Emergency contact:** | Click here to enter text. | **Contact phone:** | Click here to enter text. |
|  |  |  |  |
| **Laboratory locations covered by this SOP – building and room number** | | | |
| Click here to enter text. | | | |

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| **Type of SOP** |  | Process |  | Hazardous chemical |  | Hazardous class |

# Hazards Identification

## **GHS Classification**

|  |  |
| --- | --- |
| Simple asphyxiant | SIAS |
| Flam. Gas 1 | H220 |

## **GHS Label Information**

### **Pictogram**

Logo, icon

Description automatically generated

### **Signal Word**

Danger

### **Hazard Statement(s)**

|  |
| --- |
| H220 - EXTREMELY FLAMMABLE  CGA-HG04 - MAY FORM EXPLOSIVE MIXTURES WITH AIR  CGA-HG08 - BURNS WITH INVISIBLE FLAME |

### **Precautionary Statement(s)**

|  |
| --- |
| P202 - Do not handle until all safety precautions have been read and understood.  P210 - Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking. Heat, Open flames, Sparks, Hot surfaces  P271+P403 - Use and store only outdoors or in a well-ventilated place.  P377 - LEAKING GAS FIRE: Do not extinguish, unless leak can be stopped safely.  P381 - Eliminate all ignition sources if safe to do so.  P304, P340, P313 - IF INHALED: Remove person to fresh air and keep comfortable for  breathing. Get medical advice/attention.  CGA-PG05 - Use a back flow preventive device in the piping.  CGA-PG02 - Protect from sunlight when ambient temperature exceeds 52°C (125°F). |

### **Other Hazards:**

Burns with invisible flame.

Chemical asphyxiant. Exposure to low concentrations for extended periods may result in dizziness, or unconsciousness, and may lead to death.

# Physical and Chemical Properties

|  |  |  |  |
| --- | --- | --- | --- |
| CAS | 1333-74-0 | Melting Point/Range | -259.2 °C (-434.56 °F |
| Molecular Formula | H2 | Boiling Point/Range | -252.9 °C (-422.97 °F) |
| Molecular Weight | 2 g/mol | Flash Point | < -150 °C (< -238 °F) - closed cup |
| Physical State, Color | Gas, colorless gas | Upper flammability/ explosion limit | 77% |
| Odor | Odorless | Lower flammability/ explosion limit | 4% |
| Odor Threshold | No data available | Autoignition Temp. | 566 °C (1051 °F) |
| Evaporation Rate | No data available | Decomposition Temp | No data |

# First Aid Procedures

**If inhaled,** move to fresh air and keep at rest in a position comfortable for breathing. If the person is not breathing, give artificial respiration. Avoid mouth to mouth contact. If breathing is difficult, trained personnel should give oxygen. Call 911. Then call EHS at 480-965-1823.

**In case of skin contact,** adverse effects not expected from this product.

**In case of eye contact,** immediately flush eyes thoroughly with water for at least 15 minutes. Hold the eyelids open and away from the eyeballs to ensure that all surfaces are flushed thoroughly. Contact an ophthalmologist immediately.

Use nearest emergency eyewash immediately. Call 911. Then call EHS at 480-965-1823.

Ingestion is not considered a potential route of exposure.

# Leak and Accident Procedure

## **Personal precautions**

* Do not breathe gas. Ensure adequate ventilation.
* If the leak poses a respiratory or explosion threat, evacuate the lab and call EHS (480-965-1823).
* Do not attempt to stop leaks unless a gas sensor confirms it is safe to approach the hydrogen gas generator and shut it off. Contact Lab Manager to determine next steps for any suspected leaks.

**Danger:** EXTREMELY FLAMMABLE GAS. Forms explosive mixtures with air and oxidizing agents. Stop generation of product with shut-down button, if safe to do so. Remove all sources of ignition, if safe to do so.

Evacuate personnel to a safe area. Flammable gas may spread from leak. Do not re-enter the area until the emergency response command has communicated it is safe to do so. Work with the Lab Manager to assess the equipment and system installation status including the gas supply lines.

*Include the gas shut-down procedure here. Include a photo or schematic of where any buttons/valves required for shutdown are located.*

## **Environmental precautions**

Shut off the gas generator, if safe to do so.

## **Methods and materials for containment**

* If the lab was evacuated due to unsafe atmosphere, a fellow lab worker shall call 9-1-1, and then EH&S at (480) 965-1823.
* Follow posted ASU Emergency Response Guide procedures for hazardous materials incidents. Do not attempt to repair leaks.
* Wear appropriate PPE if not already being worn
* If the hydrogen gas sensor(s) indicate that the hydrogen gas has not yet reached its lower explosive limit (4%), and the hydrogen gas generator can be safely approached, shut off the gas flow by turning off the hydrogen gas generator.
* If the gas sensor alarm indicates the hydrogen gas is above 4%, evacuate personnel to a safe area. Flammable gas may spread from leak.
* Do not re-enter the area until the emergency response command has communicated it is safe to do so.
* Repairs on gas systems should only be performed by knowledgeable and qualified personnel.
* Work with the lab manager to assess the equipment and system installation status including the gas supply lines.

# Other precautions for handling, storage, and use:

When handling product under pressure, use piping and equipment adequately designed to withstand the pressures to be encountered. Never work on a pressurized system. Use a back flow preventive device in the piping. Gases can cause rapid suffocation because of oxygen deficiency; store and use with adequate ventilation. If a leak occurs, turn off the hydrogen gas generator and shut down the system in a safe and environmentally correct manner in compliance with all international, federal/national, state/provincial, and local laws. Work with the Lab Manager to evaluate next steps for the leak. Schedule the appropriate repair of the leak with outside contractors or the FDM FM KE Hazardous Materials Operations team.

Post “No Smoking/No Open Flames” signs in use areas.

Use only where temperature will not exceed 125°F (52°C). There must be no sources of ignition. Follow appropriate codes and requirements (e.g, NFPA 30, NFPA 55, NFPA 70, and/or NFPA 221 in the U.S.) or according to requirements determined by the Authority Having Jurisdiction (AHJ).

# **Incompatible materials:** Oxidizing agents. Lithium. Halogens.

Keep away from heat/sparks/open flames/hot surfaces. – No smoking.

Can form explosive mixture with air. May react violently with oxidants.

# Emergency and Standard Operations Shut Down

## **Emergency Shut Down**

FSE strongly recommends only running the hydrogen gas under the direct supervision of lab personnel. If hydrogen gas will be running through system while the system is unattended, an automatic shut down function (the hydrogen gas supply shutting off upon sensor detection of 4% or more hydrogen gas) is required.

* *List the steps required to quickly shut down hydrogen gas supply in the event of an emergency.*
* *Include photos of relevant buttons, valves, or other controls.*
* *Clearly label and identify the gas type on each gas line.*
* *Clearly label the hydrogen gas generator shut-off button with bright red markings.*

## **Standard Operations Shut Down**

* *List the steps required to shut down hydrogen gas supply in the event of tool maintenance, or tool inactivity for 1 week or more.*
* *Include photos of relevant buttons, valves, or other controls.*
* *Clearly label and identify the gas type on each gas line.*
* *Prior to disconnecting any part of the system, FSE requires a purge source (inert gas) for safely purging the hydrogen out of the gas panel and lines.*
* *Prior to leaving the system out of operation for 1 week or more, FSE strongly recommends the system to be purged with inert gas (left in an inert state). Vent or isolate the hydrogen generator lines piped to the tools so that they are at atmospheric pressure when not operational.*
* *Place signage at the tool (including your contact information) indicating the tool’s status.*

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# Personal Protective Equipment (PPE), Handling Requirements, & Engineering Controls

## **Personal Protective Equipment (PPE)**

### **Respiratory protection**

* The required engineering controls noted below must provide adequate ventilation to ensure a safe breathing environment.
* In the case of leaks, personnel must shut down the equipment.
  + If the gas sensor alarm indicates it is not safe to get close enough to shut it off the hydrogen generator or its power supply, evacuate from the lab immediately.
  + Do not re-enter the area until the emergency response command has communicated it is safe to do so.

### **Eye, Skin, & Hand protection – During Gas Use**

Wear appropriate PPE based on other hazards in the lab.

## **Handling Requirements**

* Keep away from heat, hot surfaces, sparks, open flames, and other ignition sources. No smoking. Use only non-sparking tools. Use only explosion-proof equipment.
* Wear close toed shoes and long pants.
* Never apply flame or localized heat directly to any part of the gas generator. High temperatures may damage the generator and could cause the device to catch fire.
* The lab where the material is being handled must have an approved / certified emergency eyewash and safety shower.
* Ensure you are wearing the required PPE and using appropriate engineering controls as stated above.
* Lab emergency contact information must be readily posted. Easy access to a cellular phone or land line is readily available.
* All lab personnel are required to have completed ASU Compressed Gas Safety training and mentor verification.
* FSE strongly recommends that all lab personnel be present when the hydrogen generator is powered on, and directly oversee all hydrogen gas use.
  + If hydrogen generator is permitted to remain powered on while the system while it is unattended, an automatic shut down function (the hydrogen gas supply shutting off upon sensor detection of 4% or more hydrogen gas) is required.

## **Engineering Controls**

If you are using a hydrogen gas generator, then the hydrogen generator must be covered by the same ventilation and gas sensor monitoring as all other connectors and valves in the experimental apparatus (see below).

*Attach or append the hydrogen gas generator manufacturer’s user guide/manual here.*

If you are using a compressed gas cylinder, and if the cylinder contains 4% or higher H2 gas, see the [FSE H2 Gas Cylinder SOP](https://safe.engineering.asu.edu/wp-content/uploads/2022/08/FSE-H2-Gas-Cylinder-SOP-Template-080822.docx) Template instead.

*Include a labeled diagram, schematic, or photo of the entire apparatus, from the hydrogen gas generator to the facility’s external exhaust connection(s). The following attachment is a template that can be edited. Keep in mind that each connection point creates a potential leak hazard and each area where connection points occur, will require a gas sensor monitoring in that area (gas mixing units also require external exhaust and sensors).*



* Post “No Smoking/No Open Flames” signs in storage and use areas.
* Using a H2 gas generator with automatic leak detection shutoff functions is strongly recommended.
* The H2 gas generator, connection point to the gas generator, and any other areas with gas connectors or valves must also have external exhaust and gas sensor monitoring.
* Prior to disconnecting any part of the system, FSE requires a purge source (inert gas) for safely purging the hydrogen out of the lines.
* Prior to leaving the system out of operation for 1 week or more, FSE strongly recommends the system to be purged with inert gas (left in an inert state). Vent or isolate the generator lines piped to the tools so that they are at atmospheric pressure when not operational.
* Hydrogen gas is a very small molecule and can pass through the interstitial space of many solids and elastomers. Only use system/apparatus components that are specifically certified and rated for use with hydrogen gas.
* Due to small molecule size, the best-performing hydrogen gas fittings are ones that have the most surface-to-surface contact with each other. Fittings with a single point of contact, such as ball-and-cone fittings, can leak easily.
* **Never** re-use piping or fittings for flammable or toxic gases.
* Only clean 316 stainless steel piping, with orbitally welded connections, can be used for conveying pressurized hydrogen gas.
* Do not design your system with any hydrogen gas pipe bends or turns greater than 90°.
* H2 gas flow should be kept linear, with any other introduced gases coming in from side branches. Joints or bends in the piping must be orbitally welded by trained and certified personnel. Contact your lab manager for guidance.
* Hydrogen is small enough to pass into the interstitial spaces in the crystalline lattice of steel. This can cause embrittlement of steel and crack propagation. All H2 gas lines must be securely bracketed to structural supports in a way that prevents mechanical stress along the gas lines and fittings.
* All metal piping must keep a consistent diameter throughout the apparatus (1/4” diameter is recommended). Large-to-small pipe fittings create mechanical stress.

All lines from flammable or toxic gas cylinders must have the following:

* Check valve / non-return valve between the H2 gas source and the mixing or use chamber
* A bypass valve (3-way ball valve that allows for gas shut-off, and allows for the gas to bypass the use chamber and pass directly to exhaust – see Gas Schematic Template)
* If gases are mixed, the mixed gas must also have its own check valve and bypass line between the mixing chamber and use chamber.
* Anywhere there is a mechanical fitting, valve, or an operation area, gas monitoring and exterior exhaust is required.

*If any parts of the apparatus were purchased, attach or append the manufacturer’s user guide/manual to this SOP.*

*List the maximum flow rate(s) and maximum pressure that the gas system is certified to tolerate. Ensure regulators are properly sized to laboratory apparatus requirements. Always assume the regulator can fail full-open at the highest flow rate/pressure.*

*Note the air change rate for the laboratory space where the hydrogen system is located.*

## **Hydrogen Gas Generator Maintenance**

*Include the maintenance schedule.*

*Include the maintenance procedures that are required. If the maintenance must be performed by a technician, include their company contact information.*

*Keep a maintenance log with the lab documentation.*

[Hydrogen Gas Generator Maintenance Log](https://www.dropbox.com/s/kor30bhssgs6f2t/Hydrogen%20Gas%20Generator%20Maintenance%20Log.xlsx?dl=0)

## **Gas Monitoring System (Sensors)**

*Hydrogen gas or flammable gas detectors are required, in the breathing zone around the area of use (everything not in an exhausted enclosure), and any other locations where hydrogen could accumulate (fittings or valves).*

*Blue strobe lights, activated by high-level gas alarms, are required to indicate when the lab has a hazardous gas leak in progress. Where these blue lights are not visible through windows into the lab space, the lights must be placed outside any doors providing access to the room with the leak. It is also recommended to have a remote or web-accessible gas sensor display outside of the room to check levels without potentially entering a flammable environment.*

*All extractive gas sensors must be exhausted to the exterior of the building, the same as any other area or airflow that may contain hydrogen gas.*

Gas sensors should be calibrated to low level alarm at 2% and high level alarm at 4%. While you may observe different alarm set points in other units at ASU, FSE restricts the high level alarm to the LEL for work with flammable gases.

Low level gas alarms will send a supervisory notification to the building’s fire alarm control panel, but there are no building fire horns/strobes. If the sensor registers more than 2%, immediately shut down any suspected leak sources. Press the Hydrogen Generator Shut Off button, if safe to do so.

A 4% H2 level detected by the sensor should trigger the general building alarm and force the evacuation of all labs and rooms in the building. FSE strongly recommends installing the sensor such that, in the event of high level alarm, the hydrogen generator is shut down automatically. If the hydrogen generator may be powered on when the system is unattended, this automatic shutoff function is *required*. The high level alarm shall also trigger a blue strobe light, which must be visible through windows or exterior displays outside the lab.

*Attach or append the gas sensor manufacturer’s user guide/manual here.*

## **Gas Monitoring System Maintenance**

*Include the maintenance schedule.*

*Include the maintenance procedures that are required. If the maintenance must be performed by a technician, include their company contact information.*

*Keep a maintenance log with the lab documentation.*

[Gas Monitor Maintenance Log](https://www.dropbox.com/s/a739xqw45c1420w/Gas%20Monitor%20Maintenance%20Log.xlsx?dl=0)

## **Waste Gas Abatement**

Hydrogen gas is flammable and can be ignited by static discharges within exhaust ductwork. If there is any chance that hydrogen gas will enter the building exhaust at concentrations above the LEL/LFL (Lower Explosive Limit / Lower Flammability Limit), then a waste gas abatement device must be used between the release point and the building’s exhaust. Since hydrogen is most easily abated through combustion, this device is often referred to as a burn box.

Gas abatement devices are only designed to handle specific gases. If non-hydrogen gases will be used or generated in the apparatus during the process, check with the gas abatement manufacturer and provide the manufacturer with the highest gas flow rates that might be used. Ensure all gases are compatible with the abatement system, and that gases emitted into the exhaust meet both ASU and national safety & emissions regulations. (ASU EHS will review the plan to ensure emissions are appropriately addressed.)

*Attach or append the gas abatement manufacturer’s user guide/manual here.*

## **Gas Abatement Maintenance**

*Include the maintenance schedule.*

*Include the maintenance procedures that are required. If the maintenance must be performed by a technician, include their company contact information.*

*Keep a maintenance log with the lab documentation.*

[Gas Abatement Maintenance Log](https://www.dropbox.com/s/qaqriypd6iglboc/Gas%20Abatement%20Maintenance%20Log.xlsx?dl=0)

# System Start Up or Change Requirements

Before the hydrogen gas generator can be switched on, or if any changes are made to an existing gas process or apparatus, all parts of the tool/apparatus & engineering controls, and their design and implementation, must be reviewed and approved by:

* The research group PI, collaborating PI, and all researchers working with hydrogen
* Your school/department Lab Manager
* The FSE DO Infrastructure & Safety Team
* The FDM FM KE Hazardous Materials Operations Team
* ASU EHS & ASU Fire Marshall

## **Verification of System/Apparatus Function**

Before the first time the hydrogen gas generator can be switched on,,

or if the system is moved to a new location,

or if any modifications are made to the system,

then the system must be fully checked for functionality.

This includes:

* Leak testing with an inert gas (preferably helium, to match the small molecule size of the intended use gas)
* Gas cabinet function tests, according to KE Hazardous Materials Operations team’s Standard Operating Procedure



* Gas sensor testing, including fire alarm panel codes, power outage testing, sensor-initiated pneumatic gas shut-down
* Testing of the hydrogen generator shut-down button

# Protocol and procedure

*Add your lab’s specific procedures in this section.*

* *Write out separate steps in a bulleted or numbered list format for easy reading.*
* *Please include photos whenever possible.*
* *Be specific and descriptive – future generations of researchers in your lab may need to learn the procedure from this document.*

## **Running Experiments**

*Experimental procedure section*

## **Purging Lines Before Tool Inactivity (Parking the Tool)**

H2 is a very small molecule. When taking a break of 1 week or more between experiment runs, gas supply sources should be powered down and the lines purged with an inert gas. If your lab’s gas system does not have the hardware to allow inert gas purges, then bleed gas lines to atmospheric pressure during research breaks.

See Emergency and Standard Operations Shutdown Procedure section above.

## **Experiment Log**

You must keep a tool experiment log as part of your lab’s documentation.

Use the following template as a guide, and add columns as needed.

[Experiment Log Template](https://www.dropbox.com/s/8p9evyybhp8q4ux/Experiment%20Log.xlsx?dl=0)

**Important note:** Any deviation from this SOP requires advance PI approval with review of the Lab Manager and FSE DO Infrastructure and Safety Team member.

# Documentation of training

* Prior to conducting any work with this material, Principal Investigator or designee must provide to his or her laboratory personnel specific to the hazards involved in working with this substance, work area decontamination, and emergency procedures.
* The Principal Investigator must provide his/her laboratory personnel with a copy of this SOP and a copy of the Safety Data Sheet or SDS provided by the manufacturer.
* The Principal Investigator must ensure that his/her laboratory personnel have attended appropriate/required laboratory safety training or refresher training within the last one year.
* Lab personnel is responsible for maintaining the training documentation.
* Any modifications to the Tool/Apparatus or Gas Delivery/Monitoring System requires a Safety Review with the FSE DO IaST and FDM FM KE Hazardous Materials Operations Team.

**I have read and understand the content of this SOP.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Employee name** | **ASU affiliate no.** | **Signature** | **Date** |
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