Gaseous Hydrogen Safety Considerations

CHS Webinar Q&A

Key words: ignite, static charge, electrolyzers, ignition, electrical classification, releases, vent stack, vent, atmosphere, flare, fire, separation distance, flame arrestor, toroidal ring, airfield, pipeline, materials, compatibility, cast iron, piping, leak, gas detector, calibration detector, portable, outdoors, truck, attributes, set point, extinguish, explosion, deluge, relief, TPRD, indoors, threshold, natural gas, blending, material compatibility, odorant, PRD, pressure, mobile, helium, fueling station, railroad, train, oxygen, Korea, overpressure, composite, tank, cylinder, laboratory, odor, fuel cells, conversion, delayed ignition, jet fire, hazard analysis, jacketed, barriers, liquid, residential, furnace, risk, BLEVE, emergency response, deflagration, detonation, training, underground, storage, tube trailer, fueling station, gasoline, diesel, electric charging, rupture panel, instruments, valves, actuator, procedure, dispersion, model

The information in this document provides answers to the questions that were raised during the Center for Hydrogen Safety April 27, 2023 webinar. The Q&As are sorted by topic with the question number for reference. The Q&As are sorted by topic with the question number for reference. Redundant questions were deleted from the original list.

Ignition 5, 28, 29,

5. Can static discharges really ignite hydrogen releases?

Static is a frequent source of ignition attributed to various hydrogen releases. Low levels of static electricity are sufficient to ignite hydrogen – air mixtures. Static charges can be created by the atmospheric disturbances and storms, high velocity particles entrained by the gas impacting stationary objects, and human activity. Grounding of equipment and operators is important to lower the probability of static discharges.

28. When hydrogen electrolyzers are installed in a ventilated building, how can we prevent the high-voltage equipment from being a potential ignition source?

Electrolyzers should be installed per manufacturer recommendations and meet the criteria of their listing, such as ISO 22734, *Hydrogen generators using water electrolysis - Industrial, commercial, and residential applications*. There are several methods such as partitions, enclosures, ventilation, and purging that can be used to address non-classified electrical equipment.

29. Is there any guidance available to help hazard analysis teams evaluate the likelihood of ignition for hydrogen releases?

There is no consensus on the "correct" answer. Small leaks of short duration have a much lower probability of ignition compared to large releases. Ignition probability is affected by the operating conditions, whether the release is from a leak or vent stack, and the surrounding environment. Since the probability of ignition is high, hazard analyses will usually assume the hydrogen will likely ignite and should consider the potential consequences of ignition to the system and surroundings.

Vent 6, 12, 16, 24, 33, 41, 42, 59, 64, 69, 81

6. What are the best practices for metallic vent stacks?

There are dozens of safety considerations for safe design of hydrogen vent stacks. Their primary function is to vent the hydrogen safely, so vent stacks should be designed such that the gas dispersion and radiation profile (if ignited) do not impact surrounding equipment, buildings, or people. Documents such as CGA G5.5, *Hydrogen Vent Systems,* provide numerous details regarding design. Vent stacks should be designed to handle expected thrust loads, weather conditions, and hydrogen ignition scenarios. Various building and electrical codes describe basic grounding requirements.

12. For H2 vents, are there any special considerations for noise levels?

As with any high pressure gas, hydrogen vents can be very loud. Consideration must be given to the surrounding population and special provisions can be taken to reduce the noise level of releases if needed. When installed, care must be taken that the sound quieting system can withstand the flow/pressure of the release and does not impede the required flow.

16. In the past, it was acceptable to vent small amounts of hydrogen (e.g. compressor seal vents) to the atmosphere – is this still the case?

Each system must be evaluated individually, and it depends on the amount and location of possible releases. Routing vent lines to a vent stack is the most common approach when venting directly to atmosphere is not acceptable.

24. Are there any specific design considerations or standards in place to prevent stack fires?

Vent stacks should always be grounded in accordance with electrical standards which will reduce the probability of, but not eliminate, vent stack fires. There are numerous design features, such as toroidal rings, that have been suggested to reduce vent stack fires. However, given the many sources of ignition that can potentially ignite vent stack releases, it is virtually impossible to eliminate all such fires so proper design of the vent stack to be able to withstand over-pressures and continuous flame are critical to the design.

33. How far should an H2 vent stack be from the closest tank or structures?

Guidance for location of vent stacks is provided by NFPA 2, *Hydrogen Technologies Code,* which also references CGA G5.5, *Hydrogen Vent Systems,* for additional guidance. Minimum distances to vent stack outlets should be determined from dispersion and radiation analyses. The height of the vent stack and orientation of the release will affect the minimum separation distance.

41. Is installing a flame arrestor at the vent generally accepted practice?

The suitability of flame arrestors depends on the design of the system, but generally flame arrestors are rarely needed for hydrogen systems when there is a 100% hydrogen atmosphere upstream of the vent, and when the downstream vent system is designed to withstand internal ignition. Flame arrestors can also cause potential blockage or restriction of flow, so relative risks need to be carefully assessed when they are installed on vent lines.

42. Are there effective methods to prevent ignition of vented hydrogen streams from vents using toroidal ring designs?

There is some indication that toroidal rings can reduce static buildup and ignition of hydrogen from a vent. However, while toroidal rings may help with static, they have not been proven to eliminate all static ignition sources. There are also other sources of ignition that they would not prevent, so they might reduce but not eliminate, vent stack fires. Another method that can be reliably used to reduce or eliminate unintended vent stack fires is to dilute the flow below the flammable range. This can be a potential mitigation for small releases, but often becomes impractical with larger releases due to the amount of diluent needed.

59. What are the guidelines on where to route a hydrogen stream from a PSV (Pressure Safety Valve) release or depressure system?

The routing will be dependent on the system design, size of release, and evaluation of the hazards. Smaller systems are rarely vented to a flare due to complexity, availability and permitting considerations. Facilities handling large amounts of hydrogen such as production plants will often have a flare system since they have more capability for this additional onsite infrastructure.

69. Is there a maximum hydrogen flow rate that can be vented to the atmosphere? For big electrolyzer systems, it could be necessary to route these streams to a flare system.

There is no maximum flow-rate that can be vented to the atmosphere, but the hazard analysis should consider the potential risk of dispersion, radiation, and overpressure as part of the vent system design. Flare systems are often used at large hydrogen production facilities as one means to prevent a large unignited cloud from forming but will depend on the specific application.

81. What are some considerations of hydrogen vent stacks at an airfield with regard to planes overhead?

Dispersion and radiation analysis should be conducted to ensure that the hydrogen cloud will not interfere with the flight path of aircraft. In addition, there may be maximum height requirements due to airport requirements depending on the location of the stack.

Material Compatibility 9, 21, 23,

9. Are there any specific safety considerations regarding the transportation of hydrogen in pipelines, both steel and polyethylene?

Hydrogen affects the mechanical properties of most materials. For example, hydrogen reduces the fracture toughness and increases the fatigue crack growth rate in steels. There is a significant amount of research, analytical work, and codes and standards development being undertaken to improve our understanding of how these materials can be utilized in pipelines. The results of the efforts will be revealed as requirements in codes like ASME B31.12, *Hydrogen Piping and Pipelines,* and ASME B31.8, *Gas Transmission and Distribution Piping Systems*, and then addressed by national regulations, such as those provided by the US DOT Pipeline and Hazardous Material Administration (PHMSA).

21. It's interesting to note that cast iron can be used in certain circumstances. However, the ASME B31.12 standard prohibits its use. Are there specific pressure ranges or operating conditions in which the use of cast iron may be accepted?

Because cast irons are relatively brittle materials, they should generally be avoided in industrial and transmission pipeline applications. In low pressure applications like residential distribution piping systems, the use of cast irons is probably acceptable.

23. What guidance is available regarding material compatibility in relation to hydrogen piping? Is austenitic steel, such as 316SS, always the recommended choice?

Acceptability of materials is highly dependent on the specific application. Applied stress levels, exposure to contaminants, the operating temperature, the partial pressure, and number and magnitude of material stress cycles are some of the factors that affect material selection. Guidance is provided within documents such as ISO 11114, *Gas cylinders - Compatibility of cylinder and valve materials with gas contents,* ASME B31.12, *Hydrogen Pipe and Pipelines,* and NFPA 2, *Hydrogen Technologies Code*. The Sandia Technical Reference site (https://h2tools.org/technical-reference-for-hydrogen-compatibility-of-materials) also provides information for users to make informed selections. For ambient temperature systems designed to rules described in accepted codes and standards, austenitic stainless steel is frequently a good choice.

Leak Detection 19, 22, 25, 48, 55, 56, 57, 61, 66

19. If the flame from hydrogen is not visible in daylight, would it still produce a sound that is detectable?

Releases from high pressure hydrogen systems often make a sound. In those cases, sound might be the easiest way for a person to know there is a hazard. However, leaks can be relatively small and diffuse, thereby not making much sound, or alternately large and so loud that they can be very difficult to find. In both cases, it can be hazardous to move into or through an area.

22. How frequently do gas detectors need to be calibrated, and can we perform the calibration ourselves?

The manufacturer's calibration requirements should be followed to ensure proper operation of the detection system. The requirements will vary depending on the type of detector and the environment in which they are installed. Calibration can usually be performed by the user/owner if properly trained and supplied with calibration gas, etc.

25. What are effective devices and protocols that can be used to detect hydrogen?

Training personnel and equipping them with portable gas detectors to properly identify the gas that is leaking can play an important role in both troubleshooting and emergency response.

48. Is there value in having detection for outdoor hydrogen systems?

While hydrogen gas detectors are less effective outdoors, they can be an important safeguard as part of an overall hydrogen system design. They have been used in many cases to automatically shut down equipment and isolate hydrogen supply. Location and type of detectors depend on the system design and siting, but when installed, should be in areas that are most likely to be exposed to hydrogen releases. Dispersion analysis can help with that assessment.

55. What are leak detector requirements for hydrogen refueling stations, production assets, pipelines, etc.?

Leak detection system requirements depend on the system design and applicable codes. The appropriateness of detection equipment depend on many factors, including the type of system, application, location, and probability of leaks. For example, hydrogen refueling stations are required by code to be equipped with leak detection systems.

56. In a vessel, how much hydrogen leakage or loss is usually expected?

Leakage/loss depends on the vessel design. Metallic or metallic lined vessels have extremely low permeability and losses through the vessel walls are typically imperceptible. Conversely, Type IV composite vessels which have non-metallic liners are subject to permeation. They are required to meet maximum permeation rates as part of their certification. Fugitive emissions from piping systems can also be considered and is dependent on the specific design and level of maintenance.

57. Do heavy-duty hydrogen fuel cell trucks have a requirement to detect hydrogen leaks with sensors near their fuel cell system and/or near their hydrogen storage tanks?

Detection systems are nearly always installed but the system design and installation details of detection equipment are up to the manufacturer. Standards are being developed for this market.

66. What attributes are important for a hydrogen leak detector? What concentration of hydrogen is the normal set point?

Speed of detection, detection limit, location, and cross-sensitivity are some of many criteria that might be used for selecting a detector. A common setpoint for gaseous hydrogen detection is 25% of LFL, or 1% concentration in air. However, the detection limit also depends on the system and exposure. When specific hazards are likely, detectors may have detection limits in the low-ppm range. Lower detection limits can offer earlier detection, but also at the risk of spurious trips.

Fire Protection 38,75,

38. Most MSDSs recommend not to extinguish a hydrogen fire, rather to try to disconnect the hydrogen source. In which cases is extinguishing recommended?

Situations where extinguishing a hydrogen leak prior to stopping flow is safer are rare. Hydrogen releases have a high potential for inadvertent re-ignition and subsequent explosion. Some vent stacks might be equipped with an extinguishing system, but these often can be more hazardous than allowing a properly designed vent stack to continue to burn until the source is isolated.

75. Is a water deluge a common active fire protection system in hydrogen facilities?

No, this is not a common or preferred approach. Isolating the source of hydrogen is the best safety practice. Water systems could extinguish the flame but allow the gas to continue leaking and result in an explosion if reignited.

Pressure Relief 49, 50,

49. What about TPRD (Temperature Actuated Pressure Relief Device)? Are they efficient to avoid storage tank explosion caused by overpressure during an external fire?

This is a complicated subject. Thermally activated pressure relief devices can be an important safeguard for hydrogen vessels if properly designed and installed in accordance with code requirement. Requirements vary globally and often depend on the type of vessel and its intended service (e.g. mobile or stationary). However, as with any device, TPRD's offer both advantages and disadvantages. System design, vessel location, surrounding exposures, other vessel protection options, type of vessel, consequences of a large release, and probability of inadvertent release are just a few of many parameters that should be considered.

50. In a mobile transportation hydrogen storage system, is it required to have a TPRD or PRD (Pressure Relief Device) on each vessel in the system?

Requirements for TPRD/PRD's depend on the local regulations. Some jurisdictions require them, some do not. Others make them optional based on results of performance testing.

Other Topics

1. What piping modifications and other safeguards need to be considered for the use of natural gas – hydrogen blends?

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Hydrogen has been transported safely through pipelines for over 50 years. There are dozens of pipeline networks in safe operation globally, with several individual networks that approach up to 1000 miles.

Significant testing and some demonstration projects are underway to ensure safety. Some of the aspects under investigation include compatibility of the pipe and other materials, effect on odorants, and the need to modify existing residential and industrial equipment. Blending initially is at relatively low levels where its impact on the operations of the existing natural gas distribution system is minimized.

3. Is there a threshold quantity of hydrogen for which some of the more common indoor safeguards may not be needed?

Documents such as NFPA 2, *Hydrogen Technologies Code*, and the *International Fire Code* have quantity thresholds that differentiate requirements for the design of systems and enclosures. However, even the smaller quantities present a hazard under specific conditions, especially for systems that have the potential to release hydrogen into a confined or unvented space. Good engineering judgement must be used regardless of the size of system. Also, the quantity of hydrogen connected to the system from outdoor storage must be considered in the overall design.

10. Is 'sniffer testing', as performed with N2/He in hydrocarbon industry, a viable leak detection technique in the Hydrogen context?

Nitrogen/helium blends are frequently used to leak test hydrogen systems.

11. What are the unique safety considerations with the sub-cooled hydrogen fueling method that Daimler Truck has developed?

All systems must be designed for the applicable operating parameters such as pressure, temperature, and flow. The sub-cooled liquid hydrogen (sLH2) approach for fueling is comparable to other processes commonly used to handle cryogenic liquids in the industrial gas industry where remaining gas is condensed during the fill operation. These processes often operate above the critical pressure and/or temperature of the fluid. A sLH2 system operates at much lower pressure, under 20 bar (290 psi), than "cryo-compressed" hydrogen (CCH) systems which commonly operate at 350 bar(5100 psi). sLH2 systems operate more like a liquid hydrogen (LH2) system that operates at a slightly higher pressure, while a CCH system is more comparable in operation to a high pressure gas system.

13. Are there any specific considerations, hazards or safety barriers that are applicable to the operation of hydrogen trains?

Hydrogen has been used as a fuel to operate cars, buses, trucks, submarines, aircraft, forklifts, trains and virtually every type of mobile equipment. Each has special considerations which often drive specific requirements for that vehicle type. For example, higher g-loadings of rail operations and operations within tunnels are a couple considerations, but there are no significant barriers that would prevent the application of hydrogen for trains for a properly designed system.

14. What were the causes of the 2019 explosion at the Korean research facility involving an electrolyzer and what were the lessons learned about design?

The suspected cause was a mixture of oxygen and hydrogen that passed downstream from the electrolysis unit into several storage vessels. Hydrogen-oxygen mixtures are very hazardous. Subsequent ignition resulted in internal pressure that exceeded the limits of the storage system. The design of electrolyzers, detection of upset conditions, and preventing the accumulation of oxygen within the hydrogen system is important for safe operation.

17. Is there a USA or Canadian standard being written for composite hydrogen storage cylinders?

Composite cylinders can be manufactured to standards written by CSA, ASME, and ISO depending on the application and local requirements. Several ISO standards can serve as the basis for composite cylinder approvals within North America.

18. What are some of the safety considerations for use of hydrogen cylinders within a laboratory?

Cylinders used within a laboratory can be used safely by meeting the requirements prescribed in NFPA 2, *Hydrogen Technologies Code,* and NFPA 45, *Standard on Fire Protection for Laboratories Using Chemicals*. Special consideration should be given to both safe handling and storage of cylinders. Regarding lecture size cylinders, their small size can make them susceptible to damage and mishandling. A release from an open valve or relief device can be hazardous, particularly if the potential hazard is underestimated.

26. Can hydrogen be odorized like natural gas?

Most common odorants will contaminate fuel cells. Additionally, hydrogen's small molecule and high buoyancy make it challenging to find a compatible odorant. Research is being conducted on fuel cell compatible odorants, but there are none currently in use. Like liquefied natural gas, liquid hydrogen also can’t be odorized due to its cryogenic temperature.

27. How may we confidently determine the condition of existing natural gas pipelines and networks that their owners wish to repurpose for hydrogen service?

The conversion is based on the condition as determined from a variety of non-destructive techniques which are commonly used for pipeline mechanical integrity programs. Existing natural gas pipelines are frequently evaluated for conversion to hydrogen, hydrogen-natural gas blend, and other fluid services. The conversion can be done safely if handled with the proper expertise and modifications.

30. What are important safety considerations for containerized electrolyzer systems?

The containerized electrolysis unit should be installed per manufacturer instructions, the requirements of its listing such as to ISO 22734, *Hydrogen generators using water electrolysis - Industrial, commercial, and residential applications,* and NFPA 2, *Hydrogen Technologies Code*. A primary consideration for indoor installation is the potential for hydrogen releases from the system, both planned and unplanned. Another consideration is the total quantity of hydrogen that could be released within the container or indoor area, especially with respect to the available ventilation.

31. Should overpressure due to delayed ignition of a hydrogen release as well as jet fires be considered when setting separation distances?

Each installation should be evaluated based on the results of a hazard analysis considering both of these scenarios. Separation distances as listed in documents such as NFPA 2, *Hydrogen Technologies Code,* are a minimum starting point but may need to be adjusted based on analysis. Recent work by NFPA 2 has also included overpressure criteria, but the consequences can vary depending on system design and surroundings.

32. Can double pipes be used for hydrogen leak detection?

Double pipes can be used in certain circumstances to reduce the likelihood of external leaks and increase the likelihood of detection by monitoring the space between the two pipes. Vacuum jacketed piping is double walled and is used in liquid hydrogen service to provide insulation. While not equipped with gas detection in the annular space, loss of vacuum is used to indicate an internal leak. If the outside pipe is not designed to withstand the pressure of the fluid within the inside pipe, it must be equipped with a vent to prevent buildup of annular pressure.

35. Are passive fire protection barriers typically provided to protect structures, pipe racks, etc., against hydrogen jet fires?

Each system should be evaluated for exposure of equipment to jet fires. The design team should develop a plan to mitigate exposure as part of the hazard analysis. Fire barriers, walls, enclosures, and insulation systems are frequently installed to meet code requirements where separation distances are not sufficient or where the probability of exposure to a jet fire is high. Barriers are sometimes installed for high risk exposures such as storage vessels, even if not required by Code rules.

43. Are remote impoundment basins required for liquid hydrogen facilities like those used for LNG facilities?

Liquid hydrogen is much less likely to pool than liquified natural gas (LNG) due to its low heat of vaporization. Very large facilities are often equipped with methods to enhance vaporization, such as crushed stone under tanks, as well as diversion systems to allow liquid hydrogen to spill and boil off in a safe area. Care needs to be taken that diversion systems do not create a hazardous situation by reducing ventilation.

45. There are talks about changing the home furnace heating source from natural gas to gaseous hydrogen. What are the implications, especially from an explosion perspective, and for any compressed gas cylinder setback distances in a rural setup?

Codes and standards to address issues like this one are under development, along with applied research and field trials. As with any new application, appropriate codes and standards must be developed to meet public risk targets.

47. Can an external fire on a liquid hydrogen storage tank result in a BLEVE (Boiling Liquid Expanding Vapor Explosion)?

By definition, liquid hydrogen can BLEVE, but this is highly unlikely. Liquid hydrogen is stored in a double wall tank with vacuum insulation. This protects the primary pressure vessel from direct impingement and the very cold liquid provides self-cooling of the vessel walls. Tanks are also equipped with redundant pressure relief systems that are sized for fire exposure.

52. Must a pressure vessel containing hydrogen be depressurized in an emergency?

In most cases, it is not necessary to depressurize hydrogen systems in an emergency. Pressure vessels are usually isolated in an emergency. The best actions to assure safety during an emergency should be identified during the hazard analysis.

53. Will a flammable hydrogen/air cloud detonate? If so, under what conditions?

Flammable hydrogen releases can result in deflagration and transition to a detonation. Whether the deflagration transitions to a detonation depends on numerous parameters such as cloud size, hydrogen concentration, confinement, and congestion. Releases into confined or congested areas are more susceptible to generating significant deflagration over-pressures and more likely to transition to detonation.

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54. How can I implement a hydrogen safety training program in a company where hydrogen is part of the future but not currently used or produced?

CHS has suitable introductory courses. These, along with a general overview of hydrogen, would probably suffice until work begins on systems design or actual use occurs. At that time more detailed courses should be taken by all those involved in these activities.

58. What are the concerns about underground hydrogen storage?

Underground storage tanks can be either installed in a vault or directly buried. Both offer additional protection from external impact and fire, but each has unique challenges. Vaults must be properly ventilated and designed to not create an explosion or asphyxiation risk. Direct burial vessels should not have any underground leak points and must be protected from corrosion. Both types of installation must have hydrogen vents routed to a safe location above grade.

60. What are general considerations for gaseous hydrogen tube trailer filling operation siting and safety features to consider? The hydrogen would be supplied by upstream compressors discharging at approximately 8000 psi (55 bar).

Systems should be sited in accordance with national and local standards such as NFPA 2, *Hydrogen Technologies Code*. The nature of a trailer filling operation is not much different than a vehicle fueling station, so the hazards are comparable and similar safeguards such as walls and sensors will apply. These facilities might be larger and industrial standards and regulations will also apply based on quantity stored at the location.

63. What risks are there with co-locating hydrogen fueling, petrol fueling, and electric vehicle charging? For example, does the potential overlap of hazardous areas of hydrogen and petrol introduce any unique mitigations?

Exposure between these products is bidirectional. A hazard analysis should consider what happens to alternate fueling equipment if an incident with one of the fuels occurs. Care must be taken to have the appropriate separation distance and mitigations according to the applicable codes. Limited experience with existing stations has shown that these multi-fuel stations can be successful when installed per code rules.

68. Should all containerized systems be fitted with rupture panels in the roof/walls?

Rupture panels can add an additional layer of overpressure protection against internal overpressure. Given the propensity of hydrogen to generate higher over-pressures when ignited compared to other fuels, rupture panels are often part of the safety design for containerized systems. The need for a rupture panel for a specific system will be determined by the system hazard analysis and the applicable codes. Documents such as NFPA 68 and 69 provide guidance on how best to provide explosion prevention and protection.

72. Is it common practice to use Safety Instrumented Systems (SIS) i.e., SIL-1 or higher rated systems on hydrogen systems?

While not required, Safety Instrumented Systems with a specific SIL rating are often used on hydrogen systems. The hazard analysis provides guidance as to whether a SIL rating for a given exposure is required and at what level. The SIL level depends on the probability and consequence of occurrence of a given hazard. Hydrogen equipment may be provided with different SIL levels within the same overall system.

77. Are there simulation models for potential leaks from dispensers at stations?

There are numerous models that can be used to assess the consequence and risk of leaks and releases. One such model is HYRAM which is publicly available from Sandia and the US DOE.

79. What are the emergency response procedures for a hydrogen-related incident?

Emergency response procedures must be developed for each system based on its design. The procedures generally include steps to clear personnel from the immediate area, isolate the hydrogen, shut down the equipment, contact local responders, and protect surrounding equipment/structures until the hazard is mitigated or the incident is over.

80. Are pneumatic or electric operated valves preferred for use in a fueling station?

Both types of valve actuators are used, and both offer advantages and disadvantages for a given application.