Venting for Gaseous and Liquid Hydrogen
CHS Webinar Q&A

Key words: LH2, BLEVE, tank, flaring, flare, flame, fire, flow, vent, stack, pressure, purge, temperature, valve, disc, vapor, radiation, water, heat, exhaust, TPRD, ignition

The information in this document provides answers to the questions that were raised during the Center for Hydrogen Safety January 30, 2024 webinar.

1.) **What are the typical criteria for determining the venting flow rates of LH2 facilities? For example, how quickly should LH2 be emptied in case of a potential BLEVE (boiling liquid expanding vapor explosion) caused by a fire near the LH2 storage tank?**

    There are several levels of documents which can be used to assist with the design, sizing, selection, and installation of the pressure relief device settings for LH2 tanks.

    Pressure vessel design codes, such as the ASME Boiler and Pressure Vessel Code will provide minimum requirements for design of pressure vessels (including LH2 tanks), relief devices, and relief systems. However, these codes will not provide the sizing criteria nor anticipate all of the potential demand cases that might be imparted upon a vessel.

    In the US, the model fire codes require compliance with NFPA 2, which then references documents such as CGA S1.2 and CGA S1.3 for sizing criteria. These documents have been customized by the industrial gas business specifically for cryogenic fluids such as LH2. API Standard 520 "Sizing, Selection and Installation of Pressure-Relieving Devices in Refineries" of is also a helpful document to provide additional guidance.

    For LH2 storage tanks, usually the highest process demand is an engulfing fire with a loss of vacuum insulation to atmosphere. This failure mode can result in additional heat flux from air condensation in the annular space which must also be addressed.

    It is not required to proactively vent the contents of an LH2 tank when exposed to fire. Relief devices are required to prevent the accumulation of internal pressure to unsafe levels. Within the ASME BPV, this is 121% of Maximum Allowable Working Pressure for scenarios involving fire exposure. It is common practice, but not required, that at least one device be non-reclosing (e.g. a rupture disc) for both managing the high flow required as well as to relieve the contents of the tank. Reclosing relief devices will maintain pressure in a fire and are more likely to lead to a vessel rupture if the fire ultimately weakens the pressure vessel.

    LH2 tanks are unlikely to BLEVE due to the vacuum insulation outer jacket (usually carbon or stainless steel) preventing direct impingement of fire onto the main pressure vessel, as well as the internal cryogenic contents maintaining the main pressure vessel walls at a cooler temperature until the contents have been relieved by the relief devices.

2.) **In what circumstances, such as specific flow rates, would you suggest flaring LH2 instead of venting it?**

Generally flaring is not recommended. Normally GH2 is not flared for most hydrogen equipment as the piping diameters are smaller. The largest stacks are the LH2 vent stacks on trailers and on tanks for the main safety valves are 3”. For GH2 systems the flare stacks are generally smaller in diameter.

Flaring is a deliberate ignition of a hydrogen stream. If the hydrogen stream is to be ignited, the timing of the ignition must be exact at the very beginning with a flame igniting the hydrogen before the cloud gets too large and represents a deflagration/detonation danger.

For relief devices, this is very difficult due to the large instantaneous flow rate
Flaring is also not typical as:

- A steady and constant flow is needed to maintain ignition
- Reignition explosively is possible if flameout occurs
- Timing of the initial ignition could cause a large cloud to be ignited

If a flare system is used, it must

- Dispose of H2 safely
- Prevent explosions
- Have a steady flow rate or controls that assure ignition is maintained. Variable velocities indicate a flare stack may not be advisable.
- Control the flare to assure
  - Pilot ignition
  - Flameout warning systems
  - Limit the backflow of air into the stack
  - Flame dip does not occur
- Variable velocities can cause
  - Flame blowout/burn-off - High velocity
  - Flame Dip -Allows air into the larger vent system- Low velocity

API 521 is a code that addresses flaring, besides the ANSI document

There is some information on vent stack flaring below. The ANSI/AIAA G-095A-2017 Guide to Safety of Hydrogen and Hydrogen Systems former NASA NSS 1740.16 document addresses vent stack flow rates for flaring.

This document states “Quantities of hydrogen of 0.113 to 0.226 kg/s (0.25 to 0.50 lb/s) have been successfully vented from a single vent 5 m (16 ft) high”. .226 kg/s is a very large flow rate (340,000 scfh/8000 nm3/hr). Per NASA Figure A4.1, there is no flame dip shown (flame receding into the vent stack) below a 3 in stack size, which is consistent with the best practices.

The flare systems themselves must incorporate pilot ignition, flameout warning mechanisms, and a means to purge the vent line, ensuring comprehensive safety measures are maintained throughout the process.

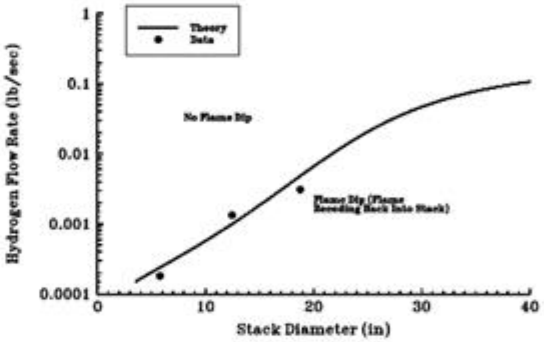

Figure A4.1
Flame Dip as a Function of Stack Diameter and Hydrogen Flow

Source:

Grumer, J., A Strasser, J. M. Singer, P. M. Gussey, and V. R. Rowe, "Hydrogen Flare Stack Diffusion Flames: Low and High Flow Instabilities, Burning Rates, Dilution Limits, Temperatures, and Wind Effects," BM-RI-7457, Bureau of Mines Report of Investigation (1970)

Peterson, P., "Explosions in Flare Stacks." *Chemical Eng. Prog.*, 63(8), August (1967): pp. 67-70.

3.) For a flare stack a radiation study is normally required. Is a radiation study necessary for vent stacks as well?

Yes, for all stacks. GH2 has a minimum prescriptive height of 10 ft. There is no minimum prescriptive height for LH2. However, 25 ft has been a best practice for the industry for years. Vent stack outlets that orient the release vertically help reduce the radiation exposure at ground level. Care must be taken to consider varying weather conditions, particularly wind, as well as surrounding exposures that might be elevated in the vicinity of the vent stack outlet, such as nearby equipment, buildings, catwalks, and grade elevation changes.

4.) What temperature do you suggest for preconditioning LH2 before venting it?

Liquid hydrogen is rarely vented as a liquid. If liquid hydrogen is vented, there should be a means to ensure that it is fully vaporized. The vent systems for LH2 tanks are connected to the vapor space on the tanks to ensure in most instances, this occurs.

Most vents from a liquid hydrogen system will vent gaseous hydrogen, but this gas, may still be as cold as -420 F. There are no code requirements for warming the vented hydrogen, and cold gaseous hydrogen is frequently vented safely through the use of a tall enough stack, preferably with a vertical discharge, such that the cold hydrogen sufficiently mixes with the ambient air before it would otherwise reach the ground. The vent systems for the safety of people, must meet the radiation requirements of CGA G-5.5 and API 521

Some practical considerations include:

1) The wind can greatly affect the rate at which hydrogen rises due to the low weight of the hydrogen molecule.

2) Warming to at least -390 F will ensure that the hydrogen is above neutral buoyancy. However, venting hydrogen into the atmosphere at these cold temperatures can still cool the surrounding air and create downdrafts that can push the hydrogen towards the ground if not vented at a high enough elevation.

3) Uninsulated vent system piping below about -300 F can create conditions where oxygen enriched liquid air can form and drip to the ground. While this can be addressed with proper materials of construction under the piping, it can still create personnel hazards, especially if dripping down the sides of a tall vent stack.

4) Venting cold hydrogen below the atmospheric dewpoint will result in a visible water vapor cloud. While this can draw attention to the cloud and can create some confusion as to the extent of flammable mixtures within the cloud, it can be very difficult to warm hydrogen sufficiently to avoid all water vapor formation.

5.) What pressure should the hydrogen vents be designed for? Some guidelines mention 40 barg for deflagration/detonation, but it seems vendors do not consistently adhere to this recommendation.

Vent systems are typically open to the atmosphere, so it’s easy to overlook that they must be designed to withstand significant internal pressure. The two primary sources of pressure within vent systems are: 1) backpressure from the flowing gas, and 2) internal deflagration/detonation.

The large flows of gas exiting relief devices and vents will create backpressure within the vent system. The backpressure often must be limited to 10% to meet code requirements for reclosing relief devices such as relief valves, but can be significantly higher for non-reclosing relief devices such as rupture discs or TPRD’s. For high pressure systems such as fuel stations that might have relief devices set as high as 1000 bar, the back pressure can be substantial. Even 10% would be 100 bar, but there might be situations with rupture discs where backpressure as high as 400-500 bar is possible immediately after activation of the device. The maximum backpressure must be calculated during the design and the vent system appropriately designed for that pressure.

Vent systems are also subject to internal deflagrations or detonations. The vent system may be full of air prior to a vent from a relief device or manual vent. For a short period of time, a flammable mixture may form until the air is swept out by the hydrogen. Due to the high length/diameter ratio of piping, this can lead to an internal deflagration and even a detonation.

The developed overpressure is a function of a number of variables but CGA S1.3 recommends to design the vent system to withstand 300 psig and comparable EIGA documents recommend 40 bar (~600 psig). These pressure ratings are fairly reasonable for typical vent systems below 6” size, but can be challenging for larger vent headers.

6.) Are most vent line failures due to backpressure or fatigue?

The most common modes of failure for vent lines is backpressure and thrust forces.

Backpressure failures can be from several causes:

- Inadequate calculation of the backpressure caused by the high flow rates. Vent system design pressure is often only designed for the maximum 10% backpressure that is required by ASME Code. However, it should be noted that the large flowrates from rupture discs and TPRD’s can often have backpressure as much as 50% of the system design pressure.
- Vent stacks are not required to be designed for the full process pressure of the system that they protect, so plugged lines can create pressures much higher than their design. A best practice is to design the vent stack burst pressure above the MAWP where possible, but this is not always practical, especially for 700 bar hydrogen fueling stations.
- Inadequate installation. Vent stacks are often not pressure tested after installation as they should be. This can lead to installation errors not being identified. Examples include inadequate welds or incompletely tightened fittings, especially compression fittings.
- The flow/pressure reaction forces. CGA G-5.5 has equations for determining the reaction forces on vent piping and its supports. The reaction forces from this formula, are greater than the pressure times the area. The first fittings and vent stack end supports in a vent system are most susceptible to these reaction forces.

7.) Does adding mesh to the vent outlet increase the risk of DDT (Deflagration to Detonation Transition) if hydrogen ignites?

All vent stacks/systems should be bonded and grounded to minimize ignition sources. Higher-pressure streams from higher velocities have a greater risk of igniting for several reasons, including particle impingement. Adding mesh could create more impact points for particulate, which would increase the potential for ignition, but would not increase the probability of a DDT. Similarly, high flow releases at high pressure can create supersonic flow leading to a shock wave. While this shock wave may be sufficient to ignite the hydrogen, mesh on the outlet will not create the conditions for a DDT.

Mesh must also be designed for substantial flow area to minimize backpressure on the venting system.

Instead of mesh, the outlet of the vent systems can include small diameter stainless steel bar (for example 1/8” – 1/4”), that does not add much turbulence and applied backpressure.

8.) What are the advantages of the T-outlet design? With two 90-degree elbows, does it significantly increase back pressure during venting?

The main advantage of a “tee” style design is that the thrust loads at the vent exits are balanced. This means that an unequal force that might push the vent stack over is not present. Generally, the tee is also of the same size as the main vent line, thereby doubling the vent area for less pressure drop. The main disadvantage of a tee stack is that they generally vent with a horizontal discharge which means a hydrogen cloud closer to the ground and higher radiation exposure at grade. The tee is also often equipped with a downward facing miter cut to reduce the probability of rain or snow from entering the stack. However, a downward miter cut can direct the exit flow downwards, normal to the miter, if the vent is at high velocity. This can propel the hydrogen even closer to the ground than anticipated. If miters are used, the vent pipe should be oriented slightly downwards, but with the miter cut facing upward. This will help prevent moisture from entering the stack and if supersonic flows occur, the vent flow will be directed further upwards. CGA G-5.5 Hydrogen Vent Systems shows recommended orientations of vent stack outlets.

9.) What are the main factors to consider when deciding between using a vent or a flare?

Per above, it is the amount of hydrogen flowing, vent stack diameter, igniting in a timed manner, and assuring the flame does not go out.

10.) Is it possible to install flame arrestors on hydrogen gas vent stacks?

Flame arrestors can be installed on hydrogen gas vents. The purpose of a flame arrestor is to prevent the migration of flame backwards and upstream into the vent stack or system itself. Generally, flame arrestors are not needed since: 1) the vent stack should be designed to withstand fire or explosion within the stack, and 2) the process generally does not contain a flammable mixture within it, so there is no danger of the flame propagating into the system. In these cases, flame arrestors are not needed and should be avoided since they create additional hazards of blocking or restricting the vent flow. For example, a flame arrestor on a vent stack serving a liquid hydrogen system might get cold and build up ice, thereby restricting flow.

There are situations where flame arrestors can be appropriate. An example would be a vent stack from a compressor crankcase. Compressor crankcases are often vented to atmosphere, and where there is a possibility of hydrogen leakage into the crankcase, that vent might use a vent stack to ensure that leakage goes to a safe location. Since the crankcase might then have an air-hydrogen mix, a flame arrestor can prevent the propagation of flame backwards into the crankcase if it were to ignite on the vent stack. The crankcase is usually confined and congested so it could result in an overpressure significant enough for it to rupture.

The European Industrial Gas Association (EIGA) Doc 211/17, 7.4 does not allow flame arrestors due to the backpressure associated with them.

11.) Are there differences in vent system design between horizontal LH2 tanks and spherical tanks regarding vent placements?

There are no differences in the process design of the vent stack since the venting requirements will follow the same sizing and pressure rating requirements regardless of vent configuration. However, vent systems often create liquid air on their exterior due to the cold venting temperatures. Since this liquid air will drip off the stack, it should be diverted such that it does not directly impinge on the outer vacuum jacket of the vessel. The jacket is often constructed of carbon steel which is not rated for the cold temperature of the liquid air, and as a result, may crack and cause loss of vessel integrity. Horizontal tanks will usually place the vent stack such that liquid dripping from the bottom of the stack will drain to the ground. This is more difficult due to the geometry of a spherical tank so the stacks must be sited and supported differently and/or a shield be placed to prevent impingement.

12.) What are the specific grounding and lightning protection requirements for H2 vent stacks?

CGA G-5.5 states: All vent stacks shall be grounded and meet the requirements of NFPA 70, National Electrical Code, for integrity and system design and also references NFPA 77, Recommended Practice on Static Electricity, and NFPA 780, Standard for the Installation of Lightning Protection Systems.

For lightening refer to NFPA 780 and for grounding of the Hydrogen equipment, refer to NFPA 70 (Article 250 and Article 510 are good starting points)

Best practices in the past have used large stranded wire for grounding connected to a grounding grid. Lightening typically has a larger grounding current requirement than grounding and bonding of nonelectrical equipment for static electricity.

13.) The presence of a flapper on a vent seems counterintuitive, as restrictions are typically avoided. Could you provide the standard that specifies this?

There is no standard which specifically specifies the use of a flapper. A properly designed flapper should provide de minimus restriction to vent flow, yet still provides weather protection which allows for a vertical release of the vent stack flow, which is best from a dispersion and radiation perspective. Flappers are extensively used successfully and safely on nearly all liquid hydrogen road tankers as well as a supplemental means to vent large flows from stationary tanks in a vertical direction.

However, vertical vent systems with a flapper must be monitored to ensure the flapper closes after operation to ensure no water enters the vent systems. LH2 systems are especially susceptible to this due to water freezing on the vent stack cap and its components and expansion contraction.

14.) If the vent system is appropriately designed and sized for fire cases, is a deluge system necessary?

No, in nearly all cases, a deluge system is not needed. The proper sizing of relief devices using documents such as CGA S1.3 will ensure that they are of sufficient size to address worst case scenarios. In addition, if the system has been sited per separation distances from exposures in accordance with documents such as NFPA 2, then there should not be a significant risk of fire exposure. However, a deluge system to protect and cool vessels exposed to fire may be part of a system where evaluated by a system HAZOP and risk analysis. Care must be taken that the deluge system does not spray on the vent system which could lead to potential blockage. Similarly, if a system uses a thermally activated relief device (TPRD), it's critical that the device is not cooled by the deluge system such that it does not activate as intended. Additionally, a deluge system could extinguish the hydrogen fire. A hydrogen fire should not be extinguished unless the source of hydrogen is isolated.

15.) A picture of H2 cylinders showed vents. What makes this design poor?

I am not sure which picture you are referring to so I will attempt to answer.

If you are referring to the incident where a fire occurred and the vent system was damaged, then this may have been due to lack of proper supports and incomplete assembly of the test systems. In the past, vent systems were not pressure tested for strength but that is changing.

If you are talking about small standard H2 cylinders (250 scf or less) then a review of the rupture disc operation is in order. Most individual cylinders have a lead-backed (referred to as fused) rupture disc (CGA type CG4 or CG5) that does not connect to a vent stack. Due to the required mobility of cylinders, a vent stack is not required. The rupture disc is not supposed to vent hydrogen unless the cylinder is engulfed in a fire both melting the lead back and then over-pressuring the cylinder/ rupture disc. If engulfed in a fire, the rupture disc opening Is required to maintain cylinder integrity. Although adding hydrogen to a fire is not a perfect solution, it is better than a cylinder explosion and then still adding hydrogen to the fire.

An interstage regulator relief device not connected to a vent stack.
This design is poor and occurs more frequently than we would like. It is typical for a 2-stage regulator to have an interstage safety relief device that is not connected to a vent stack. If the 1st stage of the regulator fails open, the increased pressure can open the interstage relief device, If this is not connected to a vent system (which it normally is not), hydrogen will flow to wherever the relief device is pointed.

16.) Could you offer more details on concerns regarding pilot ignition on a flare?

At NASA Cape Canaveral, they used a natural gas line connected to the vent stack outlet with a thermal sensor to make sure the pilot was lit. They may also have had a sensor to ensure the H2 fire was lit.

In cases where substantial quantities of unused hydrogen is vented and the timing and amount of the flow rate is known and controlled, flaring might be useful. NASA guidelines stipulate that flaring is appropriate for hydrogen vent rates surpassing 0.2 kg/s (~0.44 lb/s). Flare systems themselves must incorporate pilot ignition, flameout warning mechanisms, and a means to purge the vent line, ensuring comprehensive safety measures are maintained throughout the process.

17.) We have an onsite Emergency Response Team with a substantial amount of Liquid Hydrogen but haven't found ERT-specific training for handling Liquid Hydrogen Fires. Are you aware of any existing training?

AICHE ELA253 CHS " Introduction to Hydrogen Safety for First Responders" is a good reference and discusses both LH2 and GH2. LH2 fires are very unusual. LH2 releases usually are GH2 so the fires at either ambient for low flow or the GH2 is a cryo temperature for high flow. Fires from LH2 tanks ignite less frequently than GH2 high-velocity releases. The colder the gas the less potential for ignition.

The guidelines for managing a hydrogen fire is to eliminate the source of the fire before putting the fire out while keeping equipment exposed to higher temperatures cool.

18.) Are there specific requirements or suggestions for vent header lines? For instance, when several sources are connected to a single, larger vent system.

Design of vent header lines is critical to the safety of the system. From a process perspective, the pipe design must be sufficient to withstand back pressure, thrust forces from the flow, and must be of a sufficient size to not create a restriction that prevents proper flow or activation of the devices. Per ASME BPV Code requirements, backpressure should be limited to no more than 10% of the set pressure.

When more than one source is connected to a single vent, two critical design issues are the pressure rating and flow capacity. The vent header should be of sufficient size to simultaneously meet the required flows from the different sources where it's possible for them to activate at the same time. This is a particular concern where there may be many, sometimes even dozens, of devices on pressure vessels used for fire protection where all vessels can be exposed to fire at once.

Pressure rating and set pressures of the devices are also a concern. For example, a 3000 psig set pressure device with the typical 10% allowable back pressure, would allow up to 300 psig in the vent header. If a 300 psig set pressure device were connected to the same header, then it would not activate if required due to that backpressure, leading to possible overpressure of the process system. Best practice would be to use different headers on systems that operate at significant differences in pressure.

Another consideration is to make sure that common vent headers do not create a common mode failure such that redundant devices could be blocked from a common failure. Care must also be taken that incompatible materials (e.g. hydrogen and oxygen) aren't vented on a common manifold and that contamination (e.g. compressor oil) doesn't affect other portions of the system where a source of contamination is present.

When designing a vent system, the designer must review in a process safety analysis that the hydrogen cannot flow to unexpected locations. It is never a good design to tie a hydrogen vent system into a building ventilation system.

Maintenance is also an issue since vent headers can be an overlooked cross tie between portions of systems that otherwise are properly isolated on the upstream side. For example, if maintenance is being performed on a relief device, and a separate device activates elsewhere on the same header, then backflow could create a hazard while the vent piping is disassembled.

19.) There was a discussion about "liquid" vent systems. Could you clarify if there are situations where direct release of LH2 to a vent system is acceptable? Our policy has always been to avoid venting flammable liquids without first vaporizing them.

There is no specific requirement not to vent liquid hydrogen from a vent system. Best practice would be to only vent gas from the top of the vessel to relieve pressure. If liquid must be vented, it should be vaporized first.

Note: It is very unusual to have LH2 flow from a liquid tank out the vent system, as the vent system is connected to the vapor space on the LH2 tanks and there is a large amount of heat transfer into the fluid leaving the vent stack due to the large temperature difference between the cold GH2 and the environment (between 400 and 525 degrees F, a large multiplier).

However, there are liquid-venting scenarios that must be considered during upset conditions such as when a road tanker might have rolled over. Liquid can be vented from the gaseous portion of the system so the system should be designed for that possibility.

20.) For continuous venting of GH2, do you recommend continuous purging with nitrogen?

No, but it depends on the application. Nearly all vents less than 4” in size are not purged with N2. This is primarily due to: 1) large flows required to dilute hydrogen below the flammable range, 2) the cost of the nitrogen, 3) the potential blockage of the stack when being inserted a vent header/stack serving a liquid hydrogen system, 4) the potential for backpressure (depending on the source) to damage or restrict operation of relief devices, and the lack of incidents with non-purged system.

However, a nitrogen flow can be a means considered for specific systems warm GH2 system as part of a hazard assessment. For example, a nitrogen purge might be appropriate for a large diameter vent header that operates at very low pressure such that it might not be able to be designed for an internal deflagration.

If a nitrogen purge is to be used on a liquid hydrogen system, then the vented hydrogen should have a means to be warmed above -320 F to prevent liquefaction or freezing of the nitrogen. N2 is not allowed for the purging of LH2 systems per CGAG-5.5.

21.) When discussing design considerations, it was rightly noted the need for a qualified person to do the design. Are there any specific certifications or qualifications required for this role? Any recommended trainings?

Refer to the white paper completed by the HSP for LH2. The same criteria should be applied to a vent system. See below.

White_Paper-Qualified_Individuals_for_Liquid_Hydrogen (h2tools.org)

Similar qualifications for vent system design include:

1. A “qualified” individual for liquid hydrogen should be qualified in all aspects of vent systems, as discussed in the categories listed below. Questions are included for each category to help ascertain if the hydrogen expert is qualified.

2. Hydrogen Properties

a. Is the individual aware of the pressure and temperature design requirements of vent system

b. Is the individual aware of the flow rates from a vent stack and the potential hazards to the surroundings with a liquid/gaseous hydrogen release?

3. Design

a. Has the individual previously designed and managed the installation of GH2 and LH2 vent systems?

b. Is the individual familiar with the hydrogen vent codes

c. Does the individual understand how relief device set points and flow rates are determined for the vent system (examples may include understanding that the relief devices must be designed for overfill from a transport pump, heat leak, fire, loss of vacuum, and runaway tank pressure control)?

d. Does the individual understand how to calculate back pressure in the vent system from flowing devices?

e. Does the individual understand the mechanical design needs for the vent systems (e.g., cold temperatures for LH2 thermal expansion, liquid air, and ice)?

4. Process Equipment and Properties of Materials

a. Is the individual aware of how a GH2 or LH2 vent system is typically piped

b. Does the individual know what materials of construction are typically used with vent systems and their supports

c. Has the individual calculated expansion contraction rates of metals involved in liquid hydrogen storage or movement?

5. Safety Systems and Reviews

a. Has the individual led or facilitated a hazard review for vent systems?

b. Is the individual aware of the safety systems connected to a vent system and their maximum flow rates?

6. Emergency Procedures

a. Does the individual have knowledge of emergency procedures for a hydrogen system? What is the basis of this knowledge?

b. Has the individual trained any fire departments on the system design, the hazards of hydrogen, and the safety systems associated with hydrogen's use?

7. Operations (current and historical)

a. How many operating hydrogen systems has the individual visited and studied?

b. What historical problems have the individual observed with a hydrogen system (example may include incorrect expansion contraction calculations, icing of lines, vent systems)?

c. Does the individual understand how to review the system for correct components, pressure rating, pressure testing, and venting (examples may include an operational readiness inspection)?

d. Does the individual understand how changes are made and documented from design through installation/startup, and during operations (for example, a management of change process)?

e. Does the individual understand how the training of onsite personnel for the vent system will be accomplished, and what to include in the scope of the training?

f. Does the individual understand the operation of a vent system and the associated dangers (water condensation, venturi air pulled into the vent system, etc.)

8. Maintenance

a. Has the individual worked on a hydrogen system on site during initial construction and after the hydrogen system is active?

b. Does the individual understand how a hydrogen system is purged (examples may include purging with nitrogen, if warmed to ambient conditions, or purging with helium, if at liquid hydrogen temperatures) prior to opening for repair?

22.) Can you offer guidance on the circumstances (such as H2 mass flow, outlet velocities, etc.) under which a thorough assessment of vapor cloud explosions above vents is deemed necessary?

Several organizations published a paper together on this topic in 2017 (see attached). Based on comparisons with tests and CFD simulations, the following conclusions were drawn:

1. The gas concentration for vapor cloud explosion blast load calculations for H2 jets can be limited to approximately 10% to 75%. Note that testing for H2-air VCEs in congested environments has been performed by organizations such as Baker Risk and concluded that 10% is the lowest H2 concentration that needs to be considered. This published this as well.

2. For ignition of the H2-air jet at 30%H2, a mass release rate of about 0.5 kg/s is needed to get above a TNO Muli-Energy Severity Level of 4 (i.e., where VCE blast load perspective starts getting significant with a maximum overpressure of 0.1 bar). This corresponds to a flame speed of about 100 m/s and is shown in Figure 13 of the attached paper.

3. Ignition of the H2-air jet at 60%H2 (worst-case ignition location) requires a mass release rate of about 0.1 kg/s (100 g/s) to get above a TNO Muli-Energy Severity Level of 4.

More testing on this has been done and is being done, so these might get refined in the future, but it is not expected that there will be major changes in the “threshold” mass release rate needed to produce a jet that (if ignited) can represent a VCE hazard. Of course, the blast loads from a hydrogen jet won’t extend a long distance because the explosion energy (i.e., flammable cloud size) is limited compared to traditional VCE cases (e.g. where a large flammable cloud fills all of a refinery process unit). Lastly, if a facility owner defined a hazard level of concern (e.g., greater than 0.5 psig at 100 feet), then a mass release rate of concern could be calculated.

23.) What precautions should be taken for GH2 vent design concerning temperature?

The vent system should be designed for the temperature at which it operates (ambient for GH2 and Cryogenic for LH2). The outlet of the vent system should be designed for a fire to ensure the mechanical integrity of the vent system.

The supports should also be designed for these temperatures and the associated expansion and contraction.

It should be ensured that moisture cannot enter the vent system and freeze plugging the vent system, which may be a single point of failure.

24.) Is there a recommended separation distance for multiple vent stacks, such as one for pressure relief, one for ventilation, and another dedicated to purging?

Vent stacks and building ventilation systems are different and should be analyzed/designed differently. NFPA 2 has different location requirements for vent stack and ventilation system outlets. There are code requirements for elevation, distances from exposures, and between exposures.

There are no specific regulatory or code requirements for vent system separation distances. These should be evaluated as part of a hazard assessment. A primary consideration is that a fire on one should not lead to ignition of another stack which might also be venting at the same time. Dispersion analysis can be performed to ensure that there is adequate separation. Additionally, the vent and ventilation system exhausts should not be able to be pulled into an air intake.

25.) What's the best practice for sizing and conducting radiation analysis for relief scenarios with high instantaneous flow but short duration due to limited inventory?

Several programs can predict this such as Hyram or PHAST. The inputs are critical to a safe answer.

This is not a simple answer due to the many types of flame lengths and flame orientations due to pressure and direction. NFPA 2 recommends that vent systems should be designed so that if the safety relief valve is relieving at capacity the radiative heat felt by an individual at grade does not exceed 500 Btu/hr/ft2 (5.68 MJ/hr/m2) (A.10.4.4)

NFPA 2, section E has a lot of good information on this subject

As an example, let’s look at a gaseous H2 cylinder release through a rupture disc. The flow is straight up through a vent. If ignited, initially the radiation will be at it’s highest. As the pressure in the cylinder is reduced the flow rate is reduced, and thus so is the radiative area. At the same time there is a maximum time in which a person can be in the radiative heat flux. Distance to radiation heat flux level of 4732 W/m2 (1500 Btu/hr · ft2) with exposure to employees for a maximum of 3 minutes.

The heat flux location will define how transient flow vs radiation locations will be defined. The heat flux values in NFPA 2 include safety factors.

Auxiliary information

- 1,577 W/m2 (500 Btu/hr ft2) is defined by API 521 as the heat flux threshold where personnel with appropriate clothing may be continuously exposed. This value is close to, but actually less than what the Society of Fire Protection Engineers determined to be the “no-harm” heat flux threshold (540 Btu/hr ft2), that is, the maximum heat flux to which people can be exposed for prolonged periods of time without experiencing pain.
- 4,732 W/m2 (1,500 Btu/hr ft2) is defined by API 521 as the heat flux threshold in areas where emergency actions lasting several minutes may be required by personnel without

shielding but with appropriate clothing. It is also defined by the International Fire Code as the threshold for exposure to employees for a maximum of 3 minutes. This value is close to the heat flux level used by other standards (e.g., NFPA 59A, EN 1473) as the threshold for public exposure (1,600 Btu/hr ft2).

- 20,000 W/m2 (6,340 Btu/hr ft2) is generally considered the minimum heat flux for the non-piloted ignition of combustible materials, such as wood.
- 25,237 W/m2 (8,000 Btu/hr ft2) is the threshold heat flux imposed by the International Fire Code for non-combustible materials. Other standards use somewhat larger values for heat flux damage to prevent damage to non-combustible construction.
  - *API 521, Guide for Pressure Relieving Systems, 1997 Ed., Table 8, pg. 41*
  - *SFPE Engineering Guide, Predicting 1st and 2nd Degree Skin Burns from Thermal Radiation, March 2000, page 8*
  - *API 521, Guide for Pressure Relieving Systems, 1997 Ed., Table 8, pg. 41*
  - *2003 International Fire Code, Sec. 2209.5.4.2(3)*
  - *According to literature, exposure to a heat flux of 1,600 BTU/ft2-hr will lead to 2nd degree burns over the exposed skin in approximately 30 seconds.*
  - *The Center for Chemical Process Safety)CCPS) book titled "Loss prevention in the process industry" lists 23,800 W/m2 as the minimum heat flux for unpiloted ignition of various kinds of wood*
  - *2003 International Fire Code, Sec. 2209.5.4.2(3)*
  - *NFPA 59A sets a threshold of 10,000 Btu/ft2-hr for a property line that can be built upon.*

26.) At what flow velocity in the vent system is ignition a realistic risk due to particles? Would low flow velocities, below 1 m/s, lack sufficient kinetic energy? Do you agree?

It is not possible to define ignition potential by just velocity without more data (i.e. pressure, materials involved, direction of impact). Due to the multiple methods of developing an ignition source (friction, impact, electrical charge) and the low ignition energy, it is assumed that hydrogen in the air will ignite (between 4 -74%), as it does 30-40% of the time with no known ignition source (see GH2 chart below). Therefore, to try and manage impingement by velocity as an ignition source is not a practical method to assure no ignition.

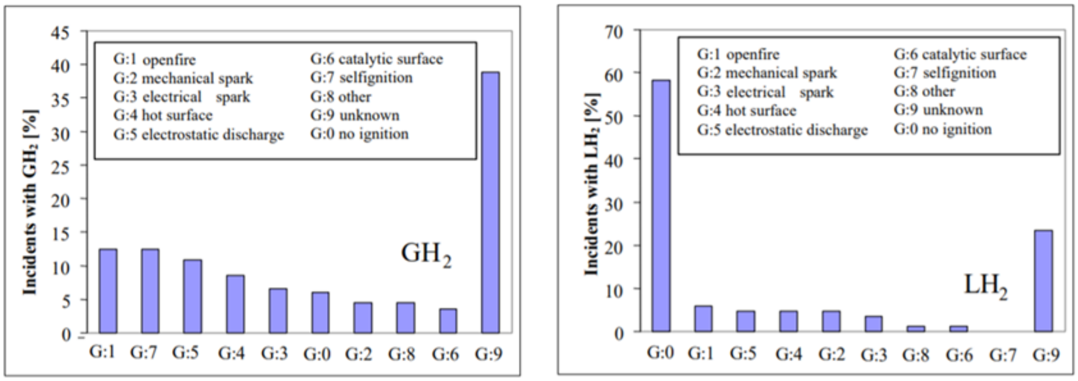

Image from: W. Breitung, Analysis Methodology for Hydrogen Behavior in Accident Scenarios 2016
Original data from: Kreiser et al. 1994

Other Information:
The ignition energy of hydrogen is .02 millijoules. By definition, a joule is equal to the kinetic energy of a kilogram mass moving at the speed of one meter per second.

From “Mechanical Sparks as an Ignition Source of Gas and Dust Explosions” from The Italian Association of Chemical Engineering Online:

Mechanical sparks are small particles, which due to the impact between two objects are torn loose from the surface of one of the two colliding objects. The kinetic energy is turned into heat and deformation work.

Mechanical spark generation is dependent on the pressure with which the one object is working against the other, the relative speed between the objects, the friction coefficient and the hardness of the materials involved.

Extrapolation of the experimental results using a model it could be shown that incendive hot surfaces can be generated also at relative speeds of < 1 m/s.

Additionally, tests were performed using a file traveling at 1m/s against a metal surface, and the ignition of hydrogen over many concentrations was observed.

27.) Is purging the same as sweeping? How can we ensure no ingress of oxygen into the stack to prevent the creation of a flammable/explosive environment if we're not constantly sweeping the vent headers and the stack (e.g., with nitrogen)?

Purging can be accomplished in several ways including by using pressure cycles, sweeping, or vacuum. Sweeping is the least reliable but can be effective on simple pipe runs. In most cases, vent systems are open to the atmosphere and the ingress of air from the outlet is likely. However, the vent system should be designed to handle fire or explosion internally. This generally is not difficult and is a best practice that can also be found in several standards which are incorporated by reference in Codes.

While air that enters from the vent stack outlet is expected to be within the vent stack, any leaks or openings in the vent system should be repaired such that they don’t act as a venturi and aspirate air while venting. A continuous source of air ingress should be avoided.

28.) I just want to know about the backpressure from CGA vent design. Is a minimum, e.g., 10% back pressure of the release pressure considered?

The ASME BPV Code, and other Codes by reference, require less than back pressure of 10% of device set pressure from the release flowrate for proper operation of reclosing relief devices such as relief valves. Backpressure from non-reclosing or non-ASME devices may be higher so an analysis is required. It’s not enough to assume the vent system need only be designed for 10% of the set pressure. Instantaneous backpressure can reach as high as 50% of set pressure for some PRD or TPRD applications.

29.) How can we avoid air entry and subsequent liquefying/freezing in the LH2 vent line?

It is normal for some air ingress to occur from the vent stack outlet. This is not a hazard if the stack has been properly designed to withstand an internal explosion or fire. Once hydrogen flow from a device is initiated, it will sweep out any air that might be in the stack. Generally, if the vent rate is insufficient to sweep the air out, then it's also insufficient to freeze or liquefy air in the stack. However, it's important to prevent air from being pulled into the stack from a venturi effect, so leaks or holes where air can enter the vent piping should be eliminated.

30.) Is a change in venting system required for Green Hydrogen projects? If yes, how do green hydrogen projects differ from blue or brown hydrogen projects?

The colors of hydrogen are not different hydrogen molecules. The colors represent the different methods to produce hydrogen. The colors are based on how much carbon is produced into the atmosphere during the manufacture of hydrogen.

That being said there is no difference in hydrogen vent systems design by color, only by the design parameters (i.e. temperature, pressure, flow rate, etc.)

31.) Could you further describe the importance of the orientation of SRV placed on the outlet of venting systems?

The SRV orientation is critical for many reasons. Many of these are:

1. Manufacturer recommendations – Manufacturers may require a certain orientation based on the internal design.

2. To ensure no back pressure changes the setpoint beyond allowable design

3. To ensure moisture does not enter the relief device. This is critical for the operation for LH2 and also for GH2 (in climates that may drop below the freezing point of water).

4. To ensure other impurities do not enter the relief device (for instance, if oil is backed into the vent system).

5. To ensure the relief device is supported correctly and the reaction forces during the device opening are managed for no movement.

The orientation of the vent system must also ensure moisture cannot block the relief valve outlet.

32.) Is water icing at the outlet a potential issue? Does this risk decrease if the orientation is upward?

Water icing at the exit of a stack is certainly an issue in cold climates. Significant effort has been put into vent stack outlet design to minimize the probability. Documents such as CGA G5.5 have topworks that are recommended. Stacks that face upward have a higher probability of having water, ice, or snow enter the stack and freeze.

33.) With the introduction of hydrogen-heated homes/communities, where low flows would be required to purge home piping or distribution piping (compared to industrial scale), would portable flare systems be a more reasonable way to manage hazardous areas when large stacks are impractical to bring to the site and ignition sources cannot be controlled due to being in public areas?

See 2 above for use of flare stacks.

For known, fairly continuous, low flow rates, flaring could be safely used. However, for low flows a hydrogen vent ignition represents little risk for venting at height outdoors.

34.) What is the heat flux limit for hitting equipment or people, and is there a design code?

Recommended limits of heat flux for various exposures is provided in documents such as API Standard 521, the International Fire Code, the National Fire Protection Association and the Society of Fire Protection Engineers. Selection of a specific thermal radiation level is dependent upon a risk analysis. Some salient exposures are listed below.

- 1,577 W/m2 (500 Btu/hr ft2) is defined by API 521 as the heat flux threshold where personnel with appropriate clothing may be continuously exposed. This value is similar to the Society of Fire Protection Engineers “no-harm” heat flux threshold 540 Btu/hr ft2.
- 4,732 W/m2 (1,500 Btu/hr ft2) is defined by API 521 as the heat flux threshold in areas where emergency actions lasting several minutes may be required by personnel without shielding but with appropriate clothing. It is also defined by the International Fire Code as the threshold for exposure to employees for a maximum of 3 minutes.
- 20,000 W/m2 (6,340 Btu/hr ft2) is generally considered the minimum heat flux for the non-piloted ignition of combustible materials, such as wood.
- 25,237 W/m2 (8,000 Btu/hr ft2) is the threshold heat flux imposed by the International Fire Code for non-combustible materials.

NFPA 2 has also published Annex material which provides additional detail on the harm values used for the calculation of separation distances.

35.) Are there any key differences in flare and blowdown compared to natural gas and LNG design?

Yes, there are differences due to the differences in the fluid properties.
We’re not sure what is meant by blowdown. If this means that should the gases be vented to a vent stack, possibly, but for certain these need to be vented to a safe location.

36.) What is typically the criterion that sizes or defines the venting flow rate of an LH2 facility, for example, emptying LH2 in x minutes due to a possible BLEVE (boiling liquid expanding vapor explosion) of the LH2 storage tank?

Relief device sizing for liquid hydrogen tanks follow recognized standards such as CGA S1.3. The sizing criteria include a worst-case scenario of an engulfing fire with loss of vacuum integrity.

LH2 tanks are unlikely to BLEVE due to the vacuum insulation outer jacket (usually carbon or stainless steel) preventing direct impingement of fire onto the main pressure vessel, as well as the internal cryogenic contents maintaining the inner pressure vessel walls at a cooler temperature until the contents have been relieved by the relief devices.

While not required by Code, nearly all LH2 tank designs follow a best practice of having at least one non-reclosing relief device to better empty the tank of its contents during a fire.

37.) For H2/air enclosures piping to exhaust blower, is ducting sufficient, or is industrial piping recommended to provide some small deflagration resistance (#150)?

Exhaust systems (sometimes referred to as ventilation systems) are used to exhaust hydrogen and air mixtures. Normally these are used to vent streams with less than flammable range hydrogen in air.

That is, hydrogen detectors trigger venting or the ventilation systems runs during all hydrogen operations. In these instances, low concentrations of hydrogen are expected, but deflagration is not expected in these systems and no pressure rating/deflagration protection is needed.

However, if it is determined that higher concentrations of hydrogen may be expected in the vent system, pressure-appropriate designs can be implemented, based on conditions.

38.) What is the internal deflagration pressure for an H2 system?

The deflagration pressure is dependent upon many variables.

However, some general concepts are:

1. Deflagration pressure is proportional to operating pressure

2. Deflagration pressure is inversely related to initial temperature

3. Deflagration pressure is based on concentration and H2/O2 ratio

4. In general, an internal deflagration is unlikely to exceed about a 10:1 pressure ratio and an internal detonation pressure is unlikely to exceed 20:1.

39.) Can you speak to liquid hydrogen accumulation in a vent and the accumulator design to catch this liquid?

Liquid hydrogen will almost never accumulate in a vent system since vent systems are typically designed without insulation. The extremely cold liquid hydrogen temperature of -420 F. Additionally, vent stacks on an LH2 tank are connected to the vapor phase of the tank. Only in a few rare instances will LH2 be entrained in the gas stream.

Accumulators are recommended at the bottom of vent stacks to catch any moisture that might enter the stack from rain, snow, or condensation.
Condensation will occur inside of the vent stack after cold GH2 has flowed through the stack and then stopped. Moisture will accumulate on the inside due to cryo pumping of moist air into the vent stack.

The accumulator collects the water below the relief device inlets to avoid blockage and should be checked and drained each time the liquid hydrogen tank is filled.

40.) In a plant where other chemicals are sent to a common flare system, is any special precaution needed for sending H2 to the flare instead of venting it separately?

1. Understand any reactions the hydrogen can add to what is being vented. For instance, O2/H2 vented in the same stack would not be a good idea.
2. Understand all the flow and operating parameters of the streams to ensure no back flow into the hydrogen system or vice versa.
3. Ensure the venting/flaring system can handle the hydrogen flow parameters.

41.) Can you share some details on delayed ignition incidents?

Delayed ignition is a significant hazard for hydrogen releases, either intended or unintended. The primary concern is the overpressure and energy release created from a vapor cloud which could contain a significant quantity of hydrogen. The H2Tools Incidents database contains a number of examples of delayed ignition.

42.) Is there any advice on designing low-pressure manual vents (used for purging in/out of service (<0.5 barg) venting horizontally rather than vertically directed away from a building?

Low-pressure vents at mostly low hydrogen purity are not as large safety risk as high-pressure pure hydrogen vents. These vents should still go to a vent stack, but it will probably be small in diameter and thus the tee vent at the top can be small.

If the purge requires high flow, if purging horizontally, the reaction forces of the flow exiting and the hydrogen cloud should be modeled based on NFPA 2 to ensure the safety of the surrounding area.

43.) How do we define a small vs. large release? Are there any criteria, such as the size of the container/process volume or vent size?

A release is defined by the amount of hydrogen, the rate of hydrogen flow, vent location (indoors or outdoors), geometry in the area (confined or not), and pressure.

A small or large release should be differentiated by the damage that can occur because of an ignition. This can be a fire, deflagration, or detonation.

Therefore, the relative size of the release will vary based on all the variables above.

If outdoors in an unobstructed area, a small release could be defined as a release that keeps the flammable hydrogen cloud from damaging its surroundings.

44.) The examples of transportation venting displayed today have all been individual pipes. Do you recommend against manifolds? If they are used, what considerations should be taken into account?

Typical practice for gaseous tube trailers is to vent relief devices independently to the top of the vehicle. This is primarily to accommodate the large flowrates and high thrust forces involved from these releases. It's fairly easy to do this since the vent lines are fairly short due to the maximum road height of trailers. Regulations do not prohibit piping multiple devices into a single header and this manifolding is an acceptable practice provided that the design is done properly. It is important to design the header sufficiently large to be capable of handling the combined flow of the devices. These devices are primarily for fire protection and it's likely that many, or even all, of the vessels would be exposed to fire at the same time.

It is common for LH2 transports to have all the relief devices/bleed valves connected to one vent stack.

45.) Can the vent system be eliminated from H2 production from Electrolysis and be replaced only by a flare?

A vent system should still be installed in case the flare system does not remain ignited.

46.) Are vent systems ever provided with "sparkers" at the outlet that can provide ignition energy to ensure prompt ignition?

This may be able to be accomplished as a method for ignition. We have not seen it.

As flaring is not usually recommended, especially when timing is an issue, a sparker that takes time to ignite would not be recommended.

47.) If the vent has a small flow, won't the flame be invisible?

Yes, small flowrate vents may be invisible, particularly in daylight. Sometimes it may still be possible to see heat striations in the air from the heat generated by the fire, but it can be difficult to discern at low flowrates.

48.) Why does LH2 release lead to potential plugging? Is it because of other materials or components, e.g., water or other liquids? Should liquid H2 rainout be considered a credible scenario?

Plugging is a concern before, during, and after a release. Prior to the release, water may accumulate in the vent system from weather conditions (rain, snow, etc) or from condensation, particularly if there is intermittent flow which causes the stack to get cold. This water can freeze due to ambient conditions prior to a release, thereby blocking the stack. It is also possible for other contaminants such as oil or glycol to be present if the vent system is connected to compression equipment that use these fluids. If water, oil, glycol or other fluids are in the stack prior to a release, it's also possible that the cold temperatures from the hydrogen itself can freeze them and progressively block the stack over time.
Liquid rainout is unlikely since nearly all relief devices and manual valves will vent gas rather than liquid. Note that this can still be as cold as -420 F so will freeze contaminants in the stack. In the rare situations where liquid might be vented into a stack, rainout is in theory possible. However, due to the very cold temperatures, low latent heat of vaporization, and height of the vent stacks, rainout is very unlikely except for the very largest systems and vent piping. Typically, liquid hydrogen is also stored and saturated at an elevated pressure, so a significant portion of the liquid hydrogen will immediately flash into a vapor when released to atmospheric pressure. As LH2 tank vent systems are connected to the LH2 tank gas phase, it is rare to see LH2 entrainment on the gaseous vent stream.

49.) You mentioned vent stacks are not required to be purged. So, how do you prevent the creation of an explosive atmosphere in the hydrogen vent system?

The potential of an explosive atmosphere is inherent with any vent system and must be addressed through adequate design. Purging for most vent stacks is impractical due to availability or cost. In addition, and particularly for LH2 systems, the purge gas can cause potential safety issues. The primary way that explosive atmospheres are addressed is through ensuring that the design of the vent system can withstand an internal deflagration or detonation. This is not that difficult for smaller systems (less than 6”) but can be challenging when vent systems are larger and/or operate more as ducting than pipe. Where the vent system can't be built strong enough for the potential internal overpressure, purging can be a necessary and prudent safeguard.

Additionally, the amount of O2 in the vent stacks is typically small (i.e. 1.22 scf /.1 lbs. in a 3” dia/25 ft tall vent stack). As hydrogen flows into the stack the time that there is a flammable (between 4 and 74%) region within the vent stack is also small.

For a detonation there must be the correct amount of hydrogen and oxygen. In a 3” vent stack, 25 ft tall there is ~ 1.25 cu ft of oxygen at atmospheric pressure. (=.1 lbs/.0032 lbmoles). The flammable range of H2 is 4-74% H2. At the stochiometric ratio, there is ~.0064 lbMoles of H2 that can react with the O2 in the vent stack. This represents ~.013 lb of h2 that can react. This is quite small amount energy release

Calculations

Radius – 1.5”
Piping Volume = (1.5/12)^2*3.14*25 ft = 1.22 scf
Weight – 1.22 scf/12.08 scf/lb =.1 lb
Moles - .1 lb/32 lb/lbmole =.0032 lbmoles

H2 + ½ O2 = H20
.0064+.0032 = .0064
.0064 lb moles H2 X 2lb/lb mole = .0128 lb H2

50.) Can a redundant vent stack be used to reduce the chance of blockage resulting in catastrophic failure?

Yes, and this is frequently done. A redundant vent stack might have its own independent redundant relief devices, or it may take the form of a secondary stack attached to the same devices. When a secondary vent stack is installed in parallel using the same relief devices, there often will be a means to isolate the second stack, such as a rupture disc, from the first except in emergencies. This is to minimize both stacks from being plugged at the same time. If the pressure in the first stack builds to an abnormally high level due to restriction, then the rupture disc can activate to allow the second stack to come into operation.

51.) Do you recommend stress analysis for vent piping?

Absolutely. Vent systems will experience a variety of transient conditions of pressure, temperature, and thrust load, so stress analysis to anticipate the strength and flexibility needed are important for safe design. These issues are often overlooked and only become an issue when they are called upon to operate in emergencies.

It is a best practice to include the vent system in the process hazards analysis (PHA)

52.) What is your recommendation schedule for vent line opening inspection?

We would not open the vent system to inspect the internal piping without a good reason.

It is recommended to check for water in the vent stack trap

1. At startup and daily during startup.
2. On LH2 tank system, every delivery
3. After the 1st rainstorm after a system is installed
4. LH2 vent stacks after establishing the baseline above
   a. After every large venting event
   b. Quarterly unless baseline requires more frequent
5. GH2 stack after baseline
   a. Check caps are still on quarterly for stationary tubes.

53.) Are there additional vent stack design recommendations for cold weather climates for the potential for freezing rain or snow accumulation and blockage for designs such as CGA G-5.5 Figure 7, which includes drains for liquid water but does not account for snow or freezing rain?

CGA G-5.5 provides several options for vent stack outlets but not all options, nor does it tell when one outlet type is better than another design.

Figure 7, is one design, but in my opinion, not the best design.
For instance, for warm gas, typical no-flow, normal scenarios (like a rupture disc on a vent system), Figure 5, a capped vent pipe is the simplest.

My preference depending on the application is a design not included yet in CGA G-5.5 or Figures 6 or 8 depending on if the flow must exit vertically or not.

Water, snow, or ice mustn't plug the vent system, which may occur with Figure 7 if the weep holes become blocked.

54.) For a large electrolyzer plant, around GW scale (e.g., 300 to 600 electrolyzer stacks for hydrogen production), would you recommend installing local H2 vents for the stacks or routing these vents to a common large flare/vent system?

This decision would depend on the system design, system operation, and a hazard assessment. Likely it would be better to run all hydrogen vents to a common vent or flare system, but this might also restrict the ability to isolate smaller sections for maintenance.

55.) Will the flow rate of H2 in the vent modify the required vent height, or can the minimum 10 ft. height (min 5 ft above roof lines) be used for every case?

The distances provided are minimums. While they might be sufficient for most vents from small systems, larger vents will require both a dispersion and radiation analysis to determine the height needed.

56.) So, if I have hydrogen storage tanks, don't they need vents?

Nearly all hydrogen storage tanks and hydrogen storage systems will need some type of pressure relief system to protect the vessels from overpressure. If there are pressure relief devices, some means to vent the hydrogen to a safe location will be needed. An exception to this is hydrogen cylinders due to their relief device type (lead-backed rupture discs (CG-4/5) and the need to transport them.

However, the nature of the devices and vent systems depends on the type, size, location, regulations, and pressure of the hydrogen tank, storage tubes, or tube trailers and related system. There may be other means to protect against overpressure or fire exposure, and there are situations where the risk of a release could exceed the risk posed by the relief device and vent system. For example, many GH2 transportation trailers in the EU are not equipped with

PRD’s or TPRD’s which are not required by local regulations. Ultimately the decision and design of vent systems is based upon a hazard assessment.

57.) Is the guidance on the inverted vent top being avoided different from that of other gases, or is that applicable across the board?

We are not certain what an inverted vent top is. If this means the hydrogen flow is pointed downward in any way towards grade, then yes it must be avoided.

Less dangerous vent gases can be pointed downward, especially those that mix with air rapidly (nitrogen/oxygen/argon).

Regardless, reaction forces must be taken into account for any relief valve activation or flow.

58.) There is an ongoing push to install many tubes in one cradle and connect them to one exit. What are your experiences when the TPRD is activated?

There are many designs of storage systems where multiple vessels might be needed to obtain the required storage quantity. Regulations differ between vessels and modules which are intended for stationary or transportation purposes. Similarly, there are differences in codes globally. The issues of requiring shutoff valves on individual vessels and requiring TPRD’s are linked since generally vessels need to be in communication with the pressure relief system. A valve on each vessel will require one or more TPRD on each vessel.

There are trade-offs between the risk of having a large number of valves and TPRD’s, each of which is a potential leak/release source, and having a large number of vessels manifolded together with fewer valves/TPRD’s but then larger banks that contain larger quantity of hydrogen that will be released in a single event. The main disadvantage of multiple vessels being connected to a single TPRD is that a much larger release is possible since each vessel can’t be isolated. This may also require a much larger device to be able to vent the multiple vessels which then means a higher release rate with the associated larger vapor cloud, risk of explosion, and radiation profile. The decision is dependent upon the risk assessment and might be different depending on the location and application. When a tube has its own, individual TPRD and isolation valve (which must be closed during transport), a smaller release of hydrogen would occur.

59.) I see a lot of information around compression fitting failure for vent systems on these slides. Is there a different type of fitting recommended specifically for vent stacks?

Welded joints are always best, but they cannot always be used as a connection to tanks and tubes, as mechanical joints are needed for maintenance. Supports for the reaction forces can help ensure the mechanical joints in the piping does not pull apart.

If large diameter or thick-walled tube is installed with compression fittings, the use of hydraulic swaging is recommended.

Regardless of the piping method, reaction forces should be reviewed and supports designed for the reaction forces.

Pressure testing of the vent system is recommended to ensure the vent system will withstand relief device activation.

60.) What about hazardous area classifications?

NFPA 2 provides Tables in Chapters 7 and 8 that specify the hazardous area classifications surrounding vent stack outlets. These are based on typical vent systems and flows, but are only applicable for smaller systems. The designer of a vent system should apply the principles of documents such as IEC 60079-10-1 (also required by NFPA 2) or NFPA 497 to evaluate larger vent releases where the hydrogen cloud will extend beyond the prescriptive distances.

61.) What about the use of flame arrestors for GH2 stacks? Are they recommended? If not, why not?

Flame arrestors can be installed on hydrogen gas vents. The purpose of a flame arrestor is to prevent the migration of flame backwards and upstream into the vent stack or system itself. Generally, flame arrestors are not needed since: 1) the vent stack should be designed to withstand fire or explosion within the stack, and 2) the process generally does not contain a flammable mixture within it, so there is no danger of the flame propagating into the system. In these cases, flame arrestors are not needed and should be avoided since they create additional hazards of blocking or restricting the vent flow.

There are situations where flame arrestors can be appropriate. An example would be a vent stack from a compressor crankcase. Compressor crankcases are often vented to atmosphere, and where there is a possibility of hydrogen leakage into the crankcase, that vent might use a vent stack to ensure that leakage goes to a safe location. Since the crankcase might then have an air-hydrogen mix, a flame arrestor can prevent the propagation of flame backwards into the crankcase if it were to ignite on the vent stack. The crankcase is usually confined and congested so it could result in an overpressure significant enough for it to rupture.

The European Industrial Gas Association (EIGA) Doc 211/17, 7.4 does not allow flame arrestors due to the backpressure associated with them.

62.) What about NOx formation if the hydrogen ignites?

Hydrogen vent stack fires can create NOx. While not typical, certain municipalities will require air permits to address the emissions from hydrogen flare systems, and even from intermittent ignition of vent stacks. This is highly dependent on the location and interpretation of regulations. A hydrogen flare system is much more likely to require an air permit than a standard vent system.

63.) Have studies been done on venting mixtures of NG and H2?

We are not aware of a study for blended NG/H2. However, for high concentrations of NG, the vent system should be similar to NG, which still recommends a vent system as NG is less dense than air. For nearly pure hydrogen the recommendations of this presentation are in effect.

64.) I have seen a release of water sprayed onto a high-pressure GH2 vent. Is that a normal behavior?

Spraying water onto a vent stack, either for gaseous hydrogen or liquid hydrogen, is not recommended. While this is prohibited within the code for liquid hydrogen due to the much greater hazard of plugging the vent system, it also presents hazards for gaseous vents as well. The water can enter the vent system and plug due to ambient conditions. In addition, if the water was sufficient to extinguish the fire before the hydrogen flow is stopped, then a flammable or explosive cloud may form which can reignite unexpectedly leading to a greater hazard.

Water is only recommended to cool equipment adjacent to a hydrogen fire.

65.) Could you elaborate more on what could be common causes of the delayed ignition of the high concentration gas? Hot surface of the vent stack? Oxygen in sprayed water?

There are many potential sources of delayed ignition. Hydrogen is easily ignited, and the larger the cloud, the more likely it is for it to find an ignition source. The cloud itself may serve as an ignition source as the force of the gas release may cause dust or other contaminants to mix in the air creating a static charge which ignites the hydrogen. Similarly, the force of the release can cause surrounding materials and equipment to create an ignition source from impingement. Examples include doors being pushed against surrounding equipment, crushed stone being blown against equipment leading to an impact and spark, etc. The release may also be larger than the hazard assessment or codes anticipated, thereby extending the vapor cloud into areas with other ignition sources such as unclassified electrical equipment, hazardous activity by personnel, or surrounding equipment.

The oxygen in sprayed water would not be a hazard for delayed ignition.

66.) It was said purging is not suggested. But how do we remove hydrogen from the piping (turnaround of H2 plant) or after depressurization?

Purging is not recommended as a continuous part of vent stack operation. However, maintenance activity is a transient event and it’s prudent and recommended to purge a vent system prior to performing maintenance. It’s always possible that hydrogen could be leaking internally from a valve or other component and therefore create a hazard. Of particular note, care must be taken that proper isolation of the vent system is performed such that the vent system can’t be inadvertently used during maintenance. Since vent systems and stacks rarely have isolation valves to prevent unintended isolation of relief devices, proper maintenance on the vent system may require the entire system or plant to be taken offline.

67.) Can you provide a ballpark figure for the size of systems where flaring is recommended?

Sizing will be based on flow rate and pressure. See question 2.

68.) If H2 fires are stoichiometric, I thought they were almost invisible. What is causing the orange color in the flames shown in numerous slides during the presentation?

Hydrogen flames can be nearly invisible in daylight, especially at low flowrates. The concentration of hydrogen does not have much effect on the color of the flame. Many hydrogen incidents or fires will have a bright orange hue, or even yellow flames. The color is primarily caused by contaminants that is either naturally in the air in certain environments, swept into the air during the release (such as duct), or surrounding materials which are also burning.

69.) Do you have experience/knowledge of putting heat/electrical tracing for vent stacks where freezing hazard is there?

Heat tracing can be used as a safeguard against freezing. However, it must be understood that:

- The heat trace system uses a utility supply so may not always be operational.
- The electrical equipment must be properly classified for the area, which can be challenging for the Div 1 classification for vent stack outlets.
- The heat tracing might be damaged by vent stack fires.
- For liquid hydrogen system vents
    - Heat tracing is nearly useless for stopping freezing with a higher flow cold GH2 stream due to the amount of heat needed
    - The vent stacks can develop liquid air, so the equipment must be robust to survive cryogenic conditions without damage.
- Maintenance on the heat trace equipment might require a system outage for personnel to work on it safely.

70.) Has there ever been an issue with the freezing of air inside a cryogenic/LH2 vent system?

Yes, numerous incidents have occurred where frozen air (which contains oxygen) has built up within a hydrogen process or vent system. These incidents with vent systems incorporate more than just a vent stack, but include a vent system consisting of additional atmospheric equipment (such as a tank) where the equipment stays cold and allows air into the system in contact with a cold hydrogen stream.

Vent systems are at risk since they are “open” to the atmosphere and certain flow conditions might result in the aspiration of air into a cold hydrogen flow which then leads to the freezing of the air.

A small quantity of solid air can create an explosive hazard which then leads to cascading failures from the initial incident. Solid air in hydrogen is also shock sensitive which can lead to unexpected ignition.

71.) Would you recommend depressurizing for a fire scenario?

The answer is dependent upon the nature of the system and a hazard assessment which evaluates a balance of risk.

Keeping the hydrogen in the vessel is better so the hydrogen release does not compound the original hazard. Large flowrates from vessels can create significant risk of vapor cloud explosion, jet explosion, or radiation exposure. Vent systems can also fail from poor design or effects of the incident, so they may not work as intended to vent to a safe location.

However, once exposed to an impinging or engulfing fire, there is a risk that vessel walls may weaken and result in a vessel failure. A vessel failure is generally looked at as a worst-case scenario in most situations and should be prevented if possible. In those cases, the relief systems play a key role, and depressurization of the system is a means to prevent failure.

The most common means to depressurize a system or vessels are through the use of non-reclosing devices such as rupture discs or TPRD’s, or special instrumented systems that purposely depressurize the system in an incident. It should be noted that these devices and systems are not foolproof and could activate spuriously or in unintended situations which can lead to large releases and create significant hazards. The risk must be evaluated by a hazard assessment.

72.) Mesh at vent outlet can result in a fire at the vent. Is there any code suggesting that for hydrogen vent mesh?

Vent stacks must be designed for a fire at the outlet. The mesh is designed to ensure no blockage of the vent stack by animals/insects.

Additionally, the mesh must be designed for pressure drop to ensure code-compliant back pressure on the relief devices.

73.) If auto ignition is a concern, I'm confused why venting is recommended (or rather, why flaring is not recommended) as this would seem to be a guaranteed source of "delayed ignition." Given the low ignition energy requirement for hydrogen, wouldn't the likelihood of delayed ignition be significantly smaller for flare stacks with a pilot (e.g., propane pilot, piezoelectric, etc.)?

See the above 2 questions. Rupture discs open very rapidly. Historically, rupture discs opening at high pressure (1000 psig and above) have caused the most damage due to deflagration/detonation. Timing a rupture disc would not be possible. Additionally, how would you have a pilot light on a moving tube trailer? Even with a pilot light at the end of the stack may blow out due to the initial high velocity.