HYDROGEN VENT SYSTEMS FOR CUSTOMER APPLICATIONS

Doc 211/17

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Prepared by WG-11 Hydrogen Energy

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1 Introduction

The purpose of this publication is to provide recommendations and a methodology for the safe design of venting systems for hydrogen installations and equipment located at a customer site.

The design of hydrogen vent stacks aims at preventing the following three main hazards:

- deflagration due to the delayed ignition of the explosive hydrogen/air mixture coming out of the vent stack;
- thermal radiation generated by the jet fire (the flame coming out of the vent stack); and
- DDT (Deflagration to Detonation Transition) inside the stack due to the acceleration of the combustion of the air/hydrogen mixture that can be present inside the venting system (in the presence of an ignition source). This hazard is relevant if air can enter the venting system.

2 Scope

This publication covers the design, installation and maintenance of hydrogen vent systems used for equipment located at a customer site. This publication is not applicable to vent systems of hydrogen production sites with capacity exceeding 500 Nm3/hr of hydrogen.

It applies to Hydrogen Refuelling Stations with standard supplies of hydrogen (liquid, gas bulk, gas cylinders, on-site production of less than 500 Nm3/hr of hydrogen).

Typical on-customer-site installations to which this document include equipment items such as:

- A fixed or transportable gaseous storage connected to a piping distribution network at low or high pressure through a gas pressure release system;
- A fixed or transportable liquid storage connected to a piping distribution network at low or high pressure through a pump / vaporizer;
- A gaseous compressor to increase hydrogen pressure up to 1000 bar;
- A high pressure (up to 1000 bar) hydrogen storage;
- One or more hydrogen dispensing systems to fill in fuel cell vehicle tanks; and
- Stationary fuel cells systems.

Vehicles are excluded from the scope

The vent can be part of a gaseous or liquid hydrogen system, and the vent piping scope is from the discharge of the device(s) controlling the release of hydrogen to the vent exit(s) to atmosphere up to the point where hydrogen concentration in the atmosphere is below the lower level flammable limit. The piping up to inlet of the venting control device is also covered.

The publication does not cover:

- The design of the devices controlling the release of hydrogen;
- Flare systems; or
- Inerted vent systems.

3 Definitions

For the purpose of this publication, the following definitions apply:

3.1 Publications terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May and need not

Indicate that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

For the purpose of this publication, the following definitions apply:

3.2.1 Vent

Means of depressurizing or relieving excess of gas pressure from a system. Vents can be used for normal discharge, abnormal discharge or emergency discharge as required.

3.2.2 Pressure relief device

Device connecting a gaseous storage with a piping network allowing safe limitation of the hydrogen pressure in the vessel or piping by venting excessive pressure.

3.2.3 Deflagration in a flammable vapour cloud

Combustion mode where the flame propagates by molecular diffusive transport of the heat and turbulent mixing of reactants. The reaction front propagates at a subsonic velocity.

3.2.4 Detonation in a flammable vapor cloud

Combustion mode where the reaction front propagates by the mean of a violent chock wave that compresses the fresh mixture beyond its auto-ignition temperature. The reaction front propagates at a sonic velocity.

4 Sizing

4.1 Definition

For gaseous hydrogen supply systems, the following are examples of releases:

- Manual venting;

- Venting of upstream compressor or cryogenic pump flow feeding the system; and
- In fuelling stations, malfunction of dispensing control valve causing filling line safety pressure valve to open.

For liquid hydrogen supply systems, the following are examples of releases:

- Manual venting;
- Normal boil-off from ambient heat input;
- Liquid flash and gas displacement during filling of the tank;
- Gas returned from cool down of lines, pumps and connected equipment; and
- Boil off following loss of vacuum on a tank or on vacuum insulated lines

The following events are not considered in this guideline for sizing the vent stack:

- Catastrophic events as general fire; and
- Emergency discharge (voluntary) of stationary gaseous hydrogen storage.

These events should be considered in the risk assessment of the installation to define the likelihood of the event, the corresponding harm effects to people and goods and the appropriate mitigation measures to be implemented: design and layout requirements, standard operating procedures, and emergency procedures.

4.2 Maximum flow rate and maximum pressure drop calculation

The maximum flow rate shall be calculated as the sum of the flow rates of hydrogen collected in the vent stack coming from all devices that could be simultaneously opened. It corresponds to the highest flow rate generated by upset conditions in the worst credible conditions.

The sum of design flows of all vent devices which can open at the same time into the common vent system results in a maximum pressure drop.

The maximum pressure drop shall be taken into account for choosing the pressure relief device and defining the set pressure.

This maximum pressure drop should generally not exceed 10% of the lowest set pressure of all the relief valves which can open at the same time, and shall not exceed the maximum back pressure specified for any of these relief valves.

The pressure loss in the line between the protected equipment and a pressure relief device shall not exceed 3 % of the relief device set pressure.

NOTE Excessive backpressure can result in relief valve “chatter”, i.e. flow instability, greatly reducing the average flow and a potential source of damage to the relief valve.

4.3 Piping diameter and exit velocity

The vent piping diameter shall not be less than the diameter of any pressure-relief valve outlet, and large enough to avoid exceeding the maximum allowable pressure drop specified in 4.2.

For hydrogen, vertical venting, upward discharge is the preferred option, the higher the discharge velocity the smaller the separation distance requirements around the vent as specified in 7.1.

The sound level should comply with local regulation for normal or abnormal releases.

NOTE: Many local regulations permit to exceed the sound level limits in case of transient and/or abnormal or emergency conditions like, for example, the opening of a safety valve.

5 Structural design

5.1 Environmental loads

Seismic loading shall be considered for self-supported vent stacks.

Potential environmental loads shall be taken into consideration for the mechanical design of the venting systems, such as wind load and snow or ice accumulation.

5.2 Design pressure

Piping and connections immediately downstream of non-reclosing pressure relief devices, for example a burst disk, shall be designed to withstand the transient pressure peak generated upon activation.

Burst pressure of vent piping shall meet requirements of 5.5 to prevent damage from deflagration or detonation.

5.3 Thrust

The vent system shall be designed for the thrust of the discharging gas jet.

For any vent with a single outlet, there will be a reaction force that will produce a moment on any upstream pipe bend or a thrust at the base of the stack. Support and bracing of the piping shall be considered to compensate for the reaction forces and to prevent deflection and damage.

Vent piping supports shall be strong enough to secure piping against reaction forces resulting from full-flow discharge of fluid under any operating or failure conditions, including allowance for generation of shock waves.

Reaction forces resulting from the discharge of gas from a relief device are calculated as a function of the full flow through the orifice and the conditions of operation. Specific stress engineering methods should be applied to ensure that excessive stress is not generated in any point of the vent system.

The main relief devices and vent header will require specific support to balance the defined reaction forces. The main reaction force being opposite to the flow direction in a relief device, anchoring should be considered as below to prevent tension to be applied.

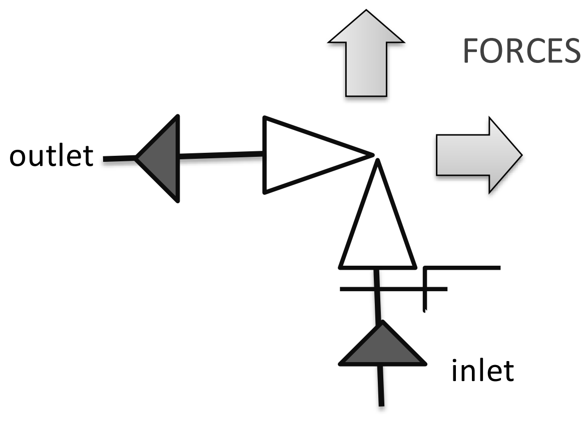


Figure 1: Reaction forces from discharge of gas

5.4 Piping and Fittings

Stainless steel grade 304 or equivalent material in terms of resistance to corrosion and fire conditions can be used for the vent piping system and the silencer, see Section 6.

Hydrogen embrittlement is not expected considering the operational conditions of the vent stack.

Vent piping should be routed and configured to minimize back pressure.

The length of the piping upstream of safety devices should be minimized as well. Such piping should be routed away from sources of potential exposure to a hydrogen flame.

5.5 Resistance to overpressure generated by ignition of an internal hydrogen/air mixture

The vent stack shall be able to withstand the maximum peak pressure created by a detonation except if inert gas is used for continuous purging and so avoiding presence of oxygen within the vent stack.

- Detonation pressure will increase with length and complexity of the vent system. Values as high as 120 bar can
- be reached for complex systems.
- Failure of the vent system from overpressure could present a potential hazard to personnel and equipment in the vicinity.

Burst pressure shall be such that the pipe system will not rupture as a result of the overpressure that could be generated inside the piping by the ignition of a flammable hydrogen air mixture possibly present in the system.

Each company may use the method of its choice to calculate the pipe wall thickness.

- The vent stack recommended design pressure shall be at least 40 bar.
- In order to define the minimum thickness for vent pipes up to DN100 to withstand the overpressures described previously, the following table can be used for carbon or stainless steel pipes.

Table 1: Minimum thickness for vent pipes

	1 inch or DN25	2 inch or DN50	3 inch or DN80	4 inch or DN100
Minimum pipe thickness in mm	0,69	1,25	1,84	2,37
NOTE: The recommendations in this table have been developed based on the method described in NFPA 67 *Guide on Explosion Protection for Gaseous Mixtures in Pipe Systems* [1][1] with the addition of a safety factor for the recognized peak overpressure that can exceed the steady state detonation effect described.				

6 Vent Silencers

When a silencer is put in place, the cross-sectional area of the tail pipe located at the outlet of the vent stack shall not be less than the available free flow through the cross section of the silencer

Silencers shall be provided with drains to prevent accumulation of water in the system.

[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

7 Functional design

7.1 Vent exit design, prevention of water ingress, water purging

Outlet shall be preferably vertical upwards (preferred option) or with an angled outlet (0° to 90° from vertical) directed upwards can be used in specific cases

The ingress and accumulation of water, snow, and/or debris that can affect the active system components by corrosion, blockage, or ice should also be considered.

Non-horizontal vent exits shall be designed to limit rain ingress

Vent systems with a non-horizontal outlet shall be equipped with a water drain valve at the bottom of the vent stack.

7.2 Prevention of blockages from animals or insects / debris protection

Hydrogen vent systems shall be protected against the hazards caused by entering of debris and/or insects inside the vent pipes resulting in potential obstruction / clogging.

Use of vent protectors equipped with wire screens, that is Mud Dauber fittings, is possible provided the proper mesh size is selected to avoid flow obstruction.

7.3 Grounding / electrical continuity

Hydrogen vent piping and associated valves/devices/systems shall be electrically grounded and bonded as required by IEC 60204-1 *Safety of machinery - Electrical equipment of machines - Part 1: General requirements* [2] to give protection against the hazards of the development of electrical charges, stray electrical currents, static electricity and lightning.

7.4 No flame arrestor

Vent lines shall not be fitted with flame arrestors, or any other restrictions that prevent the free release of hydrogen to the atmosphere.

8 Criteria

Different criteria related to heat radiation or thermal dose may be applied depending on the area classification and the category of release events as defined in 8.1 and 8.2.

8.1 Areas

- Public area;
  - unrestricted access;
- Areas of parking or access to administrative buildings;
  - restricted access to employees and visitors;
- Restricted access;
  - restricted to qualified and trained people;
    - appropriate clothing (resistance to flame radiation); and
    - potentially with detectors (flame and hydrogen analysers) → optional.

8.2 Categories of release events

- Release during normal operation / process;
  - Unrestricted access;
- Abnormal event release probability higher than 10^{-2} per year;

- Accidental release with probability between 10^{-2} and less than 10^{-4} per year; and
- Accidental release with probability lower than 10^{-4}.

8.3 Heat radiation criteria

Heat radiation criteria are given as heat flux in W/m^2 for continuous exposure or in thermal dose (kW/m2) $^{4/3}$s for short exposure.

The Eisenberg method to define the hazard zone uses the radiation dose approach. This considers that the effect of radiant heat on humans is a function of both radiation intensity and duration of exposure. Eisenberg et al. (see EIGA Doc 121 *Hydrogen pipeline systems* [3]) studied data on the lethality from thermal radiation and concluded that the dosage-response relationship for various probabilities of injury/fatality should be in the form,

$D = t\, I^{4/3}$ in units of $(W/m_2)^{4/3}$ - sec

where:

D = dosage for various probability of injury

t = duration of the exposure, sec

I = thermal radiation intensity, W/m^2

For short duration exposure (up to 45 s), the following thermal dose criteria may be applied:

Table 2: Thermal dose

Thermal Dose	Harm to people
85 - 127 (kW/m^2)^4/3.s	Pain
290 (kW/m^2)^4/3.s	Second degree burn
600 (kW/m^2)^4/3.s	Irreversible effects threshold
1000 (kW/m^2)^4/3.s	Lethal effects threshold
1800 (kW/m^2)^4/3.s	Significant lethal effects threshold (50 % of fatality)

For longer duration exposure, the following thermal flux values may be used [2]:

[2] The values include the solar radiation effect.

Table 3: Thermal flux

Thermal flux	Harm to people
1,58 kW/m^2	Maximum radiant heat intensity at any location where personnel with appropriate clothing can be continuously exposed.
2,9 kW/m^2	Time to pain threshold for 30 seconds.
3 kW/m^2	Irreversible effects threshold. For public for all cases except for very rare accidental releases.
4,73 kW/m^2	Maximum radiant heat intensity in areas where emergency actions lasting 2 min to 3 min can be required by personnel without shielding but with appropriate clothing.
5 kW/m^2	Lethal effects threshold.
6,31 kW/m^2	Maximum radiant heat intensity in areas where emergency actions lasting up to 30 s can be required by personnel without shielding but with appropriate clothing.
8 kW/m^2	Significant lethal effects threshold (5% of fatality).
9,46 kW/m^2	Maximum radiant heat intensity at any location where urgent emergency action by personnel is required. When personnel enter or work in an area with the potential for radiant heat intensity greater than 6,31 kW/m^2, then radiation shielding and/or special protective apparel (e.g. fire approach suit) should be considered.

9 Location of outlet

9.1 Safe location

Flows from vents and safety relief equipment shall be piped outdoors to a safe location where they do not generate a hazard for persons or neighbouring structures, away from personnel areas, electrical lines and other ignition sources, air intakes, building openings and overhangs.

9.2 Separation distances - Conditions to be satisfied

9.2.1 Criteria on heat radiation, hydrogen concentration, overpressure

The vent outlet location (height; distance to exposures) should be such that the limits defined for each area are not exceeded under any foreseeable venting situation.

The vent location can be calculated using thermal flux or thermal doses at a height of 1,8 m.

a. Maximum hydrogen concentrations

In air intakes, at windows and openings. In areas where persons or personnel can be present.	<4% hydrogen in air (in volume)

b. Maximum thermal radiation or thermal dose.

The heat radiation criteria defined at 8.3 may be used to define the separation distances. Different criteria may be selected depending on the access categories.

As an example, higher heat flux and and/or thermal dose may be applied for restricted areas than for parking and access or for public areas

c. Maximum overpressure effects criteria in case of delayed ignition may be applied

Table 4: Overpressure effects

Item subject to overpressure	Threshold
Windows (non-reinforced)	<20mbar
Areas with or without restriction of access or walkway	<100 mbar (persons)
Buildings (non-reinforced)	<50 mbar

9.2.2 Solar radiation

Solar radiation for thermal effects on persons should be taken into consideration as follows:

- if the worst case for thermal effects is presence of a wind of 5m/s or more, which is the case for outlets with a 0° to 90 ° slant with regards to vertical, it is not necessary to take solar radiation into account.
- otherwise solar radiation should be taken into account.

10 Hazardous area classification and safety distance definition

Zone classification according to ATEX is summarized in EIGA Doc 134 P*otentially explosive atmospheres EU directive 1999/92/EC* [4].

The tables in Appendix 1 propose calculations of horizontal distances for different flow rates, vent diameters and inclination:

- to reach a given thermal flux (3, 5 or 8 kw/m2);
- to reach LFL (4% hydrogen);
- at a height of 1,8m.

11 Venting of cold hydrogen

11.1 Hydrogen vent sources

Cryogenic and non-cryogenic hydrogen shall be vented through separate venting systems.

11.2 Material

In addition to general prescriptions, the material used in vents of cold hydrogen shall be suitable for low temperatures (cold embrittlement).

11.3 Thermal contraction

Thermal contraction shall be accounted for.

11.4 Prevention of blockage by freezing water

Build-up of ice at the point of release shall be prevented.

Releases of cryogenic hydrogen allowing build-up of ice at the point of release shall be avoided

Horizontal piping allowing ice to grow to point of release shall be avoided – see CGA G-5.4 *Standard for Hydrogen Piping Systems at User Locations* [5].

Particular attention shall be given to avoid water accumulation in the vent piping through regular activation of the water drain device.

11.5 Vaporization prior to release

Venting systems shall be designed to ensure vaporization of normal discharges of liquid hydrogen before release to atmosphere.

Vent piping of cryogenic hydrogen shall not be thermally insulated.

11.6 Condensation of air

Means shall be provided to minimise exposure of personnel to piping operating at low temperatures and to prevent air condensate from contacting piping, structural members and surfaces not suitable for cryogenic temperatures.

Uninsulated piping and equipment, which operates at below air condensation temperature, shall not be installed above asphalt surfaces or other combustible materials in order to prevent contact of liquid air with such materials. For the purposes of this standard, asphalt and bitumen paving shall be considered combustible. If expansion joints are used, fillers shall also be made of non-combustible materials. Drip pans can be installed under uninsulated piping and equipment to retain and vaporise condensed liquid air.

11.7 Protection of personnel

Exposure of personnel and equipment to falling ice from piping and vent tips shall be avoided.

11.8 Specific criteria for location

Systems venting potentially cold hydrogen from liquid hydrogen systems should b be designed taking into account the effect of condensing air leading to downward formation of an oxygen rich mixture.

12 Pressure and leak testing

An initial pressure and leak test for the vent system before start up is recommended to ensure a gas tight and detonation proof installation for not permanently inerted systems. The test pressure should therefore be the design pressure at minimum.

The pressure and leak test can be performed with nitrogen.

The testing may be limited to the piping between the pressure relief devices and the vent stack.

Means of pressure indication suitable for the test pressure shall be installed before the test. Precautions shall be taken to prevent excessive pressure in the system during the test.

Following the pressure and leak test, it shall be checked that all isolation devices introduced to perform the test have been removed.

Any defects found during the test shall be rectified in an approved manner. Testing shall be repeated until satisfactory results are obtained.

13 Inspection and maintenance

13.1 Visual inspection

The owner/operator shall perform routine site safety inspections on an annual basis at minimum.

The inspector should visually determine that the vent system discharge is free from potential obstructions such as bird nests, insect hives, vegetation, etc. The inspector should also visually inspect the support system.

13.2 Physical inspection

If the vent system is equipped with a water drain device (sump) at the bottom of vent stack, operators should periodically check the sump for accumulated moisture. This test is not applicable when ambient temperatures are below freezing since ice can accumulate in the sump. If the presence of ice is suspected, an alternate method should be devised to verify its presence. It should then be determined whether the ice will affect the performance of the vent system.

Qualified service technicians shall check all vent system valves on a periodic basis to ensure proper operational functions.

Inspection and conductivity measurement of lightning arresters and the grounding and bonding of the vent system should be performed at least every 3 years.

13.3 Field repairs

Only qualified and trained service technicians shall carry out any repairs to the vent stack system.

Presence of a hydrogen-rich atmosphere within the vent stack shall be assumed. Before and during any type of repair work, an inert gas purge shall be performed.

Personnel shall be alert and aware of the risk of ignition of the hydrogen released.

During any type of work on a liquid hydrogen system, personnel shall be aware of the extremely low temperature associated with liquid hydrogen and the hazard this poses.

All sources of hydrogen that are piped to a vent stack shall be reviewed before the repair of any specific vent system. Depending on the repairs involved, these sources could have to be disconnected or piped to a temporary vent system. Personnel shall be aware of any releases that can occur while repairing a vent system.

13.4 Ignition at outlet

Occasional ignition at vent outlet is expectable and should not be considered abnormal.

Firemen shall be instructed not to attempt to extinguish the flame or spray water at the vent stack in the case of such an ignition.

14 References

Unless otherwise specified, the latest edition shall apply.

[1] NFPA 67, *Guide on Explosion Protection for Gaseous Mixtures in Pipe Systems*, National Fire Protection Association. www.nfpa.org

[2] IEC 60204-1 *Safety of machinery - Electrical equipment of machines - Part 1: General requirements*. International Electrotechnical Commission. www.iec.ch .

[3] EIGA Doc 121 *Hydrogen pipeline systems.* www.eiga.eu

[4] EIGA Doc 134 P*otentially explosive atmospheres EU directive 1999/92/EC*. www.eiga.eu

[5] CGA G-5.4 *Standard for Hydrogen Piping Systems at User Locations*. Compressed Gas Association. www.cganet.com

15 Additional References

EIGA Doc 06 *Safety in Storage, Handling and Distribution of Liquid Hydrogen.* www.eiga.eu

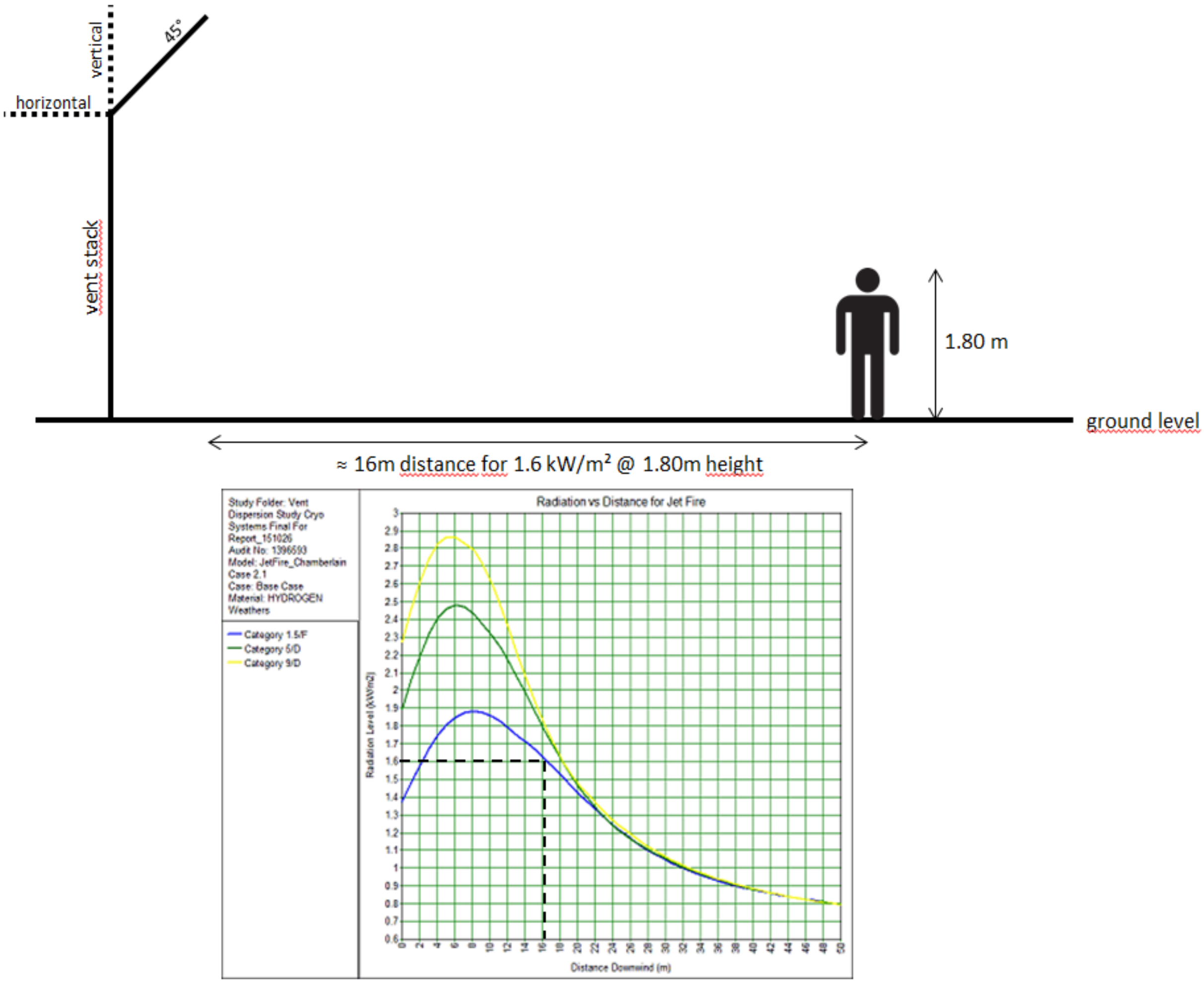
EIGA Doc 15 *Gaseous Hydrogen Stations.* www.eiga.eu

Appendix 1: Hydrogen vent modelling – Horizontal distance

Input Data

Flow Rate [Nm^3/h]	Mass Flow Rate [kg/h]	Release Velocity [m/s]			Mass Flow Rate [kg/s]
		DN50	DN100	DN 25	
100	8,9	14,1	3,5	56,6	0,002480159
500	44,6	70,7	17,7	282,9	0,012400794
1000	89,3	141,5	35,4	565,9	0,024801587
2500	223,2	353,7	88,4	1414,7	0,062003968
5000	446,4	707,4	176,8	2829,4	0,124007937

Release velocity is limited to 500 m/s as per Phast program
Vent height 5 m
LFL Calculation Height = 1,8 m



Results distance to specific heat radiation (in 1,8 m height) – Vertical vent inclination

Weather 3/F

Flow Rate [Nm³/h]	Vertical								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5000	n/a	n/a	n/a	n/a	n/a	n/a	4	n/a	n/a

Weather 5/D

Flow Rate [Nm³/h]	Vertical								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2500	n/a	n/a	n/a	n/a	n/a	n/a	6.2	n/a	n/a
5000	n/a	n/a	n/a	n/a	n/a	n/a	7,8	n/a	n/a

Weather 9/D

Flow Rate [Nm³/h]	Vertical								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	2,45	n/a	n/a	4,2	n/a	n/a
2500	n/a	n/a	n/a	3,2	n/a	n/a	7,1	5	n/a
5000	5,8	n/a	n/a	5,9	n/a	n/a	9,3	6,9	n/a

Results distance to specific heat radiation (in 1,8 m Height) – 45° vent inclination

Weather 3/F

Flow Rate [Nm³/h]	45° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5000	7,5	n/a	n/a	7,6	n/a	n/a	10	n/a	n/a

Weather 5/D

Flow Rate [Nm³/h]	45° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2500	3,6	n/a	n/a	5,1	n/a	n/a	7,4	n/a	n/a
5000	8,2	n/a	n/a	8,2	n/a	n/a	10,2	6,3	n/a

Weather 9/D

Flow Rate [Nm³/h]	45° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1000	n/a	n/a	n/a	3,5	n/a	n/a	4,4	n/a	n/a
2500	5,1	n/a	n/a	5,8	n/a	n/a	7,6	n/a	n/a
5000	8,2	5,4	n/a	8,2	5,5	n/a	11	5	n/a

Results distance to specific heat radiation (in 1,8 m Height) – 90° vent inclination

Weather 3/F

Flow Rate [Nm³/h]	90° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	3,5	n/a	n/a	4,5	n/a	n/a
1000	4	n/a	n/a	6,7	4,3	n/a	8,1	5,9	n/a
2500	9	5,1	n/a	9,9	8,1	6	12,6	10,7	8,6
5000	13,2	11,3	9,5	13,2	11,3	9,5	16,3	14	12,5

Weather 5/D

Flow Rate [Nm³/h]	90° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	3,1	n/a	n/a	4	n/a	n/a
1000	3,4	n/a	n/a	6,2	3,7	n/a	7,4	5,2	n/a
2500	8,2	6,6	4,2	9,1	7,3	5,3	11,7	10	7,8
5000	12,2	10,5	8,8	12,2	10,5	8,8	15,1	13	11,5

Weather 9/D

Flow Rate [Nm³/h]	90° inclined								
	DN25			DN50			DN100		
	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²	3 kW/m²	5 kW/m²	8 kW/m²
100	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
500	n/a	n/a	n/a	2,8	n/a	n/a	3,7	n/a	n/a
1000	3,1	n/a	n/a	5,8	3,5	n/a	7	4,6	n/a
2500	7,8	6,2	4	8,7	7	5	11,1	9,3	7
5000	11,6	9,7	8,3	11,6	9,7	8,3	14,5	12	10,8

n/a not applicable

All results are based on Cone Model with Chamberlain correlation.

For 90° inclined (horizontal) release: horizontal jet fire option as per Phast recommendation has not been used because resulting heat radiation was lower than for vertical and 45° inclined releases (seems not to be reasonable).

The height for calculation of flammable effects is 1,8 m; calculation of the LFL contour at ground level.

Results extension LFL

Weather 3/F

Flow Rate [Nm³/h]	Vertical			45° inclined			90° inclined		
	DN25	DN50	DN100	DN25	DN50	DN100	DN25	DN50	DN100
100	1,1	1,4	1,5	1,41	1,5	1,5	2	1,7	1,6
500	1,1	1,8	2,2	2,3	2,5	2,5	4	3,5	2,9
1000	1,1	2	2,6	2,9	3,2	3,2	5,4	4,9	3,9
2500	1,7	2	3,2	4,4	4,4	4,6	7,7	7,6	6,2
5000	2,2	2,3	3,5	5,8	5,9	6,1	10,2	10,2	8,9

Vent height

Weather 5/D

Flow Rate [Nm³/h]	Vertical			45° inclined			90° inclined		
	DN25	DN50	DN100	DN25	DN50	DN100	DN25	DN50	DN100
100	1,2	1,6	1,8	1,47	1,7	1,8	2	2	1,9
500	1,2	2,1	2,7	2,1	2,6	2,9	3,7	3,5	3,3
1000	1,2	2,3	3,1	2,5	3,2	3,5	4,8	4,7	4,2
2500	1,9	2,3	3,7	3,8	4	4,7	6,7	6,7	6,2
5000	2,6	2,6	4	5,1	5,2	5,8	8,9	8,9	8,3

Weather 9/D

Flow Rate [Nm³/h]	Vertical			45° inclined			90° inclined		
	DN25	DN50	DN100	DN25	DN50	DN100	DN25	DN50	DN100
100	1,2	1,6	1,7	1,38	1,7	1,7	1,9	1,9	1,8
500	1,3	2,1	2,6	1,9	2,5	2,8	3,2	3,2	3,1
1000	1,3	2,3	3,1	2,2	2,9	3,4	4	4,1	4
2500	2	2,4	3,7	3,3	3,6	4,4	5,7	5,7	5,6
5000	2,7	2,8	4,1	4,5	4,6	5,3	7,4	7,4	7,2