HyResponse

BASICS OF HYDROGEN SAFETY FOR FIRST RESPONDERS

Lecture. Harm criteria for people and environment, damage criteria for structures and equipment.

FCH
FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

Content

- Health hazards of hydrogen leaks/releases
  - Gaseous hydrogen GH_2
  - Liquefied hydrogen LH_2
- Harmful effects of hydrogen combustion on humans
  - Effect of air temperature
  - Effect of direct contact with hydrogen flames
  - Effect of radiant heat flux from hydrogen fires
  - Effect of overpressure
- Damage to structures, equipment and environment caused by hydrogen fires
- Impact of overpressure on structures and equipment
- Labelling of hydrogen systems
- Personal protective equipment
- Impact on the environment

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Objectives of the lecture

- Describe main health hazards associated with the unignited releases, fires, deflagrations and detonations of gaseous and liquefied hydrogen;
- Define harmful effects related to unignited hydrogen releases in confined spaces:
  - safe concentration levels of hydrogen and oxygen;
  - the noise level;
  - effect of hydrogen temperature;
  - effect of overpressure in case of pressure peaking phenomenon.
- Define the harmful effects of hydrogen combustion on humans:
  - effect of combustion atmosphere temperature;
  - exposure to radiant heat flux;
  - effect of overpressure
- Appreciate the principles and implementation of framework of harm criteria for people and environment, damage criteria for structures and equipment:
  - air temperature,
  - thermal dose,
  - heat flux,
  - overpressure, etc.
- Specify dangerous and Lethal Dose, 50% (LD50) thermal dose levels;
- Distinguish between direct and indirect harmful effects of overpressure on humans;
- Relate in particular the damages to structures, equipment, and environment caused by hydrogen fires/blast waves to the levels of radiant heat flux and overpressure;
- Recognise labelling systems for gaseous and liquefied hydrogen storage on hydrogen and fuel cell applications;
- List the items of personal protective equipment that should be used not only by First Responders but also by the personnel working at a FCH facility;
- Outline the impact of hydrogen on the environment.

Health hazards of GH_2

- Hydrogen gas has **no odour, no colour, and no taste**. It is not detectable by human senses. The use of odourants (e.g. mercaptans) is not possible as they poison fuel cells.
- Hydrogen is **not a carcinogen.** Hydrogen is not expected to cause mutagenicity, teratogenicity, embryotoxicity or reproductive toxicity.
- There is no evidence of adverse effects on skin or eyes exposed to hydrogen atmospheres. However, high pressure hydrogen **jets may cut bare skin** (Hammer, 1989).
- Hydrogen cannot be ingested (unlikely route). However, inhaled hydrogen can result in a flammable mixture formed within the human's body.
- Hydrogen is classified as a **simple asphyxiant**, it has no threshold limit value (TLV) (NASA, 1997).

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Sources: Hammer, W (1989). Occupational Safety Management and Engineering, 4th edition, Prentice Hall, Englewood Cliffs, New Jersey, 1989, ISBN 0-13-629379-4, chapter 19.
NASA (1997). Safety standard for hydrogen and hydrogen systems. Guidelines for hydrogen system design, materials selection, operations, storage, and transportation. Technical report NSS 1740.16

Hydrogen is a simple asphyxiant

- High concentrations of hydrogen in air (in fully/partially confined spaces) lead to **oxygen-deficient atmospheres**. People exposed to/breathing such atmospheres may experience the following symptoms: headaches, dizziness, drowsiness, unconsciousness, nausea, vomiting, depression of all the senses, etc. A victim may have a blue coloured skin, and under some circumstances, **death may occur**.
- If hydrogen is inhaled and above symptoms are observed a person should be moved to fresh air; oxygen should be given if breathing is difficult, or artificial respiration should be applied if person is not breathing.
- The system design should prevent any possibility of asphyxiation of personnel in adjacent areas (NASA, 1997). The system design shall provide for prevention of personnel entering the enclosure unless confined space entry procedures are strictly followed.
- It is recommended to **check the oxygen content before entering an incident/accident area** (no odour warning available if dangerous concentrations are present). First Responders should wear a self-contained breathing apparatus. Hydrogen concentrations have to be measured with a suitable detector (Molkov, 2012).

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Sources: NASA (1997). Safety standard for hydrogen and hydrogen systems. Guidelines for hydrogen system design, materials selection, operations, storage, and transportation. Technical report NSS 1740.16.
Molkov, V (2012). Fundamentals of hydrogen safety engineering, Part I and Part II.

Consequences of asphyxiation

- Hydrogen can cause asphyxiation by diluting oxygen in the air to the concentrations below safe level: **less than 19.5 vol. % of oxygen**

H_2 concentration, vol. %	O_2 concentration, vol. %	Physiological effect
9-28	**15-19**	decreased ability to perform tasks, may induce early symptoms in persons with heart, lung, or circulatory problems
28-42	**12-15**	deeper respiration, faster pulse, poor coordination
42-52	**10-12**	dizziness, poor judgment, slightly-blue lips
52-62	**8-10**	nausea, vomiting, unconsciousness, ashen face, fainting, mental failure, with a tolerance time of 5 min
62-71	**6-8**	unconsciousness in 3 min, death in 8 min. 50% death and 50% recovery with treatment in 6 min, 100% recovery with treatment in 4-5 min
71-86	**3-6**	coma in 40 s, convulsions, respiration ceases then **death.**
86-100	**0-3**	**death within 45 s**

Noise effects on people

level	Noise source	Health effects
140dB	Jet plane take off, firecracker, gun shot	Sudden damage to hearing
130dB	Pain threshold exceeded	
120dB	Ambulance siren, pneumatic drill, rock concert	
110dB	Night clubs, disco	
100dB	Motor cycle at 50km/h	
90dB	Heavy goods vehicle at 50km/h	
85dB	Hearing protection recommended in industry	Hearing loss, tinnitus
75dB		Cardiovascular effects
70dB		Sleep disturbances
65dB		Stress effects
60dB		Annoyance
55dB	Desirable outdoor level	
50dB	Normal conversation level	
40dB	Quiet suburb	
30dB	Shoft whisper	
20dB	Normal conversation level	

Source: Nopher, a European Commission concerted action to reduce the health effects of noise pollution. http://www.ucl.ac.uk/noiseandhealth/EC%20Brochure1.pdf

Ultrasonic sound pressure level

While **audible acoustic noise** typically ranges between **60 and 110 dB** in industrial sites, the ultrasonic noise levels (frequency range of 25-100 kHz) span from **68 to 78 dB** in high noise areas, where rotating machinery like compressors and turbines are installed, and rarely exceed **60 dB** in low noise areas.

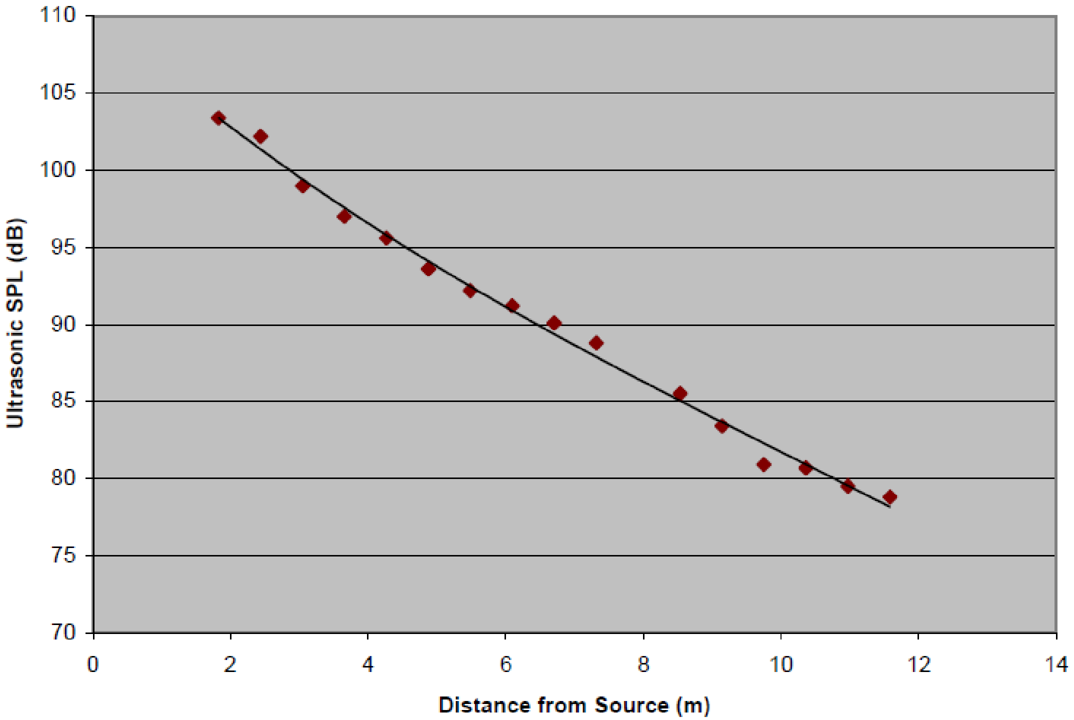

Figure 3. Sound pressure level as a function of distance for hydrogen leaks. Leak size = 1 mm-diameter orifice, differential pressure = 5,515 kPa (800 psi), leak rate = 0.003 kg/s. The curve is to guide the eye.

- A blast noise can lead to an **acoustic trauma** (a sudden change in hearing as a result of a single exposure to a sudden burst or sound).
- A danger of an impulse noise lasting less than 1 s.

Source: Hydrogen Detection in Oil Refineries, Gassonic, General Monitors.

Health hazards of LH_2

- Contact with liquid hydrogen or its splashes on the skin or in the eyes can cause serious **cold burns by frostbite or hypothermia**.
- Inhaling vapour or cold hydrogen produces **respiratory discomfort** and can result in **asphyxiation**.
- Direct physical contact with liquid hydrogen, cold vapour, or cold equipment can cause serious **tissue damage**. Momentary contact with a small amount of the liquid may not pose as great a danger of a burn because a protective film may form. Danger of freezing occurs when large amounts are spilled and exposure is extensive.
- Personnel should not touch cold metal parts and they should wear **protective clothing**. Protect the affected area with a loose cover.
- **Cardiac malfunctions** are likely when the internal body temperature drops **to 27°C**, and **death** may result when the internal body temperature drops to **15°C** (NASA, 1997).

Source: NASA (1997). Safety standard for hydrogen and hydrogen systems. Guidelines for hydrogen system design, materials selection, operations, storage, and transportation. Technical report NSS 1740.16.

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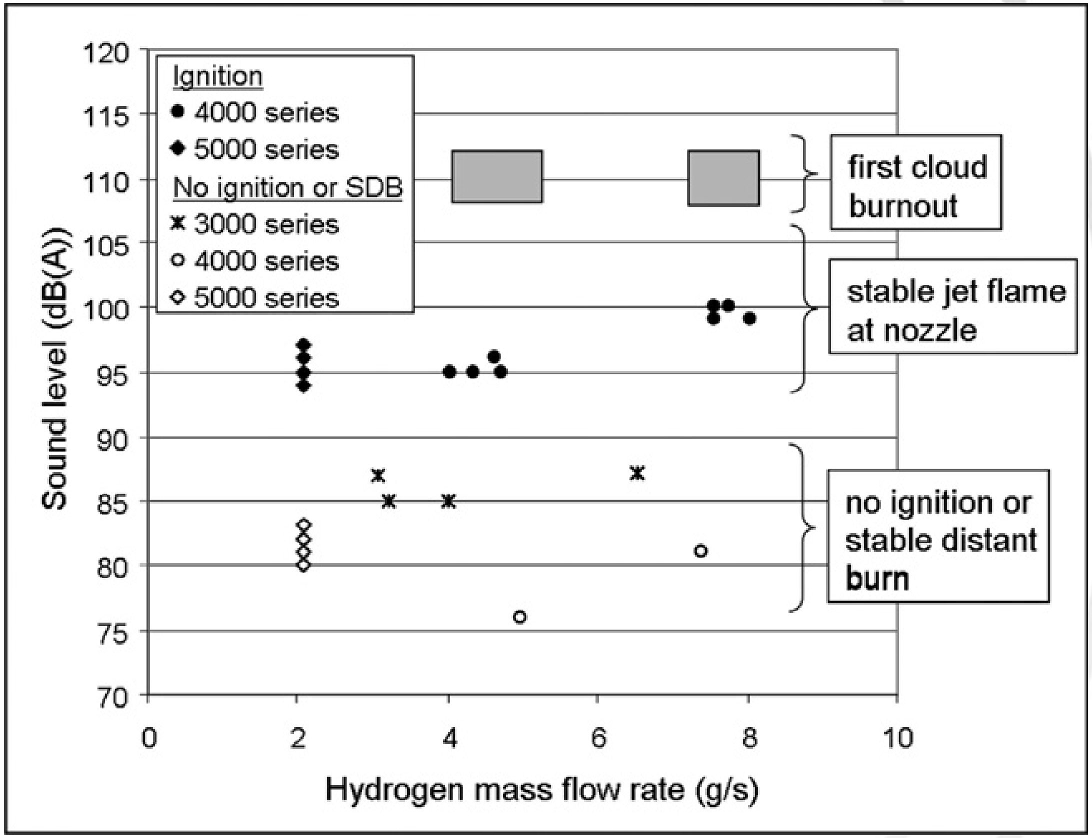
Hydrogen cryogenic jets: sound level

- The sound levels measured ≤112 dB(A)) are considered hazardous only in case of permanent or long-time exposure.
- An ear damage from short-sound waves becomes possible for levels higher than **120 dB(A).**
- **Sudden loss of hearing may occur at levels higher 140 dB**



Experiments with cryogenic hydrogen (34-65 K).

Source: Friedrich, A. et al (2012) International Journal of Hydrogen Energy. Vol.31, pp.17589-17598.

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Hazards from hydrogen combustion

- An inhalation of combustion products originated from conventional fuels is one of the major causes of an injury and a primary consequence of a fire. It is considered less serious in the case of hydrogen, because the **sole combustion product is water vapour (non-toxic, non-poisonous)**. Contrary, carbon monoxide CO can be lethal at concentrations just above 400 ppm (parts per million) (Drysdale, 1985). However, secondary fires can produce smoke or other combustion products that present a health hazard.
- The flame temperature of a stoichiometric hydrogen/air mixture is about **2,403 K** (ISO TR 15196, 2004).
- Direct contact with combusting hydrogen or hot post-flame gases resulting from combustion of hydrogen will cause severe **thermal burns**.

Sources:
Drysdale, D (1985). An introduction to fire dynamics. John Wiley and Sons, Chichester, p. 146.
SO/TR 15916 (2004). Basic considerations for the safety of hydrogen systems. International Organization for Standardization. ISO Technical Committee 197 Hydrogen Technologies. International Organization for Standardization, Geneva.

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Effect of the air temperature on people

Temperature of air, ºC	Physiological response (DNV, 2001)
70	No fatal issue in a closed space except uncomfortable situation
115	Threshold for pain (exposure time longer than 5 minutes)
127	Difficulty breathing
149	Breathing via mouth is difficult, temperature limit for escape
160	Rapid, unbearable pain with dry skin
182	Irreversible injuries in 30 seconds
203	Respiratory systems tolerance time less than four minutes with skin
309	Third degree burns for 20 seconds exposure, causes burns to larynx after a few minutes, escape is impossible

A proximity suit can provide a protection against air heated up to 1,093ºC for a short period of time (NFPA, 1997).

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Sources:
DNV Technica (2001). Human resistance against thermal effects, explosion effects, toxic effects and obscuration of vision. DNV Technica, Scandpower A/S, Det Norske Veritas, Oslo, Norway.
NFPA, Recommended practice for Responding to Hazardous Materials Incidents (1997).

Effect of radiant heat flux on people

- Due to the absence of CO_2 radiation bands and the strong absorption by ambient water vapour, the ratio of visible to infrared hydrogen jet-flames is 0.88 and the ratio of ultraviolet to infrared flame length is 0.78 (Houf and Schefer, 2007).
- A hydrogen flame radiates significantly less heat and is practically invisible in broad daylight. The maximum of its emission is about 311 nm, which is near ultraviolet (UV) radiation (ISO/TR 15916, 2004).
- Personnel near a hydrogen flame might not sense its proximity until they are in contact with combustion products. Without a suitable detection equipment, the first indication of a small flame is likely to be a "**hissing" noise** of the gas leak and perhaps "**heat ripples**" (ISO/TR 15916, 2004).
- Direct contact with combusting hydrogen or hot post-flame gases resulting from combustion of hydrogen will cause severe burns (ISO/TR 15916, 2004).
- Nevertheless convective and radiative heat fluxes still remain important and must be assessed for the protection of life, property and the environment.

Sources:
Houf, WG and Schefer, RW (2007). International Journal of Hydrogen Energy. Vol. 32, pp. 136-151.
ISO/TR 15916 (2004). Basic considerations for the safety of hydrogen systems. International Organization for Standardization.
ISO Technical Committee 197 Hydrogen Technologies. International Organization for Standardization, Geneva.

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Radiant heat flux: harm criteria for people

Radiant heat flux intensity, kW/m²	Effects on people
1.5	Safe for the general public and for the stationery personnel
2.5	Intensity tolerable for 5 min; severe pain above this exposure time
3	Intensity tolerable for non-frequent emergency situations for 30 min
5	Intensity tolerable for those performing emergency operations
6	Intensity tolerable for escaping emergency personnel
9.5	Second degree burn after 20 seconds
12.5-15	First degree burn after 10 seconds, 1% fatality in 1 min
25	Significant injury in 10 s, 100% fatality in 1 min
35-37.5	1% fatality in 10 s

Source: LaChance, J (2009). Risk-informed separation distances for hydrogen refuelling stations. International Journal of Hydrogen Energy, Vol. 34, pp. 5838-5845.

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Radiative heat flux threshold values

- 1.5 kW/m^2 – safe for members of the public (for comparison, 1.3 kW/m^2 is the average intensity of radiant heat from the sun on a hot day) (Saffers, 2010).
- 2.5 kW/m^2 - a limit for exposure of un-protected skin, at higher intensities – severe pain, tolerance time: 5 min (BSI, 2004). This is a tolerable intensity for an occupant. Above this value of heat flux or duration of exposure, the dose received should be calculated to evaluate an impact on people.
- 5 kW/m^2 is a threshold of tolerability for first responders wearing protective clothing. Long exposure should be avoided.
- 6 kW/m^2 – tolerable for occupants when evacuating. This intensity is lethal in about 38 s and pain is reached in 12 s (Saffers, 2010).
- In French doctrine the threshold values set at: 3, 5 and 8 kW/m^2 (NIO, 2013).

Sources:
Saffers, JB (2010). Principles of hydrogen safety engineering. PhD thesis. University of Ulster.
BSI (2004). Published Document PD 7974-6:2004. The application of fire safety engineering principles to fire safety design of buildings - Part 6: Human factors: Life safety strategies - Occupants evacuation, behaviour and condition (Sub-system 6). British Standards Institution.
NIO Note D'Information Operationnelle (2013). 'Intervention sur les installations d'hydrogène et Les risques lies.

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Thermal dose

- The level of thermal radiation required to produce a given level of damage is commonly defined in thermal dose units.
- Thermal dose: $TD = I^{4/3} \times t$,

where I is the incident thermal flux (kW/m^2) and t is the time (in s).

Combines intensity and exposure time

1 thermal dose unit (TDU) = 1 $(kW/m^2)^{4/3}s$)

LD50 denotes a dose, at which 50% human fatalities are expected.

Rew proposed 2000 TDU as the equivalent LD50 for incident thermal radiation on-shore (Rew, 1997).

O'Sullivan and Jagger (2004) and Chang et al. (2008) reported a guiding figure of 3500 TDU corresponding to 100% fatality for personnel with appropriate clothing. However, 100% fatality may occur at slightly lower doses. At 3500 TDU, un-piloted ignition of clothing will occur, thus even 100% clothed individuals will not survive. At this level of thermal dose, self-extinguishment is unlikely due to injury from heat transmitted through the clothing.

Sources:
Rew, P. (1997) LD50equivalentfortheeffectsofthermalradiationonhumans,in: Suffolk, Health and Safety Executive(HSE)Books.
O'Sullivan, S and Jagger, S. (2004) Human vulnerability to thermal radiation offshore, in: S. Jagger(Ed.), Health&Safety Laboratory,Buxton.
Chang, Y et al. (2008). The Study of Flame Engulfment Protection of Firefighter's Clothing, J. HanaokaTextile, Vol. 15, 345–349.

Radiation burn data

Severity of burn	Thermal dose threshold, $(kW/m^2)^{4/3}s$	
	Ultraviolet	Infrared
First degree	260-440	80-130
Second degree	670-1100	240-730
Third degree	1220-3100	870-2640

The radiation heat flux in the infrared spectrum is of most concern for generating burns.

Source: LaChance, J (2009). Risk-informed separation distances for hydrogen refuelling stations. International Journal of Hydrogen Energy, Vol. 34, pp. 5838-5845.

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Dangerous dose and LD50 thermal dose levels

Literature source	Thermal dose $(kW/m^2)^{4/3}s$ for infrared radiation	
	Dangerous dose	LD50
Eisenberg [1]	960	2380
Tsao and Perry [2]	420	1050
Lees [3]	1655	3600 (based on ignition of clothing at 3600 $(kW/m^2)^{4/3}s$).
HSE [4]	1000	2000
The Netherlands Organization of Applied Scientific Research (TNO) [5]	590	1460

Sources: [1] Eisenberg NA, et al. Vulnerability model: a simulation system for assessing damage resulting from marine spills, Final
Report SA/A-015 245, US Coast Guard; 1975.
[2] Tsao CK, Perry WW. Modifications to the vulnerability model: a simulation system for assessing damage resulting from marine spills. Report ADA 075 231 US Coast Guard; 1979.
[3] Lees FP. The assessment of major hazards: a model for fatal injury from burns. Transactions of the Institution of Chemical Engineers 1994;72(Part B):127e34.
[4] Rew PJ. LD50 equivalent for the effect of thermal radiation on humans. HSE 129/1997. Health & Safety Executive; 1997.
[5] Methods for the determination of possible damage. In: CPR 16E. The Netherlands Organization of Applied Scientific Research; 1989.

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Hydrogen deflagrations and detonations

Harmful overpressure effects on people

- Delayed ignition of a hydrogen jet, or ignition of a flammable cloud will result in, **overpressure** which can harm people and cause damage to property.
- The level of generated overpressure can vary greatly from one scenario to another and can be influenced by many factors including the level of confinement, turbulence, the presence of obstacles, volume and concentration of the flammable mixture, speed of flame propagation, etc.
- Two factors can cause harm:
  - The **level of overpressure**
  - The **impulse** is the integral of pressure and time.

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Possible effects of overpressure on humans

Direct effects:

Δp, kPa	Damage description
13.8	Threshold for eardrum rupture
34.5-48.3	50% probability of eardrum rupture
68.9-103.4	90% probability of eardrum rupture
82.7-103.4	Threshold for lung haemorrhage
137.9-172.4	50% probability of fatality from lung haemorrhage
206.8-241.3	90% probability of fatality from lung haemorrhage
48.3	Threshold for internal injuries by blast
482.6-1379	Immediate blast fatalities

Indirect effects:

Δp, kPa	Damage description
3.0	Injuries by glass fragments
6.9-13.8	Threshold for skin lacerations by missiles
10.3-20.0	People knocked down by pressure wave
13.8	Possible fatality by being projected against obstacles
27.6-34.5	50% probability of fatality from missile wounds
48.3-68.9	100% probability of fatality from missile wounds
55.2-110.3	People standing up will be thrown a distance

Source: LaChance, J (2009). Risk-informed separation distances for hydrogen refuelling stations. International Journal of Hydrogen Energy, Vol. 34, pp. 5838-5845.

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Threshold of overpressure: harm to humans

Harm criteria (selected thresholds)	Overpressure, kPa
1% fatality probability due to lung haemorrhage (Mannan, 2005): “fatality” hazard distance	100
1% eardrum rupture probability (Mannan, 2005): “injury” distance	16.5
Temporary threshold shift (Baker, 1983): “no harm” hazard distance (evacuation perimeter)	1.35

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Overpressure: effect on people (France)

- French regulatory thresholds:
  - Irreversible effects: 50 mbar or 5000 Pa or 5kPa
  - Lethal effects: 140 mbar or 14000 Pa or 14 kPa

Δp, Pa (1 mbar = 100 Pa)	**Effect**
150	Unpleasant feeling
300	Loud bang
1000	Persons fall down
17500	Lower limit for eardrum ruption
85000	Lower limit for serious pulmonary damage
205000	Lower lethality limit

Radiant heat flux: effect on structures and materials

Radiant heat flux, kW/m^2	Effect on structures and environments
5	Significant windows breakage
8-12	Intensity for domino effects
10	Heating structures; increase of temperatures and pressures in LH_2/GH_2 storages
10-12	Ignition of vegetation
13-15	Piloted ignition of wood, melting of plastics (more than 30 minutes exposure)
10-20	Ignition of fuel oil (120 or 40 seconds, respectively).
20	Intensity, which concrete structures can withstand for several hours
25-32	Unpiloted ignition of wood, steel deformation (more than 30 minutes exposure)
35-38	Process equipment and structural damage (including storage tanks) (more than 30 minutes exposure)
100	Steel structure collapse (more than 30 minutes exposure time)
200	Concrete structures failure

Source: LaChance, J (2009). Risk-informed separation distances for hydrogen refuelling stations. International Journal of Hydrogen Energy, Vol. 34, pp. 5838-5845.

Overpressure thresholds for structures and equipment

Δp, kPa	Damage description
1	Threshold for glass breakage
15-20	Collapse of non-reinforced concrete or cinderblock walls
20-30	Collapse of industrial steel frame structure
35-40	Displacements of pipe bridge, breakage of piping
70	Total destruction of buildings; heavy machinery damaged
50-100	Displacement of cylindrical storage tanks, failure of pipes

Source: LaChance, J (2009). Risk-informed separation distances for hydrogen refuelling stations. International Journal of Hydrogen Energy, Vol. 34, pp. 5838-5845.

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Threshold of overpressure: damage for buildings

Damage	Overpressure, kPa
Minor damage of the house (chosen as “minor damage”)	4.8
Partial demolition of the house-remains inhabitable (chosen as “partial demolition”)	6.9
Almost total destruction of the house (chosen as “almost total destruction”)	34.5-48.3

Source: Mannan, 2005

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Overpressure: effects on structures

Data acceptable in **French regulations for structures**:

Δp, Pa (1 mbar = 100 Pa)	**Effect**
500	Damage to window frames, doors, roofs
2000	Occasional roof damage
3500	Plaster fissures
6000	Roofs and walls of wooden houses destroyed
8500	Outer plaster destroyed
10000	Brick walls destroyed
40000	Common buildings almost totally destroyed

French regulatory threshold: Domino effects: 200 mbar or 20,000 Pa or 20 kPa

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Overpressure: effect on windows

French regulations:

Δp, Pa (1 mbar = 100 Pa)	**Effect**
200	Panes under tension break occasionally
300	Glass breaks by sound waves
500	Small panes under tension break
1000	10 % of all panes break
3000	75 % of all panes break
5000	100 % of all panes break

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Accident in Nagoya, Japan

- 1953
- Hydrogen tanks exploded at the chemical plant
- 16 people were killed
- 230 seriously injured
- 15 tonnes of hydrogen
- Please click to watch the video

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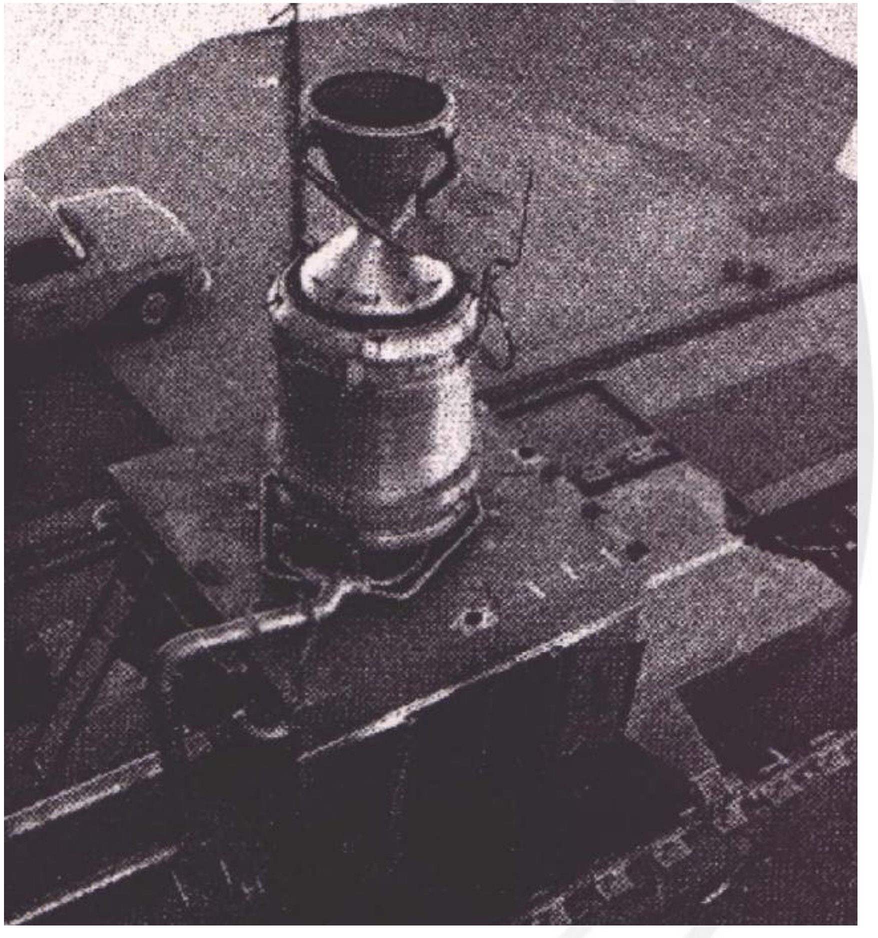
Jackass flat, Nevada, USA

- January, 1964
- Unconfined hydrogen-air explosion
- Test to measure acoustic noise due to high flow rate hydrogen
- 1000 kg hydrogen discharged from vertical rocket nozzle at 23 MPa in 30 seconds
- Discharge rate uniformly increased to 55 kg/s, maintained for 10 seconds then reduced to zero
- Ignition occurs 26 seconds after discharge begins
- Estimate 10 kg of hydrogen involved in the explosion
- Explosion heard 3.2 km away



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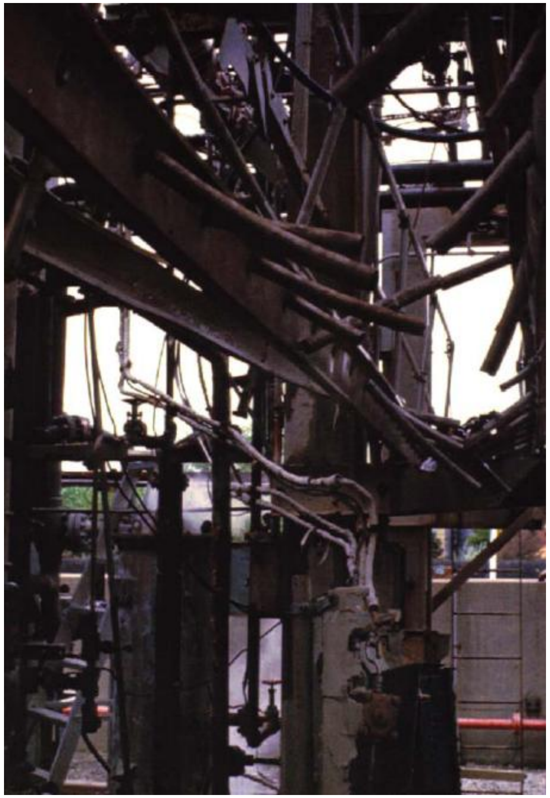
Polysar Ltd, Sarnia, Canada

- 20 April, 1984
- A large petrochemical complex
- A release of about 30 kg of hydrogen gas into a compressor shed from a burst flange operating at 4800 kPa
- A hydrogen explosion and fire
- 2 men killed and 2 injured
- Extensive major structural damage in the near field
- Glass and minor structural damage up to 1 km



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Accident: Muskingum River Power Plant's 585-MW

Source: American Electric Power (AEP)

January 2007, Ohio, US

1 person killed; 10 – injured
Significant damage to the building
Cause: **premature failure of PRD rupture disc**
Link: http://www.powermag.com/lessons-learned-from-a-hydrogen-explosion/

Hydrogen explosion demonstration, The University of Southern Maine

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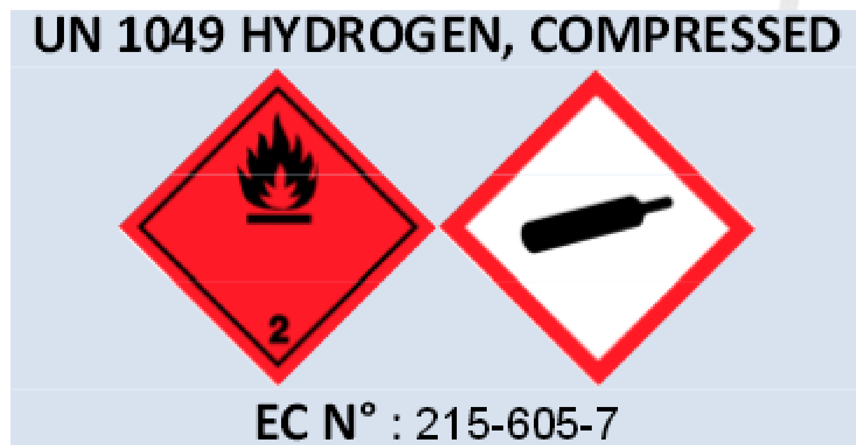
Labelling of hydrogen storage

EU regulation No 406/2010 recommends using green diamonds in white frames with words ‘H2 GAS’ or ‘LIQUID H2’ written in white letters.

cGH_2	LH_2
23	223
1049	1966



Hazards identification: work at CTIF (1/3)

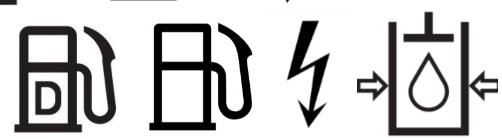
- **Used Colors:**

GREY	DIESEL
RED	GASOLINE
GREEN	GAS
BLUE	HYDROGEN
ORANGE	HIGH VOLTAGE

SYMBOLS

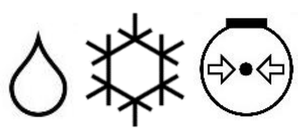
1) FIRST ENERGY SOURCE:

2) SECOND ENERGY SOURCE:



3) DENSITY COMPARED TO AIR:

4) STORED AGREGATE STATE:



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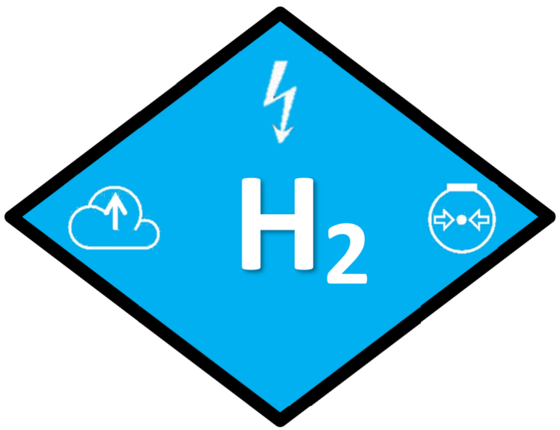
Source: Esbroeck, T and Vollmacher, K (2015). ISO propulsion energy identification. Commission for Extrication and New Technologies. Unpublished.

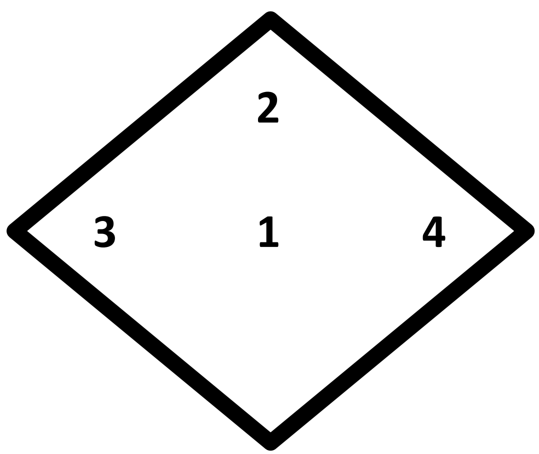
Hazards identification: work at CTIF (2/3)

- No standardized system in place for labelling FCH vehicles
- The development of a new uniform signage in the EU is initiated by the Commission for Extrication and New Technologies (CTIF).

FC: HYDROGEN AND ELECTRIC (HIGH VOLTAGE)



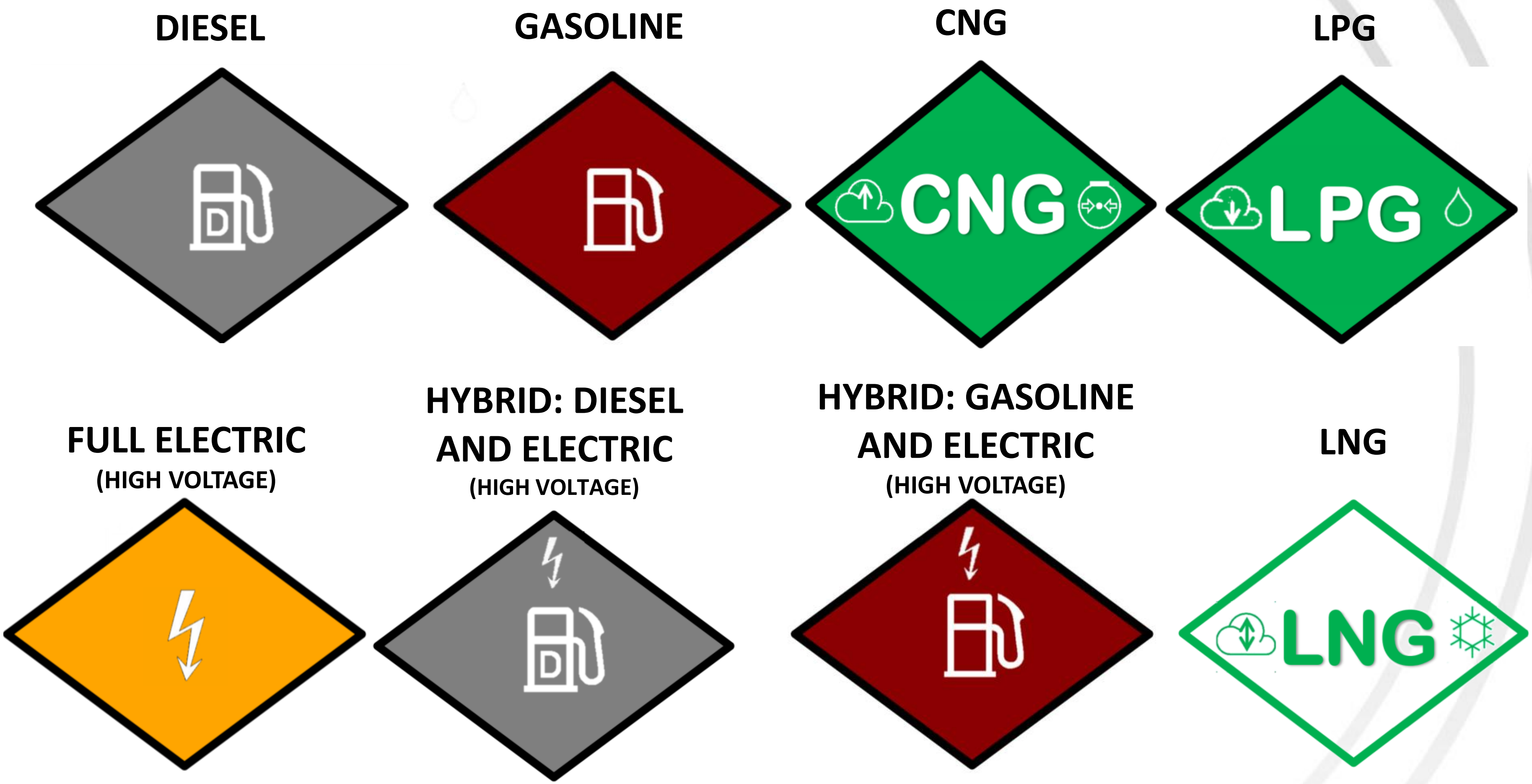
DUAL FUEL/BI FUEL: CNG AND DIESEL



1	**First energy source**
2	Second energy source
3	Density compared to air
4	Stored aggregate state

Source: Esbroeck, T and Vollmacher, K (2015). ISO propulsion energy identification. Commission for Extrication and New Technologies. Unpublished.

Hazards identification: work at CTIF (3/3)



Source: Esbroeck, T and Vollmacher, K (2015). ISO propulsion energy identification. Commission for Extrication and New Technologies. Unpublished.

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Personal protective equipment (1/2)

- **Eye protection** should be worn if appropriate (e.g. a complete **face shield** should be worn when connecting and disconnecting lines or components or **goggles** during handling of cryogenic liquids).
- Properly **insulated gloves** should be worn when handling anything that comes in contact with LH_2 or cold GH_2. The gloves should fit loosely, remove easily, and not have large cuffs.
- **Full-length trousers**, preferably without cuffs, should be worn with the legs kept on the outside of boots or work shoes.
- **Closed-toe shoes** should be worn (open or porous shoes should not be worn).
- **Clothing** made of **ordinary cotton**, **flame-retardant cotton** or **antistatic material** should be worn. Avoid wearing clothing made of nylon or other synthetics, silk or wool because these materials can produce static electricity charges that can ignite flammable mixtures. Synthetic material (clothing) can melt and stick to the flesh, causing greater burn damage. Any clothing sprayed or splashed with hydrogen should be removed until they are completely free of hydrogen gas.

Source: ISO/TR 15916 (2004). Basic considerations for the safety of hydrogen systems. International Organization for Standardization. ISO Technical Committee 197 Hydrogen Technologies. International Organization for Standardization, Geneva.

Personal protective equipment (2/2)

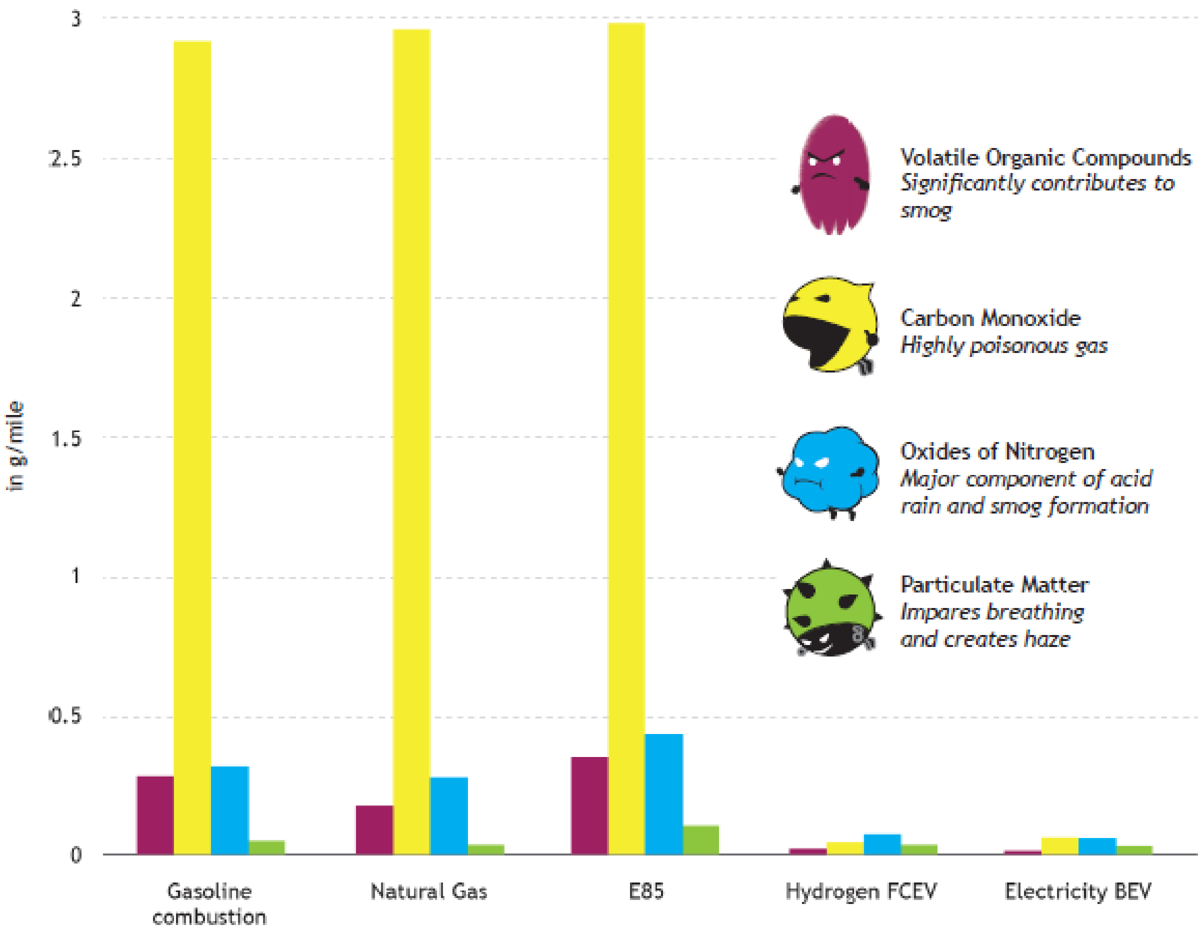
- Gauntlet gloves, tight clothing, or clothing that holds or traps (pockets!) liquid against the body should be avoided.
- **Hearing protection** should be worn if the hydrogen facility or system involves equipment that creates loud noise.
- **Hard hats** should be worn if the hydrogen facility or system involves any danger from falling objects.
- **Self-contained breathing equipment** should be worn when working in a confined space that may have an oxygen-deficient atmosphere.
- **Portable hydrogen-** and **fire-detection equipment** should be used to warn of hydrogen leaks and fires.
- Thermal cameras
- Unmanned hose or monitor nozzle
- Personnel should ground themselves before touching or using a tool on a hydrogen system if any hydrogen is or is suspected to be in the area.

HyResponse

Source: ISO/TR 15916 (2004). Basic considerations for the safety of hydrogen systems. International Organization for Standardization. ISO Technical Committee 197 Hydrogen Technologies. International Organization for Standardization, Geneva.

Environmental hazards

- Hydrogen will **not contaminate groundwater** (it's a gas under normal atmospheric conditions), nor will a release of hydrogen contribute to atmospheric pollution. Hydrogen does not create "fumes or smoke".
- FC vehicle has **zero** exhaust pipe emissions.



"From well to wheel" scheme, California, US. Air pollution emissions from a vehicle (a 2020 model year, mid-sized sedan) that uses different types of fuel.

Source: California Fuel Cell Partnership

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