For larger quantities of hydrogen, tubes will be used. These are also made of steel and the maximum pressure is 200 bar. A tube has a capacity of 1500 – 2500 Liters and contains about 35 kg of hydrogen. They are transported lying down with a tube trailer that often contains 10 tubes and are all connected to each other.

Setup of a tube trailer with the mandatory symbols.

As we have seen, there are also cars with hydrogen as fuel. Such a model contains 2 or 3 tanks made of reinforced polymer with a maximum pressure of 700 bar. The content varies between 25 and 65 Liters of hydrogen, which drowns out 5 to 6 kg of hydrogen. The tanks are connected to each other and everything is protected against exploding. This is referred to as **TPRD** = Thermally – activated Pressure Relief Device.

At a temperature of 110°C (near a fire or high temperature), the TPRD will open and the contents of the hydrogen tank will be blown off in a controlled manner. The draining of the tank will take a maximum of 3 minutes depending on the contents.

Hydrogen can also be transported in pipelines. A distinction can be made between low pressure and high pressure.

Low-pressure pipelines are currently only found in smaller pilot projects because they are in full development. These smaller pipes are usually made of PVC but can also go through an existing gas pipe. There is talk of distribution pipes (8 bar) to private homes (30 mbar) and larger buildings (100 mbar).

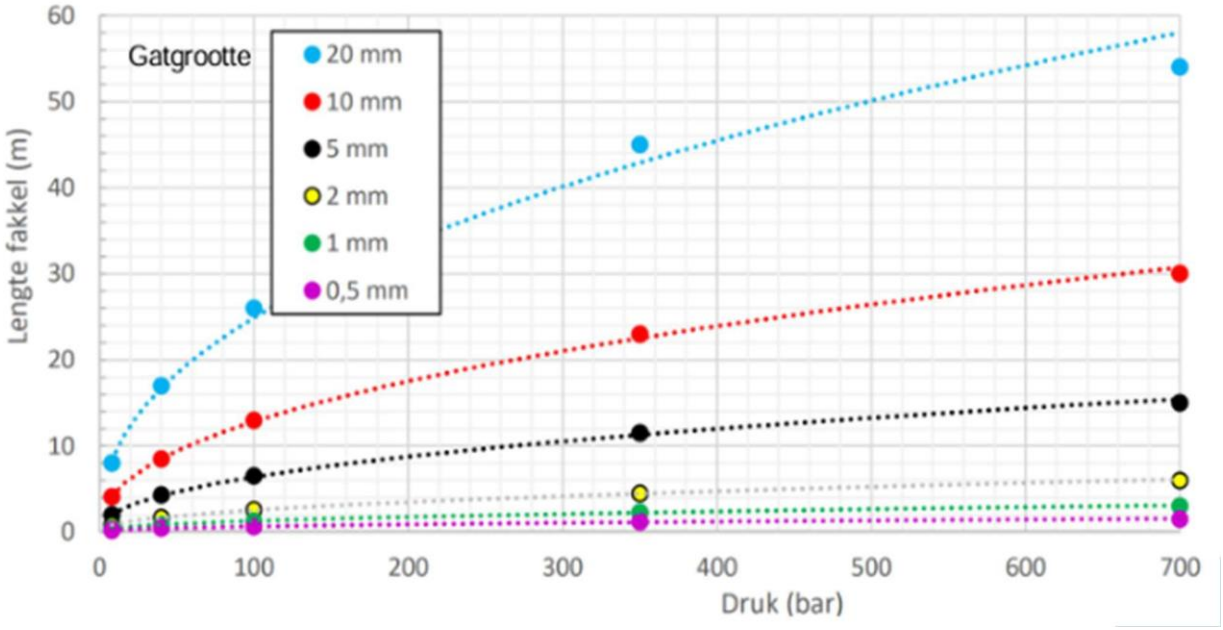
For the high pressure, steel pipes are used where existing high-pressure natural gas pipelines can also be used up to 50 bar.

16.2 Dangers of hydrogen

Leaks are a danger of all types of gases. It can happen continuously or "in a split second" (= instantaneous).

After hydrogen is released, it can be ignited immediately, slowed down or not ignited. If it is released in a closed environment, there is a risk of accumulation.

If hydrogen escapes under high pressure through a leak (or a hole) and is ignited immediately, **a hydrogen jet fire occurs**.



The length of the torch depends on pressure and the size of the hole.

Such a jet fire has several **properties**:

- Most hydrogen is released in the first minute, so the flare is the longest.
- After this minute, the pressure is lower and the torch becomes much shorter.
- The total outflow lasts only a few minutes.
- It is difficult to see without special measuring equipment.
- The flame has a high temperature with little heat radiation outside the torch.
- This makes it possible to approach the torch (even unnoticed) from a short distance.
- The escape of gas under high pressure is clearly audible.
- A flare can cause secondary fires, but constructions will not collapse quickly due to its short duration.

In the port, people often speak of controlled flaring. This is visible all the way to the center of Antwerp.

Hydrogen can also cause **explosions** where there are **2 types**:

- A chemical explosion in a chemical reaction. In the case of hydrogen, this is the burning of hydrogen cloud very quickly.
- In a physical explosion, energy is suddenly released without a chemical reaction taking place. An example of this is the tearing open of a hydrogen tank because the polymeric material from which the tank is made collapses under the effects of a fire.

An explosion also has several **properties**:

- **Deflagration**: The flame front of the explosion travels more slowly than the speed of sound.
- **Detonation**: the flame front travels faster than the speed of sound.

Chemical explosions of hydrogen are almost always deflagrations. However, at concentrations higher than 18.5%, the explosion can change from a deflagration to a detonation.

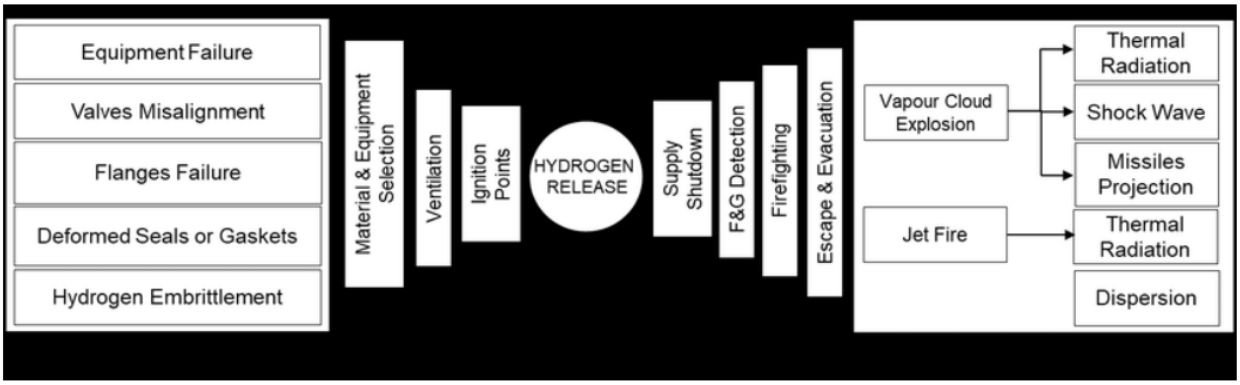
What is the effect of a hydrogen explosion? In the event of a physical explosion, overpressure is created that will be large near the source and then weaken according to the distance. A pressure wave spreads in all directions but will be reflected at obstacles. Along the way, a lot of damage can be done to buildings, vehicles, people,...

In addition to overpressure, a chemical explosion also produces hot combustion gases. A cloud fire will start in the open air. In confined spaces, the overpressure can be high due to the gas accumulation, among other things.

Burning hydrogen? Follow the practical trial of the Dutch fire brigade in collaboration with NIPV.

16.3 Some measures for hydrogen

Hydrogen can be released from a cylinder or a tank. Such an incident is an undesirable event and preventive and repressive measures are possible. A **bow tie model can be used** for this purpose, in which the causes, consequences and measures of an incident are indicated. You read such a model from left to right.



On the left are all possible causes of the incident and the measures you can take to prevent the incident.

In the middle is the incident itself. The preventive measures did not work well or were absent.

On the right are all possible consequences of the incident and the measures you can take to prevent or limit these consequences.

What are **the preventive measures** for hydrogen?

- **Safe design.** Examples are not using hydrogen and reducing the content and/or pressure of a cylinder or tank.
- **Controlling the process.** Examples are the following of standards, regulations, protocols and the like written for the construction, management and maintenance of installations.
- **Timely detection and correction of deviations.** Examples are the monitoring of pressure, temperature and flow. This may or may not be followed by manual or (semi) automatic intervention.

By taking **repressive measures,** the incident is prevented from getting bigger or the consequences are limited:

- **Prevention of large outflows:** use of rupture discs, emergency blow-off systems,...
- **Limiting** large outflows by closing the supply of hydrogen.
- **Preventing escalation** such as detection, ventilation, maintaining sufficient distance and preventing ignition.
- Personal **protection** and **assistance such** as self-reliance, escape routes, emergency procedures and cooling nearby objects.

Where will we best install hydrogen detectors in the future?
Follow the link for additional information.

16.4 Some incidents

Over the past 100 years, there have been a few incidents with unfortunately fatalities. The best known was the already discussed zeppelin of Hindenburg. Various lessons have been learned from the accidents of the last 20 years. This knowledge will be taken into account in R&D in the further development of the hydrogen story in Belgium and the Netherlands. The future hopefully looks bright...

1937 | NEW YORK

A zeppelin filled with 16 compartments of hydrogen caught fire. The probable cause was the leakage of hydrogen from one of the air sacs, followed by an ignition as a result of spark discharge.

Remarkably, the visible flames did not come from the hydrogen but from the cotton cloth from which the outside of the zeppelin was made. More information can be found by following the QR code.

2007 | HEINENOORD

In Heinenoord in the Netherlands, there is a route from Rotterdam to Antwerp with pipes and cables in the ground. Small flames were spotted in the grass near Heinenoord. These turned out to come from a leaking hydrogen pipeline. The pipe had leaked as a result of subsidence.

2013 | VRASENE

An Air Liquid tube trailer with 22 hydrogen tubes lost a number of tubes on the highway. At least one tube leaked, causing a flare. The cause was a bad weld seam on the attachment of the spare wheel. This weld seam failed, causing the spare wheel to end up on the road. Because the driver tried to avoid this wheel, the truck ended up upside down on the roadside.

2019 | Kjørbø

Hydrogen was released at a hydrogen filling station. The gas cloud that was created ignited, resulting in an explosion. Later it turned out that 6 bolts on the end of a hydrogen cylinder had not been tightened sufficiently, allowing the hydrogen to leak. It was noteworthy that the explosion involved a detonation that rarely occurs in the open air.

2019 | GANGNEUNG

In South Korea, a hydrogen tank exploded in the city of Gangneung and the entire building was destroyed. There were 2 deaths and 6 wounded. During the testing of an electrolyser, oxygen had mixed with the hydrogen, creating a flammable mixture. The mixture ignited by a spark that could have been caused by poor grounding.

2021 | DOETINCHEM

In a new hydrogen bus, hydrogen leaked from tanks on the roof of the bus. Several flares were created, causing the bus to burn out. The outflow of hydrogen from the blow-off protection should be vertically directed, but the incident turned out to be the blow-off pipe bent. This created a horizontal torch.

2023 | DELAWARE COUNTY

A pick-up truck was pulling a trailer with hydrogen cylinders in the American town of Delaware County.

The vehicle was involved in a traffic accident that caused one or more hydrogen cylinders to explode. This caused the truck to catch fire and the remaining hydrogen cylinders began to flare.

17. SOURCES

In compiling this document, we looked for information through various channels. Our thanks therefore go to the sources below.

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