HyDelta

WP2 – Odorization of hydrogen

D2.4 – The risk of not odourising hydrogen

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Executive summary

Purpose of this research
This report is part of Work Package 2: odorization of hydrogen. The aim of this work package is to fill some knowledge gaps related to the introduction of an odorant for hydrogen distribution. The specific research goal described in this report is to determine the risks of non-odorization of hydrogen and an inventory of alternative detection methods of hydrogen gas leaks.

Risks of non-odourization in gas distribution
When hydrogen is distributed to the built environment through gas pipelines as a collective energy carrier, it is imperative that the hydrogen is odourised to minimize the risk of escalating from a hydrogen gas leak to an incident. It follows from a study by Bilfinger Tebodin that in the distribution of natural gas, the barrier that odorization creates to prevent the escalation of a gas leak to an accident such as fire, explosion or suffocation is effective in 98% of the cases. Not odourising means that the chance that a gas leak will lead to a serious incident, increases by a factor of 50. In 2020, more than 25,000 natural gas air reports were made in the gas distribution network in the Netherlands. In the absence of the odorant, a large part of these disturbances would have gone undetected and could have escalated into an incident. There is no reason to believe that this will be any different in the case of hydrogen distribution.

Choosing a hydrogen odorant
A number of studies state that an odorant for hydrogen should have at least the same alarming effect as the odorant used for natural gas. This doesn’t mean that it must necessarily be the same odorant that is in use for natural gas and that is publicly known. Studies conducted as part of the Hy4Heat program warn that changing the type of odorant may pose a risk because the public's response to a new gas smell may be different. When choosing a different odorant, an extra effort will have to be made to familiarize the public with the new odorant.
The first experiences with the odorization of hydrogen are positive and the smell of the odorant in hydrogen is comparable to the smell in natural gas.

Alternative and additional safeties
Static hydrogen gas detectors can play a role in the safety of hydrogen distribution, but there is no uniformity about this in the literature sources found. According to the IFV (Instituut voor Fysieke Veiligheid), hydrogen gas detectors can be used in confined spaces to replace odorization. However, there is concern about the maintenance of these detectors and where they should be placed. No statements are made about the role of hydrogen gas detectors in the hydrogen gas distribution network.

Conclusion
The main conclusion from this literature review is that not odourising distributed hydrogen will lead to a significant increase in the number of hydrogen gas accidents if no other additional measures are taken. At the moment, odorization of hydrogen as a collective energy carrier is a necessary measure due to the lack of a worthy alternative to achieve the same safety level as with odourised natural gas.

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1. Introduction

The research question that will be answered within this part of the HyDelta program is:
What are the risks if hydrogen is not odourised and what alternatives are there to be able to detect hydrogen leaks in time? The research questions are answered by means of a literature study in which an analysis of the available sources will be made.

To answer the question about the risk of non-odorization, an analogy has been made with the use of natural gas in the built environment and the role of odorization in this. Reliable data is available on this over a period of more than 25 years. The scope of this report is limited to the gas distribution network. This is the system of pipes and aids that runs from the gas receiving station to the gas meter.
The national grid operator GTS, in collaboration with the regional grid operators, has conducted a study into the risks of (temporary) non-odorization. The role of odorization will also be highlighted from the registration of disruptions in natural gas distribution by the regional network operators (NESTOR). From these sources it can be deduced how often the barrier of odorization has been effective in gas distribution in 2020 and what the risk is avoided by odorization.
The knowledge is translated as best as possible into the distribution of hydrogen and the role of the odorant in this.

As part of the Hy4Heat program in England, research has been conducted into the risks of hydrogen distribution in the built environment. The role of the odorant and the use of additional measures such as gas detection after the gas meter are also qualitatively described. Although the total package of measures applies to both the hydrogen distribution network and the indoor installation and the influence of each individual measure has not been quantified, this source is nevertheless included in this report because it is the only recent systematic analysis on this subject.

2 The risk of non-odorization in gas distribution networks

According to the current MR Gas Quality, it is currently an obligation to odourise natural gas that is distributed [1]. The RNB Gas Connection and Transport Code states that NEN 7244-1 must also be complied with [2]. This standard says about odourising:

When gas does not naturally have an unpleasant, distinctive, alarming odour, an odorant must be added to the gas. The added odorant must be non-toxic and must be harmless in the concentration applied. The smell should disappear after burning. For specific purposes, gas may be supplied without an odorant. In that case, other systems of leak detection must permanently function in rooms in which gas pipes are installed or gas installations are installed.

2.1 The function of an odorant

Odorization plays an important role in the safety of natural gas. It ensures that a gas leak can be detected by smell. The odorization is aimed at ensuring that the odour can already be perceived far below the lower explosion limit.

2.2 Quantification of the risk of not odourising natural gas

Bilfinger Tebodin produced a report “Risk analysis under-odorization 2018” in 2019 on behalf of GTS and with the cooperation of the regional grid operators Liander, RENDO and Enexis [13]. This report and the conclusions from it have been adopted by Netbeheer Nederland. The report is not public. Some conclusions from this study are shared in this section with GTS's permission.

The gas distribution in the Netherlands has a high safety level. Incidents related to the gas distribution network must be reported by the regional network operators. The incidents are categorized in category 1 and category 2. Category 1 incidents must be reported immediately to the State Supervision of Mines (SodM) and the accident service of Kiwa Technology. Category 2 incidents must be reported to SodM and Kiwa Technology within 5 days.
Category 1 incidents concern incidents involving deaths or injuries, fire or explosion, evacuation of more than 250 people or failure to supply gas to more than 250 customers or a deviating gas quality for more than 4 hours.
Category 2 incidents concern incidents in which more than 10 people are evacuated or gas is not supplied to more than 10 customers, or a deviating gas quality of less than 4 hours.

Kiwa Technology has been keeping track of gas incident reports since 1993 and reports on this annually to Netbeheer Nederland. In the period 1993 to 2017, one report was made in which two fatalities occurred as a result of fire or explosion. During the same period there was one fatality due to suffocation. Suffocation can occur when the air, for example in a work pit, is displaced by natural gas. When the oxygen level drops to 10% or lower, unconsciousness occurs and death can occur within minutes.
When the probability is calculated what that means for a resident of the Netherlands to die as a result of fire, explosion or suffocation caused by the gas distribution system, this means a probability of 1 in 7 billion years.

In the study by Bilfinger Tebodin [13], a risk model was drawn up using the LOPA method, where LOPA stands for Layer of Protection Analysis. The cause and consequence of an incident are schematically linked, whereby the barriers that can prevent an incident are also mapped out as well as the effectiveness of those barriers. The functionality of the barriers was tested with the results from the reports of serious incidents and a good agreement was found.

For odorization, the probability that the barrier odorization will not work has been estimated at 2%. This means that in 2% of the cases no action is taken, even though the gas is odourised. A person may not be able to smell a well-odourised gas or may not take any action while sensing a gas odour. The barrier fails completely if no odorant is added to natural gas. This means that the frequency with which fatalities or injuries occur than that damage occurs increases by a factor of 50 if the odorization is insufficient.

2.2.1 Implication for the risk of not odourising hydrogen

Although the risk model and the values herein may differ for hydrogen than for natural gas, the odour tests in HyDelta indicate that the odour of an odorant is not essentially different from that of natural gas. The functioning of the barrier in the event of a leak will therefore be the same for hydrogen as for natural gas. It can therefore also be assumed for hydrogen distribution that the failure probability is 2%. Not odourising hydrogen means that the barrier created by odourization is completely removed. The chance of a serious incident will therefore be 50 times greater.

2.3 The role of odorant in natural gas distribution practice

Section 2.2 discussed the role of odorization, whereby the substantiation of the effectiveness of this barrier through odorization is based on data from 25 years of reports of serious incidents. An additional substantiation follows from the fault reports: faults are reports to the gas distribution network, such as gas air reports, which in most cases have not led to an incident.

Disruptions in the network operators' gas networks are registered in the Nestor registration system [4]. These disturbances concern the gas distribution network, i.e. the assembly of pipes and installations for the distribution of gas under an overpressure of 8 bar or less from the gas receiving station to the gas meter. An analysis of the malfunctions has shown that in the year 2020 a total of 34,234 reports of a detected gas smell were made. Of these, 9,252 reports were made during the leak survey. Leak survey is an activity that grid operators perform periodically. A distinction is made here between Class I leaks and Class II leaks. A Class I leak must be secured as soon as possible but at the latest within 24 hours. Depending on the nature, size and location, a Class II leak must be dealt with as soon as possible, in any case within six months of discovery. The presence of a gas leak is probably in most cases mainly determined on the basis of a measurement with detection equipment. The observation of gas air is then an additional observation.
This does not alter the fact that at least 25,072 malfunctions were noticed on the basis of the observation of a gas odour alone. The gas smell is most often observed at gas meters (45% of the gas smell reports) and connection pipes (37% of the reports). Some of the gas air reports at gas meters may be the result of the large-scale replacement of gas meters by smart meters. This replacement was initiated in 2013 and will be 85% complete in 2021.
Of the 25,072 malfunctions with natural gas air reports, 45% of these malfunctions were noticed by the customer and the rest was largely by third parties such as technicians.

It is impossible to predict what would have happened if these natural gas leaks had not been detected by a gas smell. In 2020, the safety barrier raised by the odourization of natural gas has worked more than 25,000 times.

3 Odorization and hydrogen distribution

This chapter describes specific recent experiences and insights regarding the use of a hydrogen odorant.

3.1 Bowtie analysis for hydrogen distribution

Upon smelling the alarming odour of the odorant, it is possible to take action to prevent further escalation to an incident such as a fire or explosion.

The Bowtie working group of Netbeheer Nederland has drawn up a Bowtie analysis for the distribution of hydrogen. The distribution of gas is defined as the assembly of pipes and installations under an overpressure of 8 bar or less from the gas receiving station to the gas meter. In this, the lack or insufficient odorization of hydrogen is named as an escalation factor. This means that due to the lack of odorization or as a result of insufficient odorization, activities (leak detection and reporting by third parties (see Appendix I)) will not function, as a result of which the barrier will be ineffective or insufficiently effective.

3.2 The smell of an odorant in hydrogen

The question is whether the odour of hydrogen odourised with THT is just as perceptible as natural gas odourised with THT. A panel test in HyDelta indicates that the odour threshold, the perceived odour characteristic and also the odour strength are comparable in both gases, with the same amount of odorant per unit volume of the gas [12]. This also applies to the other two odorants (GASODOUR® S-free and 2-hexyne) that were studied.

This observation is also supported by recent experiments in Germany in the HYPOS project [14]. Hydrogen was odourised with both the sulphur-free odorant GASODOUR® S-free and the odorant Spotleak 1009, a mixture of mercaptans. It is reported about both odorants that the odourization runs smoothly, the odorant behaves stably in the hydrogen matrix and that the smell is good.

3.3 Not odourising of hydrogen for industrial applications

Within the Dutch high-pressure gas transport network (67 bar HTL), the natural gas, which is originally odourless, is provided with odorant (THT) at metering and regulation stations. The natural gas that is supplied to the gas distribution network via the regional 40 bar (RTL) high-pressure gas transport network is therefore always odourised. Natural gas that is supplied directly from the HTL to the distribution network is odourised at the gas receiving station (GOS). Industrial customers can choose in the HTL to purchase non-odourised natural gas if this is harmful or too expensive for the customer's process. Alternatives such as gas detection are then required. In some cases, pipes with non-odourised natural gas and odourised natural gas are located next to each other and sometimes a choice can be made. If a connection point to the non-odourised gas network is offered by GTS, the connected party must take safety measures in the form of gas detection so that the risks of an accident are minimized. The customer can also place an odorant unit in its own gas receiving station [6].

Some industrial customers prefer non odourised natural gas because they use the natural gas as a raw material or because their equipment is sensitive to sulphur contaminants. In order to build in a safety barrier so that a possible gas leak can be detected early, gas detection equipment is installed. In an industrial environment, this equipment is normally well maintained and back-up systems are often present, so that this barrier always functions properly.

The plans for the so-called “Hydrogen backbone”, whereby part of the GTS transport network is made suitable for the high-pressure transport of hydrogen for delivery to industrial customers, does not provide for the odorization of hydrogen [7]. Here too, the connected parties will have to take safety measures themselves in the form of gas detection or odorization themselves. For the time being, this also applies to connections to the gas distribution network.

Air Liquide is a company that has 200 hydrogen factories worldwide and has a network of 950 kilometres of hydrogen pipelines at a pressure of approximately 80 bar in Belgium, the Netherlands and northern France. This hydrogen gas is not odourised [8]. Here too, customers must have their own safety provisions for possible hydrogen leakages.

4. Alternatives to odorization in hydrogen distribution

Leak detection by sensors as a replacement for odorization or as an additional measure is possible under certain conditions in confined spaces, but the effectiveness and efficiency for use in public spaces has not been proven. This also applies to the space near the house, such as in the case of connecting pipes.
The reasons for this are:

- it is not yet clear how many sensors need to be installed to reduce the risk to an acceptable risk;
- the number of sensors will in any case have to be high;
- these sensors will have to be maintained;
- installation will be on private land as well as in public space, but must also be resistant to vandalism, theft and excavation work;
- the measurement is affected by weather conditions (especially wind) and is therefore not reliable in all conditions.

Two sources are cited in this chapter: the Institute for Physical Safety (IVF) has made a consideration of the safety aspects of hydrogen in confined spaces and Kiwa Technology recently carried out research into the operation of gas detection equipment on behalf of Netbeheer Nederland.

4.1 Analysis of IFV

The Institute for Physical Safety (IFV) has made an analysis for the safety aspects of hydrogen in confined spaces [3].

The following types of measures are possible to reduce the risk of an incident in the event of a hydrogen leak in a confined space:

- detection of hydrogen;
- room ventilation;
- avoid or limit ignition sources;
- maintain safety distances;
- limiting the amount of hydrogen that can flow out.

IFV notes that odour recognition is the most important method of detection. This is only possible by adding an odorant. THT is mentioned as the best choice for an odorant because this scent is easily recognizable by the public and is associated with natural gas. A detector is mentioned as an alternative. It should be noted that detectors must be properly monitored and maintained as detectors deteriorate over time and where they are placed must also be taken into account. The report does not substantiate whether detectors are as effective as an odorant.
The question of what measures must be taken for the hydrogen distribution network if there is no odorization, is not answered in the IFV report. After all, the scope of the IFV report is “closed areas”.

4.2 Gas detection of hydrogen

As part of research for the Knowledge Centre for Gas Network Management, Kiwa has conducted research into the operation of gas detection equipment used by gas network operators [5]. In this respect:

- gas detection meters (GD) that are used for gas leak detection;
- gas signal meters (GS) that are used for personal protection;
- gas concentration meters (GC) used for venting and degassing.

It therefore does not concern static (fixed mounted) gas detectors.
The general conclusions are:

- the tested gas measuring devices intended for methane function properly for methane;
- When exposed to 100% hydrogen and mixtures of hydrogen and methane, none of the tested measuring devices met the same requirements over the full measuring range as those set for measurement for natural gas in VIAG. Dräger's gas detection meter with an H2 module was satisfactory, albeit that the measuring range is somewhat smaller than required in the VIAG;
- the two devices intended for hydrogen respond well to hydrogen, with a difference in sensitivity between these two devices. However, these devices are not suitable for measuring methane;
- However, there are measuring devices in the various categories that have a specific application value for use with these different types of gas. This utility value depends on the type of sensor that is used.

This means that the gas detection equipment currently used and studied for hydrogen can function properly, but only for 100% hydrogen distribution and not for natural gas or natural gas mixed with hydrogen.

Table 1 below summarizes the results for the various tested measuring principles, the specified measuring range and the field of application:

Tabel 1: Measuring range and application per sensor principle

Measuring principle	**CH_4**	**H_2**	**Max. range**	**Toepassing**		
				GD	**GS**	**GC**
Infrared			1-100%	+	+	+
semi conduction			0-2,2%	+	+	-
Palladium sensor			0- 1%	+	-	-
Catalytic			0-5%	+	+	-
Heat conductivity			0-100%	-	+/-	+
Laser spectrography			0-1%	+	-	-
Electrochemical			0 -2000 ppm	+/-	+	-
Flame ionization			0 –1%	+	-	-

Legenda:

suitable for this gas
unsuitable for this gas

5. Foreign experiences

The most concrete foreign study into the distribution of hydrogen concerns a safety analysis that was done in the context of the British program “Hy4Heat” [10].

5.1 Hy4Heat safety assessment

As part of the Hy4Heat program, a safety assessment was carried out by ARUP and Kiwa Gastec. The purpose of this assessment is to minimize the risks associated with the distribution of hydrogen to the built environment so that they do not exceed the current and accepted risks for natural gas. This takes into account the current gas distribution in the United Kingdom and the gas accidents occurring there [9].
The safety assessment assumes that the same odorant is used as for natural gas. The reason for this is that the connected parties are used to this smell and that the barrier therefore works just as well as it would for a natural gas leak. When introducing a new odorant, consideration should be given to the possibility that the odour may be less, or that the association of the odour with a gas leak is less. This makes the barrier less efficient and leads to a higher risk of an incident.
The risks of an explosion or fire after a gas leak and the risk of injury have been quantified for a number of scenarios. The researchers consider the risk of ignition of a hydrogen leak to be greater than for a natural gas leak. Therefore, additional measures are proposed. To make the safety level for hydrogen distribution equal and even slightly higher than for natural gas distribution, it is sufficient to install two excess flow valves (EFV). In this case, the EFVs are shut-off valves that are activated when the hydrogen flow rate is greater than 20 m^3 per hour. One EFV is placed in the smart meter and one further upstream between the main valve and the gas meter or preferably the connection of the main pipe to the connecting pipe. For the Dutch situation, placement between the main valve and the gas meter would not be logical because the main valve is often integrated in the meter bracket.

The analysis takes into account that these valves are tested once every ten years. The higher the maintenance frequency, the smaller the chance of this protection not functioning.

According to the researchers, installing two EFVs is therefore a measure to ensure that the distribution of hydrogen takes place at least as safely as for natural gas.
It should be noted that the EFVs will not intervene in the event of minor indoor gas leaks.
Other possible measures to reduce the risks of a gas accident have not been calculated quantitatively.

The study has led to a series of recommendations for the introduction of hydrogen in the built environment in the form of pilot projects:

- limit the outflow of hydrogen gas to 20 m3/h by means of restrictions such as an “Excess Flow Valve” (EFV);
- only install new certified hydrogen gas meters and hydrogen gas appliances;
- install the gas meters outside the home;
- avoid the use of cast iron inner pipes; ensure sufficient ventilation in the home;
- install indoor hydrogen gas detectors for customers who have a poor sense of smell;
- apply the same odorant that is used for natural gas.

These recommendations apply to pilot projects. It is possible that after experiences with these pilot projects have been gained, not all measures are needed for a large-scale introduction of hydrogen.

A risk analysis will have to be done again for the Netherlands because gas distribution and regulations are different in the Netherlands than in the United Kingdom. WP1A of the HyDelta program investigates the risks of hydrogen distribution in the built environment and what measures can be taken to reduce the risks. The results of this have not yet been published at the time of preparing this report.

Adding an odorant to hydrogen is considered by the researchers to be a very necessary part of the package of measures to reduce the safety risk of hydrogen distribution in the built environment to a sufficiently low level in combination with other measures. This means a risk level that is as high or lower as the current distribution of natural gas.

The effect of the lack of odorization or the fact that an odorant is less effective was not quantified in the safety analysis of Hy4Heat. The risk analysis was carried out on the assumption that the public reacts to a hydrogen leak in the same way as they react to a natural gas leak. Previous Hy4Heat research has shown that the odorant NB (mixture of tertiary buytylthiol and dimethyl sulfide) in use in the UK has the same alarming effect in hydrogen as in natural gas. That is why ARUP assumes the use of this odorant in its model, because then there is certainty about a good response (a signal, followed by an action) by the public to a gas leak. When using a different odorant, the question is how this response will be.

The use of the same odorant that is now used for natural gas is one of ARUP's recommendations for a pilot of hydrogen distribution in the built environment.

In the Hy4Heat report “Hydrogen odorant” the odorant NB is recommended with the justification that it is effective and not harmful to gas pipes and combustion appliances [11]. In addition, it is the cheapest option for odorization. If fuel cells are used en masse, the choice of odorant should be reconsidered, although cleaning for the fuel cell is also an option.

6.Conclusions

Risks of not odourising

An analysis by Bilfinger Tebodin shows that the odorization barrier for natural gas distribution has a failure probability of 2%. If natural gas is not odourised, this means that the barrier is completely removed and the chance of a serious incident is 50 times greater.
Odour detection through odorization is an effective barrier that has been used at least 25,000 times for the natural gas distribution system in 2020 alone. It is unknown how often the barrier indoors, after the gas meter has been used. If hydrogen were to be distributed in the current gas distribution networks in the future, and not odourised and no other safety measures applied, this would increase the probability of an incident, because there are not enough other barriers available to prevent the and thereby sufficiently reduce the risk.

Alternatives to odorization

Opinions are divided on the application and function of hydrogen detectors indoors. According to IFV, these can serve as a replacement for odorant in confined spaces, provided that the correct positioning is taken into account and maintenance is in order. In the context of the Hy4Heat project, it has been concluded that for the first pilot tests with hydrogen distribution, gas detectors should be installed in the house as one of the additional measures to be taken on top of odorization. For the distribution of natural gas, odorization for indoor use (after the gas meter) has been shown to be a very effective safety measure. In the case of collective use of hydrogen as an energy carrier, it is therefore quite possible that the installation of gas detectors as an additional safety measure is not necessary. No literature sources were found about gas detection on the gas distribution network. Gas detection on the gas distribution network as a replacement for odourization does not (yet) seem a viable option for several reasons.

The smell of an odorant in hydrogen

The first experiments in HyDelta and also in Germany (HYPOS) indicate that the function of the odorant in hydrogen is just as good as in natural gas.
It can be concluded from the analogy with natural gas distribution that odorization for hydrogen distribution is a necessary measure to reduce the chance of a gas leakage escalating into an incident (explosion or fire). Not odourising means an unacceptably high risk of incidents. When choosing an odorant for hydrogen, the condition is stated that it must have at least the same alarming effect as the current odorant that is used for natural gas. If a different odorant were to be used, it would have to be thoroughly investigated whether the alarming effect is actually just as good as for the current natural gas odorant. A different odorant can lead to a different experience, possibly causing less action by the public.

Main conclusion

From the analogy with natural gas distribution, it can be concluded that odorization for hydrogen distribution is currently seen as a necessary measure due to the lack of a worthy alternative to achieve the same safety level as with odourised natural gas. Odorization reduces the chance of a gas leak escalating into an incident (explosion or fire).
In both a study by the IFV into the Dutch situation and a study in the context of the Hy4Heat project relating to the United Kingdom, it is concluded that odorization of hydrogen in gas distribution is necessary to guarantee safety. It
The chosen odorant must work at least as well as the odorant used for natural gas distribution.

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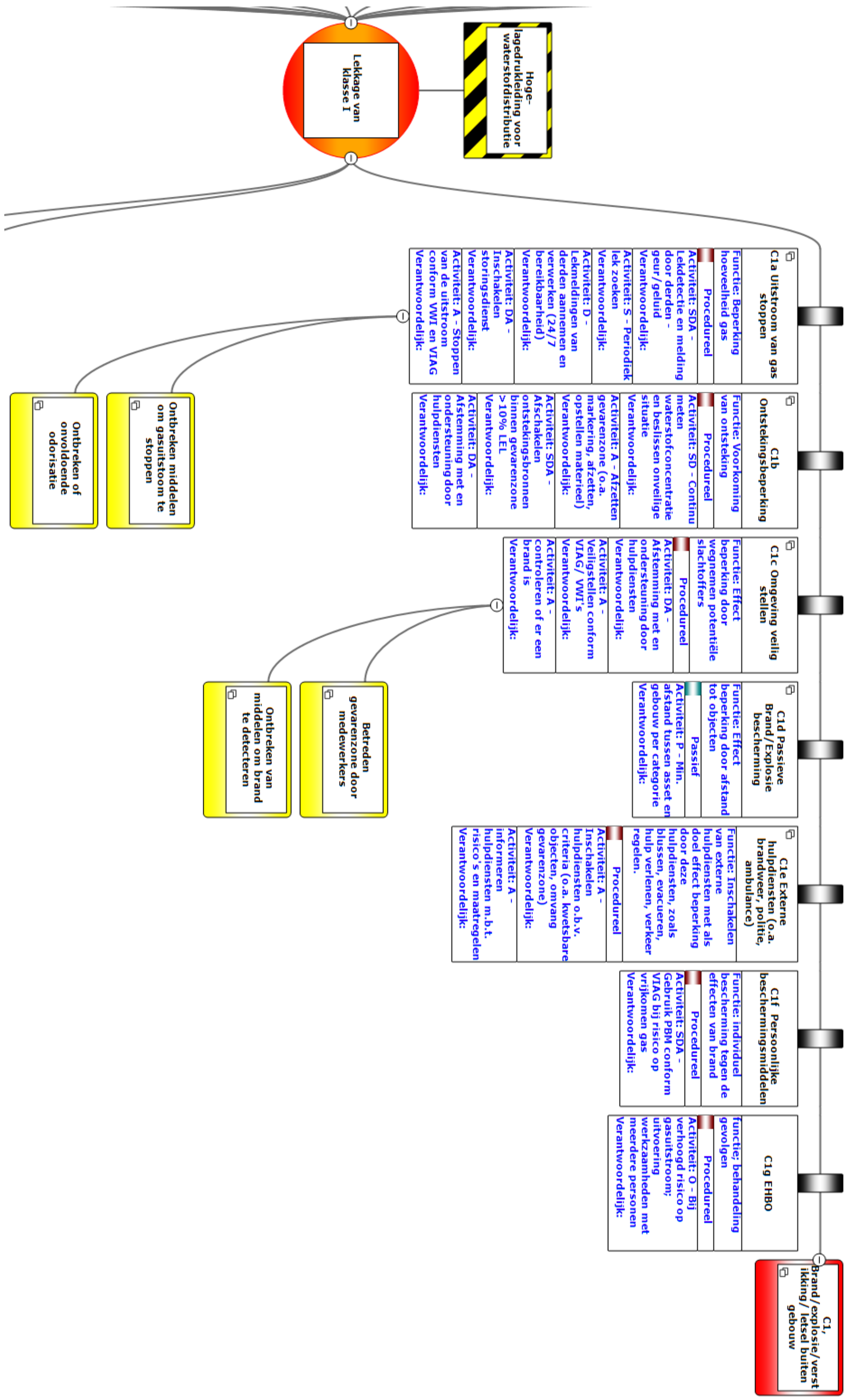
APPENDIX 1 Bowtie diagram of a hydrogen leakage



APPENDIX 2 Glossary

Indoor installation
The pipe with accessories of the installation after the gas meter

Bowtie method
The Bow-tie method is a structured analysis technique that can be used to map and analyse cause, effect and barriers

Excess Flow Valve (EFV)
An EFV is a valve that can shut off a pipe when the gas flow rate exceeds a set value

Gas distribution network
A gas distribution network is a gas transport network that is not managed by the network operator of the national gas transport network with a pressure not higher than 8 barg and is also the entirety of pipes from the city station (GOS) to the gas meter

GTS
Gasunie Transport Services, the operator of the national gas transport network

High-pressure transport network
A gas transport network managed by the national network operator with an operational absolute pressure between 16 and 67 barg

NB
Odorant used in parts of England for natural gas and consisting of terial butylthiol and dimethyl sulfide

NESTOR
Fault registration system of regional grid operators of gas and electricity

VIAG
Safety instructions Natural gas. The VIAG applies to the business operations of gas supply systems that are owned, managed and/or maintained by or by gas network operators, as well as to work on, with or near those gas supply systems that are carried out on behalf of the gas network operators.