Gas transmission network conversion to Hydrogen: impact on explosive atmosphere sizing

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Over the past decade, the natural gas industry mutated into a more sustainable equilibrium thanks to renewable gas (biogas transformed in biomethane) and, more recently, hydrogen production. Renewable gas and hydrogen can be used through either mixing with natural gas or directly. The choice between these two solutions is subject to several factors such as production capacities, distance between production units and delivery points, acceptance of the heating process of the final users, etc.

Biomethane is produced through refining biogas extracted by methanization of waste from various origins (food industry, agriculture, etc.). This refinement process generates a biomethane with very similar compositions and heating characteristics compared to natural gas. Consequently, the impacts on risk management of transmission and distribution networks are negligible. Regarding hydrogen and associated natural gas mixtures, much more questions need to be addressed.

Hydrogen is widely utilised in many industries (e.g. refining, chemical, space, metals, etc.) where risk management have demonstrated a real efficiency. The following two challenges should be overcome in order to expand the uses of hydrogen in other areas. On one hand, sustainable hydrogen production with a high level of safety needs to be secured. On the other hand, safety rules and best practices have to be considered and applied during both design and operation phases. To develop the new uses of hydrogen, the energy industry is facing two challenges: ensure sustainable hydrogen production and demonstrate a high level of safety. For this second issue, operators must adapt their safety rules and best practices for design. In this perspective, GRTgaz, the company operating the largest transmission network in Europe is stepping up its research and development effort through the work of its Research and Innovation Centre for Energy (RICE). GRTgaz has been improving its knowledge in hydrogen safety and updated PERSEE+, its internal modelling tool, originally validated for accidental natural gas or LNG releases, to calculate safety distances for hydrogen releases. PERSEE+ calculations, enhanced by CFD modelling for the most complex cases, was proven effective on the update of GRTgaz guidelines about explosive atmosphere sizing and classification.

This work highlighted a significant increase in hazardous area to contour around sources of H_2 releases, compared to similar natural gas releases. In some cases, the zoning can extend to double in size hence a full review of hazardous area classification is required for existing facilities which are planned to be converted for hydrogen use and which are established for new hydrogen projects. This article details the GRTgaz approach in reviewing hazardous area for hydrogen applications to achieve sufficient accuracy and a balance of safe design and acceptable cost. The paper explains the methodology for a detailed assessment based on gas dispersion modelling and illustrates natural gas and H_2 differences with relevant examples. It also summarizes the validation work performed through a comparison of modelling tools and experimental results to evaluate calculation accuracy.

The article may help Hazards32 delegates to initiate the process of hazardous area classification for Hydrogen or to challenge their own best practices.

INTRODUCTION

Hydrogen – a growing perspective for the company

Through the ratification of the Paris agreement on climate change, the international community under the United Nations has set up a series of challenging environmental goals to transform the global economy as to limit the impact of our power generation, production methods and consumption patterns on the climate system.

This implies for the energy sector to change drastically its business model and technologies towards a decarbonised system to ensure the growing population to benefit from an affordable and reliable energy while reducing the greenhouse gases emissions.

Generating electricity from intermittent renewable energy sources such as solar and wind power generation systems and the increase of the electricity demand will force the system to its limit. Hydrogen and hydrogen-based fuel can help the transition to a more renewable power system (Hydrogen Council, 2017). In this way, several national governments and the European Union have issued strategies and roadmaps for the development of hydrogen technologies.

Hydrogen has been used for many decades in the petrochemical and chemical industries which have derived a sound knowledge for gaseous hydrogen. With the goals to move the society to a low carbon economy, the use of hydrogen as a new energy carrier appears more and more relevant for new types of industries and for the decarbonation of historical industries relying on a hydrocarbon-based economy, such as energy providers or gas network operators.

GRTgaz, as one of the main gas network operators in Europe with a 33 700km long natural gas network, need to adapt to these new challenges linked with the energy transition and upgrade its network for the new gases such as hydrogen.

In 2014, to prepare the energy transition of the industry, GRTgaz has joined forces with partners in the Jupiter 1000 project (Terega, RTE, McPhy, CEA, Khimod, CNR, Marseille Fos, Leroux & Lotz), with the EU, national and local bodies (ADEME, Provence Alpes Cote d'Azur region) support. This industrial demonstrator produces green hydrogen thanks to two different electrolysis technologies, whose electrical supply is 100% renewable energy. The hydrogen is used for blending in natural gas for industrial customers, or to produce synthetic methane by methanation with captured CO_2 from on a nearby industrial site. This demonstrator of 1 MWh aims to compare different technologies and help development of larger Power-to-gas facilities. Only for France, the French ecological transition agency (ADEME) estimates that 30 TWh of gas could be produced each year using the Power to Gas system by 2035.

More recently, GRTgaz has joined forces with other European energy infrastructure operators to create the European Hydrogen Backbone (EHB) initiative, which aims to accelerate Europe's decarbonisation journey by defining the future hydrogen network based on existing and new pipelines.

This initiative seeks to ensure the security of supply and demand and cross border collaboration between European countries.

The hydrogen infrastructure map shows a network development through the years with some milestones in place for the next two decades (European Hydrogen Backbone, 2022).

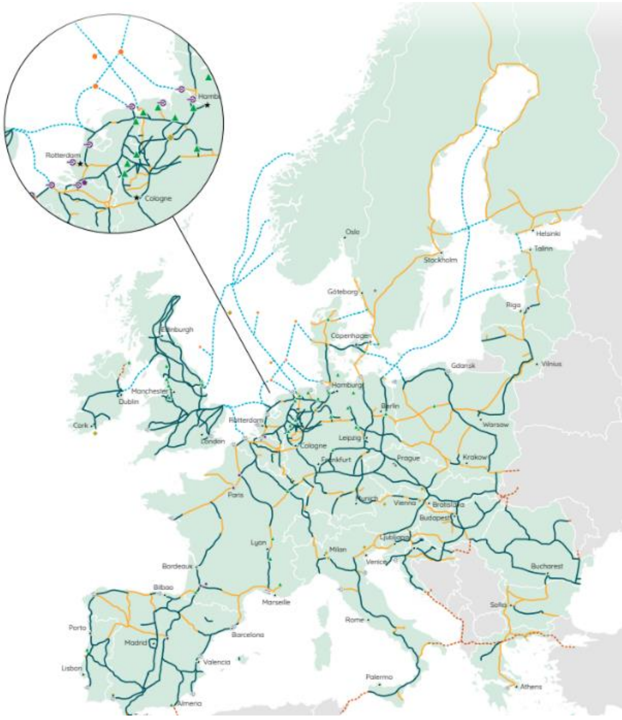

Figure 1 : Mature infrastructure stretching towards all directions by 2040 (European Hydrogen Backbone, 2022)

In this framework, GRTgaz have launched two natural gas pipeline conversion projects to initiate its transition to being a hydrogen network operator: MosaHYc and RHYn.

The MosaHYc (Moselle Saarland Hydrogen Conversion) project is a collaboration between GRTgaz and CREOS aiming to convert two existing gas pipelines to 100% hydrogen transport, enabling the interconnection of Völklingen, Perl (Saarland), Bouzonville and Carling (Moselle). It will be a 70km long network and will transport a capacity up to 20,000m^3/h.

The RHYn (Rhine HYdrogen network) project consists of a 100km pipeline among which 60km of natural gas pipeline will be repurposed. The aim of the project is to promote the Upper Rhine hydrogen ecosystem by connecting the Dessenheim area with the Chalampé-Ottmarsheim industrial zone by 2028, as well as the Mulhouse agglomeration for its mobility needs.

As part of the European hydrogen backbone vision, connection with the Baden-Wurtemberg in Germany and the Bale region in Switzerland will be investigated in the later stages of the project.

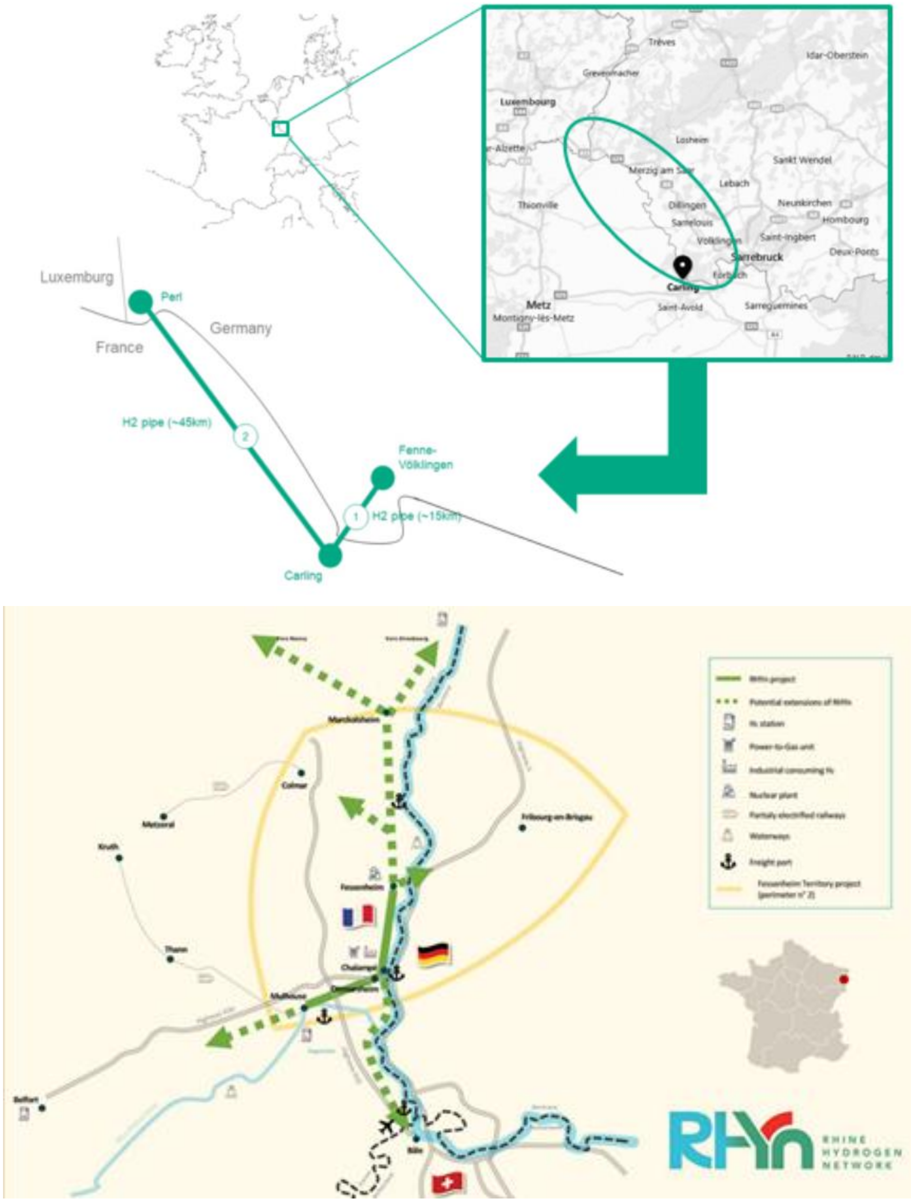

Figure 2 : Location maps of the MosaHYc project (up) and RHYn project (bottom)

Converting existing natural gas installations to hydrogen implies to address some major issues to ensure a safe design and operations such as material compatibility, hazardous area classification, operating philosophies, gas quality, etc. GRTgaz is supported by its Research and Innovation Center for Energy (RICE) in addressing these topics by carrying Research & Development (R&D) work in its different laboratories such as the FenHYx platform or the Jupiter 1000 (J1000) power to gas demonstrator.

Internal guidelines for hazardous area classification

As an EU member, France transposed the ATEX directives in the national law, to protect employees from explosion risk in areas with an explosive atmosphere. The hazardous area classification is defined in the Directive 1999/92/EC - *Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres*.

For its current natural gas facilities, GRTgaz has produced internal guidelines to quickly size hazardous area and categorize them depending on the potential releases. These guidelines aim to fulfill the EN 60079-10-1 standard and recommendations from the energy industry for hazardous area classification ([1],[2]). The guidelines provide for each category of equipment the zone type (zone 0, 1 or 2), the shape of the hazardous area and dimensions.

Most of the time, the area dimensions are given depending on release pressure and wind conditions. With these 2 simple inputs, any user of the guidelines can define its area in few minutes. For particular pieces of equipment, design flow rate, exit diameter or other very accessible input shall be considered.

Three wind speed (6, 10 and 15 m/s) are taken into account for low, medium and high windy environments defined from wind statistics. The release pressure to consider is the maximal operating pressure of the piece of equipment.

With 38 technical sheets, one per equipment category, and explanations about classification, material compatibility, etc., internal guidelines give key information for operators and engineers.

For the new H_2 facilities, a similar easy-to-use document is expected to facilitate design and operation. This article presents the method followed by GRTgaz to achieve this transition to ATEX guidelines for H_2 whilst emphasizing the process for calculating area dimensions which was the most challenging part.

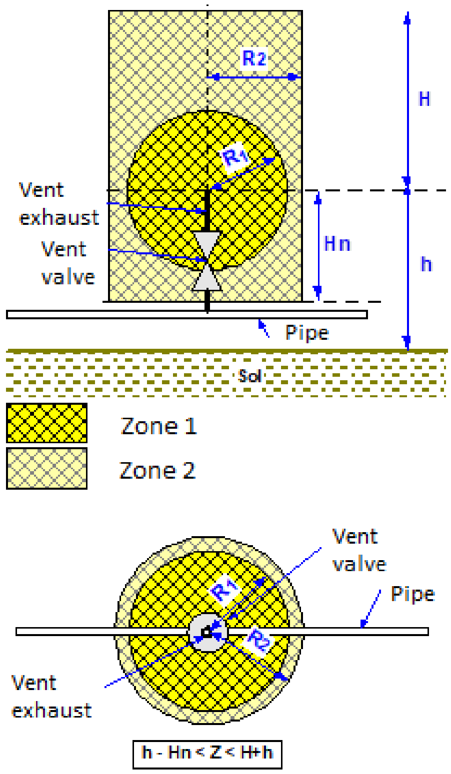

Figure 3 : Example of the area classification for a vent release

DISPERSION MODEL VALIDATION

Development on the PERSEE+ software

GRTgaz uses the PERSEE+ software ([3],[4]) for risk assessment studies and hazardous area classification. This software is developed by the company's research centre (RICE) and used by French energy companies, such as Terega, Storengy, EDF, RGDS and Elengy. It is regularly reviewed by third party experts such as DNV (2004), INERIS (2016) and TNO (2017).

For gas releases, different modules are proposed in PERSEE+ to estimate:

- Release rate thanks to an integral flow model adapted for transmission pipeline and simple networks,
- Flammable cloud dimensions (integral models),
- Flame geometry and heat radiation in case of jet fire (empirical and integral models),
- Overpressure in case of jet explosion (integral model) or unconfined explosion in obstructed area (empirical models),
- Fire resistance duration for a pipeline near or engulfed in an external fire (integral model),
- Overpressure due to pipeline rupture (integral model),
- Etc.

All these models have been optimised for natural gas and modification may be needed to handle hydrogen, since many hydrogen properties are different from natural gas properties:

- Density (at atmospheric pressure and 0°C) is 8 times lower and compressibility factor varies differently,

- Flammability range in air is larger: from 4 to 75% for hydrogen against 5 to 15% for natural gas,
- Minimal ignition energy is lower,
- Laminar flame velocity is higher (up to 8 times),
- Expansion ratio (ratio of density between non burned gas and burned gas) is lower,
- A higher flame stability,
- A lower calorific value (LCV) more than three times lower,
- Reverse Joule-Thomson effect,
- An adiabatic flame temperature higher of 100°C.

RICE started the adaptations for hydrogen and natural gas-hydrogen blends in 2016 and achieved a first step of the validation work in 2018. Users got access to the hydrogen module for the release of PERSEE+ version 1.0. New developments are in progress for the next version (PERSEE+ 2.0) but without noticeable impact on dispersion results.

For dispersion model, the main modification is the use of adapted coefficients to characterize air entrainment due to the H2 release.

Dispersion model accuracy for LFL distance: comparable with natural gas releases

For model validation, GRTgaz used publicly available data, published by Shell ([5],[6]), INERIS ([7], [10]), Air Liquide([8],[9],), KIST [11], and Defence R&D Canada [12]. These data already give a large range of releases (*Table 1*) for model validation. Even if some additional tests are still necessary, the validation process seems to be robust.

Table 1 : Main characteristics for the experimental data used for model validation

Trials	Pressure (bar)	Release diameter (mm)
SHELL - HSL	25 to 140	3, 4 and 12
KIST	100, 200, 300 and 400	0.5, 0.7 and 1
INERIS	35 and 40	12, 25, 50, 75 and 100
Defence R&D Canada	6.6 and 16.3	0.79 and 1.6 mm

For each test, the concentration calculated at probe locations are compared with the measured concentration. The agreement is generally satisfactory as illustrated in Figure 2.

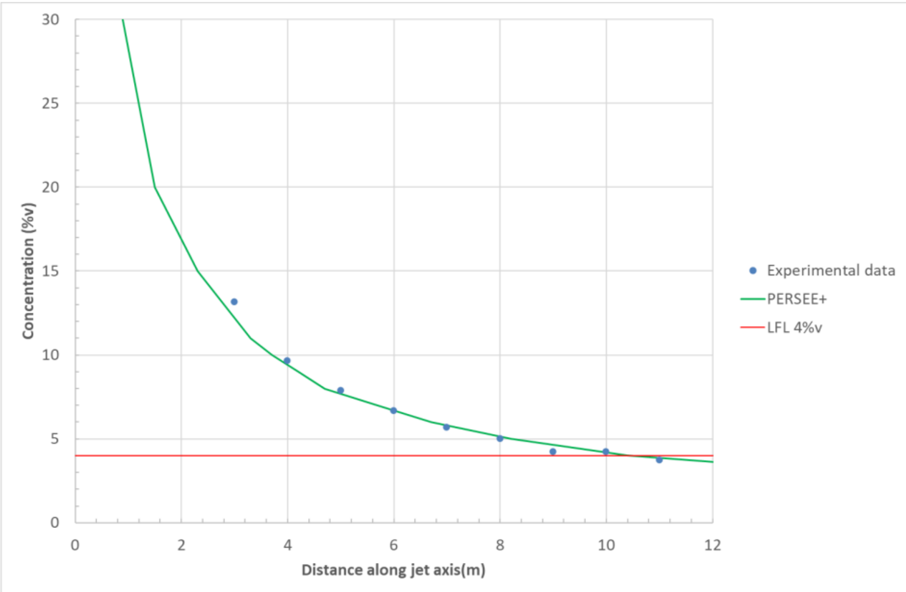

Figure 2: Comparison of calculated and measured concentration for test 9 of the Shell-HSL trials

For most of the tests, concentration is measured in the release axis and LFL distance is not directly available. As it is the result of interest for hazardous area calculation, *Figure* 4 compares interpolated LFL distances from concentration measurements and calculated LFL distances. For the previous interpolated LFL distance, based on concentration measurement, is 10,4 m such as the calculated LFL given by PERSEE+.

PERSEE+ 1.0 gives very acceptable results for the LFL distance prediction compared to experimental results, as for most of the tests the relative deviation is under 30%. All calculated LFL distances are under a relative deviation of 50%, a common criterion used to verify dispersion model validation ([13],[14],[15]). These results are fully comparable with the accuracy obtained for natural gas releases.

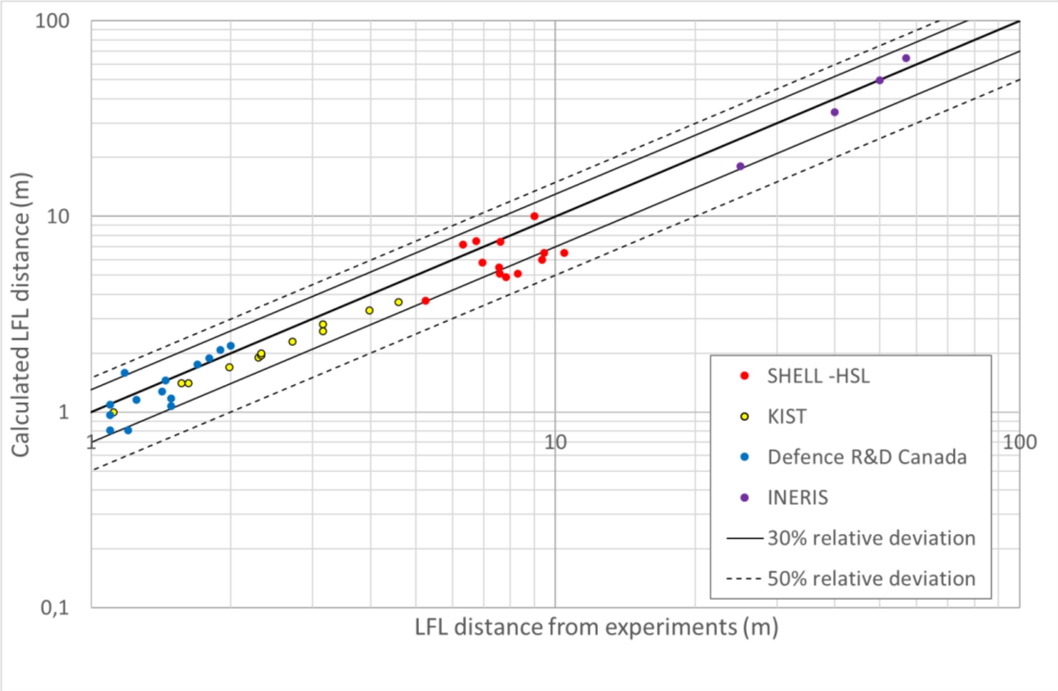

Figure 4 : Comparisons of LFL distances interpolated from concentration measurements and calculated LFL distance

Finally, in the frame of the European project H_2 Gas Assets Readiness (H2GAR), several transmission system operators (Enagas, OGE, Fluxys, Gasunie, Snam, National Grid and GRTgaz) compare accuracy of modelling tools for H_2 hazards modelling. This evaluation is done by the working group 5 on Safety. It consists in comparing results from PHAST (DNV), FRED (Shell-Gexcon), ORDER (DNV) and PERSEE+, with experiments and CFD simulations. For the 3 cases used for dispersion, PERSEE+ results are considered in good, very good or excellent agreement with the data.

This benchmark confirms the validation work done by GRTgaz and demonstrate the good adaptation of PERSEE+ for dispersion of H_2 releases.

DIMENSIONING HAZARDOUS AREA FOR H_2

Main assumptions

Historically, GRTgaz and former Gaz de France sized the hazardous area by using the LFL extend, increased by a safety factor of 1.3, based on the relative deviation with experimental result. Indeed, validation work shows an accuracy of more or less 30%.

Except for well-defined release sources (vent, relief valve, etc.), the leak area is assumed to be 0.25 mm² (normal conditions) or 2.5 mm² (harsh conditions) depending on the process conditions. A process component is considered in hard conditions if there are high flow velocities, vibrations, irregular flow rates or pressure fluctuations. For example, around pressure reducer or compressor, hard conditions shall be applied. These two leak areas are consistent with the hole sizes suggested in appendix B of the EN IEC 60079-10-1:2021 standard.

As discussed earlier, the initial assumptions are standardised in order to simplify the dimensioning but also to be reasonably conservative, such as the release pressure considered as the maximal operating pressure. For the release direction, the aim is the same. When the direction is not given by the component itself (e.g. vent, relief valve, etc.), the most conservative direction is chosen. For example, for flanges and other non-welded connections, release direction is unknown. PERSEE+ has been validated with vertical, horizontal or 45° upward jet releases. The accuracy for downward releases is not known, that is why the software does not enable to model this kind of case. For sensitivity studies on release direction, GRTgaz used CFD modelling with the Kameleon FireEx (KFX) software. This CFD code is commercialized by DNV and was originally developed by ComputIT, NTNU and SINTEF with industry partners, including Gaz de France. It is a well-known software in the Oil&Gas industry, which simulates gas dispersion and all types of fire.

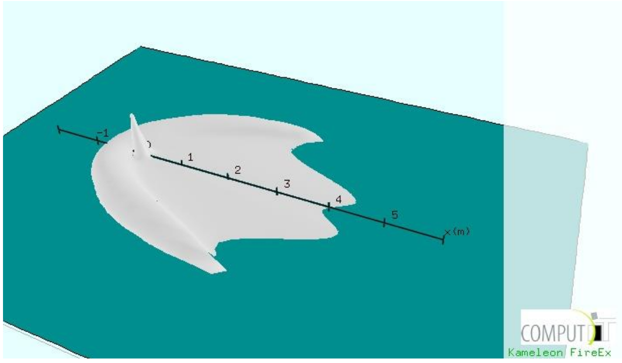

Figure 5 : 3D view of the flammable cloud for a downward H_2 release

For the sensitivity studies, two release cases were simulated with different wind speeds (from 0.5 to 15 m/s) and different release directions (-60° and -90°). The release cases have been chosen to stand for normal conditions at low pressure (5 bars) and harsh conditions at high pressure (250 bars). The LFL distances given by KFX were then compared with LFL distances calculated by PERSEE+ for horizontal and upward releases. Figure 5 shows the flammable cloud for hard conditions release (2.5 mm²) at 250 bars with high wind (15 m/s). For this case, the maximal LFL distance is observed downwind with about 4.4 m. The LFL distance for the horizontal release is about 7.9 m. The other comparisons give similar results the horizontal release direction is chosen as the most conservative one.

Finally, the hazardous areas are generally defined as cylinders or spheres. For cylinders, the dispersion calculations aim to define its height (H_{max}) and its radius (R_{max}). Hmax is the plume height calculated for very low wind speed (0.5 m/s) whereas R_{max} depends on the wind speed to consider for the specific location of the study (6, 10 or 15 m/s). For spheres, the radius is defined as the R_{max} for cylinder.

Comparisons with natural gas

Based on the same assumptions, the comparison of dispersion calculations for natural gas and hydrogen shows a very significant increase in flammable plume dimensions (vertically and horizontally) with hydrogen, for similar operating conditions. *Figure* shows, for more than 1000 release cases modelled for the guidelines, that the LFL dimensions are always larger with H_2 compared to natural gas. The increase percentage can reach 100% and, sometimes slightly more.

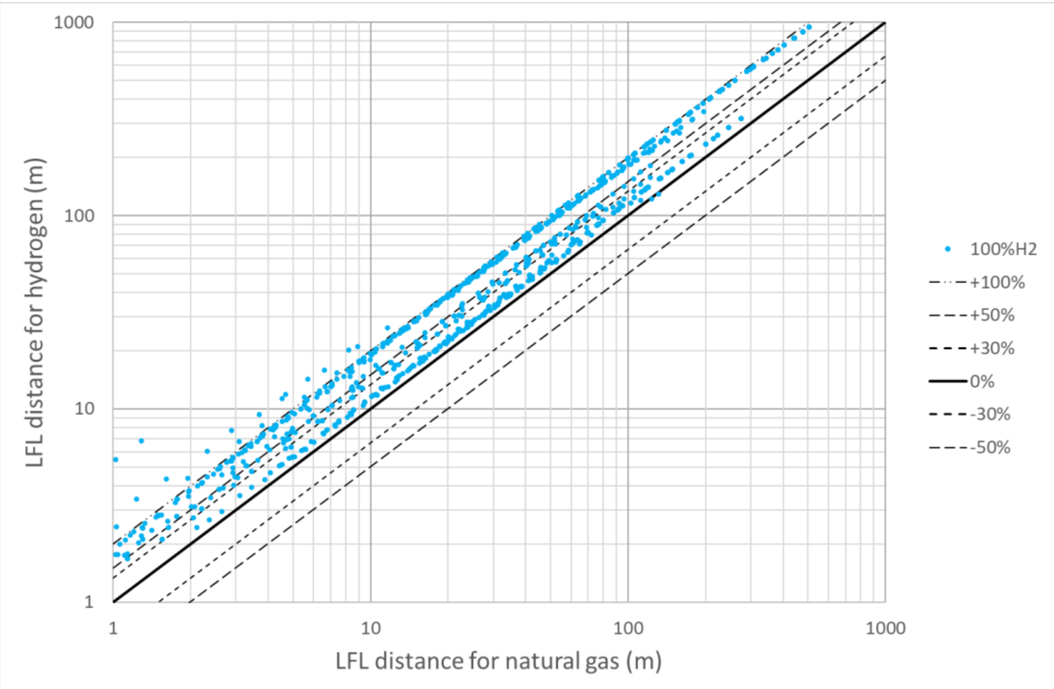

Figure 6 : Comparison of LFL dimensions for natural gas and hydrogen

Consequently, at first glance, converting existing natural gas facilities to hydrogen may raise difficulties for hazardous area definition. Facilities in which hazardous area are hardly inside fences would need to be enlarged or operated at lower pressure. However, influence of initial pressure is more complex than at first sight. Figure 7 and Figure 8 illustrate this point by comparing hazardous area for hydrogen and natural gas with two different release sources: flange leak and release at a driven relief valve.

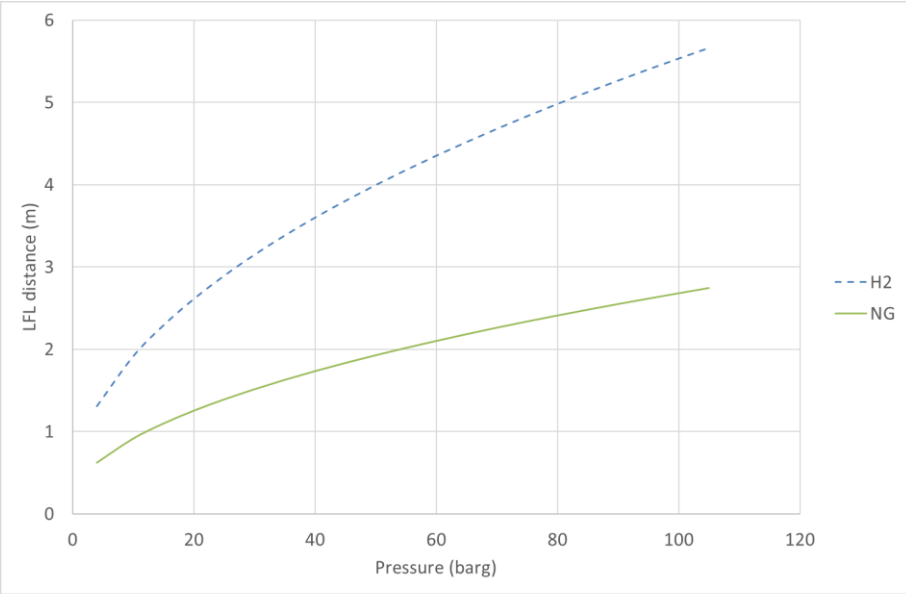

Figure 7 : Comparison of LFL distance (R_{max}) for a flange leak in hard conditions

For a flange leak in harsh conditions (2.5 mm²) at 100bars for natural gas the R_{max} distance is 2.6m. To get the same size with hydrogen, initial pressure should be reduced at 20bars. On the other hand, for natural gas and a 100mm diameter driven relief valve with an opening pressure of 100bars, the H_{max} and R_{max} distances are respectively 100m and 23m. To get the same sizes with hydrogen, initial pressure should be reduced to about 77bars. For one component, the pressure reduction factor should be 5 and for the other only 1.3. Fortunately, the reduction factor is lower for the one that gives the largest hazardous area. The difference between the two examples is mainly due to the

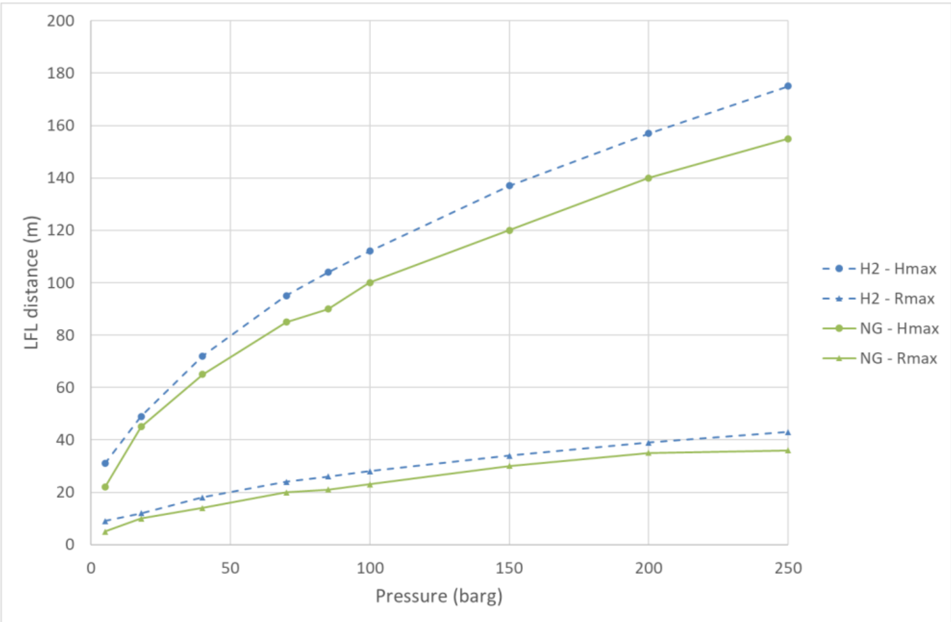

Figure 8 : Comparison of LFL distances (H_{max} and R_{max}) for a driven relief valve at 100 bar

The question of lowering pressure is raised, not only, for ATEX issue but also for material compatibility with H_2 so it might be a way to consider. However, as illustrated here, there is no easy rule to deal with this issue. A full review of the hazardous area classification is necessary when converting natural gas installations.

Finally, the sizes of the hazardous areas are only one aspect to consider. The compatibility of ATEX equipment must be also verified. As hydrogen is much more reactive than methane and natural gas, ATEX equipment must respect the requirements for the gas group IIC, whereas IIA is sufficient for natural gas. Hence, converting existing natural gas facilities will need to deeply review the conformity with ATEX directives.

CONCLUSIONS

As what many other energy companies do, GRTgaz is developing new H_2 projects to define and disseminate new best practices to design, maintain and operate H_2 facilities. The hazardous properties of hydrogen justify to review risk assessment, safety distances and hazardous area classification.

Since 2016, GRTgaz has been performing extensive work to develop a new version of PERSEE+, the company's consequence analysis software, to model H_2 releases with a sufficient level of accuracy. This approach enables to confidently perform the hundreds of calculations that are required to update internal guidelines for hazardous area classification. This article shows that hydrogen will cause a much larger hazardous area than that of natural gas under similar operating conditions. For new facilities, it may lead to more difficulties regarding facility siting, while for existing facilities, it may lead to lower operating pressures and/or equipment upgrade after detailed compliance reviews regarding ATEX directives' requirements. Internal guidelines is helpful in completion of these studies in reasonable time and efforts.

GRTgaz is still improving PERSEE+ models and their validation by conducting new experiments. For dispersion, new tests with horizontal releases at medium pressure (about 40 bars) and release in gas cabinet at low pressure (< 4 bar) will be performed.

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