From theory to practice: a training course to spread the safety rules and warnings about hydrogen safety

Romain Jambut, R&D Project Manager, GRTgaz, 1 rue du commandant d'Estienne d'Orves, 92 390 Villeneuve la garenne

Vincent Blanchetière, Safety Expert, GRTgaz, 1 rue du commandant d'Estienne d'Orves, 92 390 Villeneuve la garenne

Gilles Chatelet, Safety Expert, GRTgaz, 6 Rue Raoul Nordling, 92 270, Bois-Colombes

Anne Leprince, Safety Expert, Storengy, 12 Rue Raoul Nordling, 92 270, Bois-Colombes

Claire Saint-Macary, Head of the Industrial Safety Department, Térega, 40 Avenue de l'Europe, 64 010, Pau

Christopher Henoch, Training Manager, CNPP, Route de la Chapelle Réanville, 27 950 Saint-Marcel

To achieve the environmental goals defined in the Paris Agreement on climate change, a rapid transition of the energy sector is necessary. Renewable gases such as biogas or green hydrogen are the engine of change for the gas value chain operators.

A rapid growth in hydrogen production and use implies the need for a transportation infrastructure, to this end a consortium of European gas operators have proposed a common vision called the European Backbone, a connected hydrogen network mainly relying on the retrofitting of natural gas pipelines. This vision has led to the startup of several projects in the different countries involved such as the MosaHYc or RHYn projects in France.

Even though the hydrogen knowledge is well developed in several industries such as chemical companies, refineries, or the space industry, it is a relatively new component for the historical natural gas companies. Converting existing pipelines involves several technical challenges such as material compatibility, hazardous area classification, operating philosophies and so on.

These new projects will be operational within a relatively short period of time and training of personnel in charge of operating these future installations is a key need to ensure their safe operation.

Due to the main characteristics' differences between Hydrogen and Natural Gas a focus shall be applied on operators' safety training. Analysis of accident databases such as the Hydrogen Incident and Accident Database (HIAD) shows that lack of personnel training is one of the main factors in accidents occurrences.

Therefore, a consortium of French operators from the gas value chain (GRTgaz, Storengy & Teréga) have mandated RICE, GRTgaz's Research and Innovation Centre for Energy, to develop a training initiative dedicated to operating personnel. The aim is to provide them the essential knowledge regarding hydrogen safety while highlighting the main differences with Natural Gas.

This article details the training program set up combining the dissemination of theoretical knowledge with a practical session including situational exercises, its development process to ensure its compliance with operational needs and the evolution perspectives based on the feedback of the sessions held in the last year.

Furthermore, it describes how this training module fits into the overall personnel training program being developed by GRTgaz.

INTRODUTION

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 some 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 requires 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 space, petrochemical and chemical industries which have derived a sound knowledge for the gaseous hydrogen. With the goals set up 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 by being one of the main gas network operators in Europe, operating a 32,000 km long natural gas pipeline system, needs to adapt to these new challenges linked with the energy transition and to adapt its pipeline system for new gases such as hydrogen.

To prepare the energy transition of the industry, GRTgaz has join 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 critical of the hydrogen infrastructure 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. The maps shows that a corridor from Spain to Germany via France could emerge by 2035 with the conversion of some existing pipelines (European Hydrogen Backbone, 2022).

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

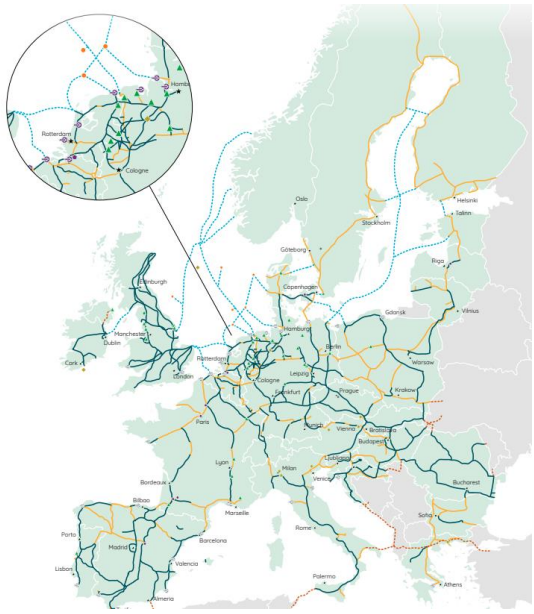

Figure 1 – Mature infrastructure stretching towards all directions by 2040 (European Hydrogen Backbone, 2022)

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 consists in a 70 km long infrastructure with a capacity of up to 20,000 m^3/h.

The RHYn (Rhine HYdrogen network) project consists of a 100 km pipeline infrastructure, including 60 km of repurposed natural gas pipeline. 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 region in Germany and the Bale region in Switzerland will be investigated in the later stages of the project.

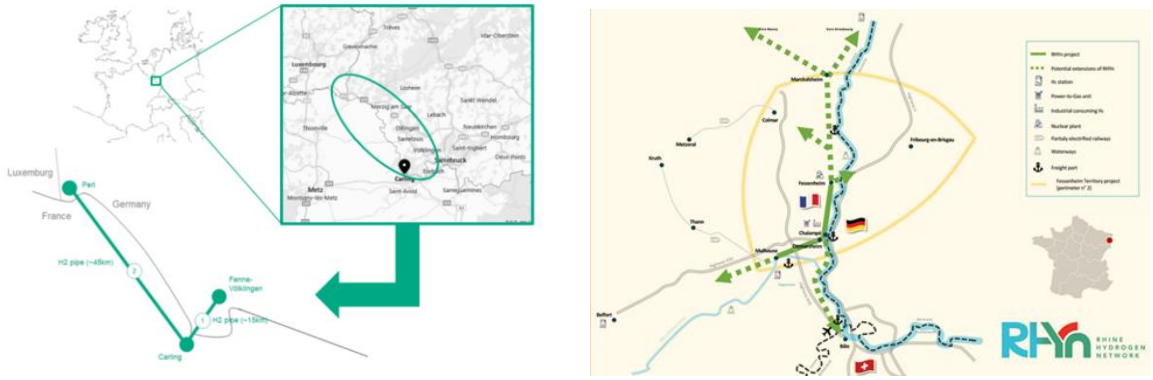

Figure 2 – Location maps of the MosaHYc project (left) and RHYn project (right)

Converting existing natural gas pipelines to hydrogen brings some major issues to ensure a safe design and operations such as material compatibility, Hazardous area classification, operating practices, 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.

While transitioning to a hydrogen economy, GRTgaz is introducing this new gas to a category of personnel so far unfamiliar with its behaviour and hazardous properties. This is a challenge that needs to be overcome by the provision of adequate acculturation and training.

Lessons learnt from the accidentology

Operating a hydrogen pipeline network with the same safety requirements as the natural gas pipeline network will require changes in companies' philosophies such as safety. The study of the past accidentology and associated lessons learnt may provide some extended useful information to help adapting the companies for operating a hydrogen network.

The Bureau d'Analyse des Risques et Pollutions Industriels (BARPI: Risk and Pollution Investigation Bureau) published in 2009 a synthesis of the 215 hydrogen accidents recorded in the ARIA database (BARPI, 2009). The analysis indicates that among recorded incidents whose root causes were identified, 70 % of them were caused by Human and Organisational Factors alone or associated with material failure. Two main root causes are highlighted: maintenance of servicing operations and process control defects.

In 2011, Mizra (Mizra et al. 2011) performed another analysis of several existing incident databases including the ARIA database as well as databases from the USA, Italy and the Netherlands. The study focused on 32 incidents which occurred in the hydrogen processing industry. As for the BARPI study, Mizra's analysis demonstrated that "operator error" is one of the two primary causes of incidents, "maintenance" is one of the main primary and secondary cause of incident and finally that "management" is a secondary cause to the primary causes sorted. Mizra puts forward the need to learn from the past accidents and implement the lessons learnt to reduce the possible risk of operating a hydrogen installation.

In the late 2021, the European Hydrogen Safety Panel (EHSP) has published a recent analysis of the Hydrogen Incident and Accident Database (HIAD 2.0) as part of the Fuel Cells and Hydrogen Joint Undertaking (FCH2JU) initiative. The HIAD is an international open communication platform collecting systematic data on hydrogen-related undesired events. The analysis performed included 426 incidents deemed with sufficient information to be included in the review. Two statistics highlighted are of concerned from the safety point of view: it has been found that 70% of the incidents occurred in normal operation, and it is also demonstrated that the human factor whether it is an individual factor or a job factor or an organisation and management factor, is one of the main causes of incidental or accidental situations.

In 2019, the EHSP published via the FCH2JU a list of Safety Principles stating simple and understandable objectives acting as preventive barriers of risk reducing measures on various elements of the chain of events during a hydrogen accidental scenario (FCH2JU, 2019). By comparing data derived from the HIAD analysis to these Safety Principles, the ESHP found that the major contributing factor with more than 23% of occurrence is the Safety Principle number 9: "Train and educate staff in hydrogen safety". This clearly indicates that the lack of training of operators and plant personnel as well as the lack of understanding of hydrogen hazards is a key area of improvement.

The EHSP emphasises the need for the training to be periodic, to cover both young and senior personnel categories and to be sufficiently stringent for the personnel to keep its skills and follow the procedures in place. It is also highlighted that the training should include not only information on the physical properties of the hydrogen, but also specific details and hazards associated with the hydrogen equipment on the installation.

The analysis of the past accidents and lessons learnt from the existing hydrogen industry clearly stressed the need to start the acculturation and training of its personnel in the early stage of the company process to move toward a safe hydrogen economy.

Developing a comprehensive training module on hydrogen safety

Setting up the basis of the knowledge

With the rapid development of the Hydrogen projects within GRTgaz and the start-up of several hydrogen facilities (J1000, FenHYx Laboratories), the issue of operators training has become a priority for GRTgaz to ensure that these new facilities will be operated with the same safety standard and quality as the existing natural gas system.

The first approach adopted by GRTgaz to meet the demand in the short time frame was to contract a training session with an external company. This has enabled to instil in the staff a first knowledge regarding hydrogen safety, but it was not renewed in agreement with the feedback received from the first operators who had followed the session. It appeared that the content available at the time was more tailored for production or usage applications and perceived rather anxiogenic than pragmatic.

On this observation, GRTgaz decided in 2019 to mandate RICE for the development of a tailored hydrogen safety training module focusing on the key issues of the gas transmission operators. Having received similar demands from Storengy, the main gas storage facilities operator in Europe, and Térega, the gas pipeline and storage facility operator in the Southwest part of France, it was proposed to the three companies to mutualise the sponsoring of this training module. The three companies being used to mutualise R&D work through RICE research programs and sharing common interests and objectives regarding the safety culture, a mutual agreement was rapidly found.

This co-sponsoring offers a main advantage in terms of disseminating the safety principles as it harmonizes the knowledge between the different operators of the gas value chain sharing a common interconnected network. This is also in line with the French Energy Regulation Commission requirements, encouraging the different regulated operators to collaborate and mutualise their efforts for the development of new energy vectors.

The three operators being familiar with handling natural gas and having a sound understanding of the safety principles associated with its operation, the development of the educational content was focused on providing an appropriate understanding of the differences between Natural gas and hydrogen hazards.

After a review of the existing training offer on the market, RICE proposed a theoretical content based on the available knowledge in the literature and also obtained through its research activities. The content was organised in different parts including an overview of the hydrogen economy, hydrogen properties, hydrogen hazardous phenomena, gas and fire detection and modelling of hydrogen accidental scenarios. The overall content was scheduled on a one-day format but was found to be more suitable for the needs of the safety engineers than the operators. Workshops were held to adjust the theoretical content to the needs of the operating personnel and to give room in the planning for the addition of a practical session to help to visualise the phenomenon.

The search for a partner for the practical part

Once the theoretical part set up, the main challenge was to implement a practical part within the module. Several constraints increased the difficulty of this task: the milestones set up by the sponsors to train their personnel operating hydrogen installations and the COVID crisis with its confinement and supply shortage issues.

To overcome these problems, RICE looked for a partner with in-place testing facilities that could correspond to the training objectives and willing to join forces and developed a common project. This partner should also be able to demonstrate the principal safety challenges of hydrogen and allow for situational exercises. In 2021, RICE turned to CNPP, (National Centre for Prevention and Protection), expert in industrial safety, and training first responder about hydrogen safety.

CNPP is located in Vernon in the Normandy region (France) and possesses a unique facility dedicated to the research, qualification and training in the field of safety and in particular regarding fire safety. As part of their training offer, CNPP is proposing a hydrogen training for first responder with an installation allowing real scale accident simulations and exercises.

Following some initial discussions, a workshop was held in April 2021 during which GRTgaz safety experts and CNPP trainers exchanged to build a practical session adapted to the operators need. The workshop included demonstration of the proposed test bench for the training module and the possible changes in the CNPP proposed scope to adapt it to suit the required GRTgaz' specifications.

The installation proposed by CNPP is presented in the picture here below.

Figure 4 – Photography of the installation used for the hydrogen safety practical training module

This simple installation offers the possibility to reproduced real scale characteristic scenarios occurring on the gas installations such as a puncture leak, a tubing rupture or a flange break. Using hydrogen bottles as a hydrogen supply source allows as well to cover the pressure range existing on the natural gas facilities of the three sponsoring companies.

A mutual understanding was reach and it was decided to hold several training sessions for selected personnel of the three sponsoring entities in the following months to test, adapt and calibrate the content of the overall training module proposed.

The training content set up.

The training content developed and approved by the sponsors is hence a combination of the expertise of RICE and CNPP. Being dedicated to operating personnel with strong schedule constraint related to their day-to-day tasks, the content has been tailored to fit in a one -day session. The session starts with the delivery of the theoretical knowledge in the morning by a RICE personnel to the trainee in a classroom on the CNPP site, allowing the trainee to move easily to the technical facilities located near the classroom in the afternoon for the technical part of the training delivered by a CNPP employee.

The knowledge background delivered in the session is tailored for each company to include, their recent hydrogen projects, R&D activities to address the safety challenges, the impact on their operational procedures such as ATEX philosophy, Personal Protective Equipment choice, maintenance philosophy, etc. This approach was adopted to help the communication effort within the companies in the dissemination of their hydrogen development.

The content of the proposed session is tailored follow:

- Theoretical part:
    - Hydrogen context: this section presents the main evolution of the hydrogen context from fossil fuel demand decrease to existing hydrogen transmission and storage facilities with a focus on the actual project from the different sponsoring companies.
    - Hydrogen properties: overview of the hydrogen physical properties in comparison with Natural Gas.
    - Review of the accidentology and lesson learnt, regulations, codes and standards
    - Leak and dispersion: understanding material compatibility before moving forward to the leak and dispersion phenomenon. Discussions goes through underground leak, aerial leaks and confined leaks and deals with leakage detection and gas dispersion behaviour.
    - Fire and Explosion: this part review the hydrogen ignition properties, discuss the evolution of ATEX requirement and describes the fire and explosion phenomena while describing of particles on the jet fires, and congestion and confinement on the explosion.

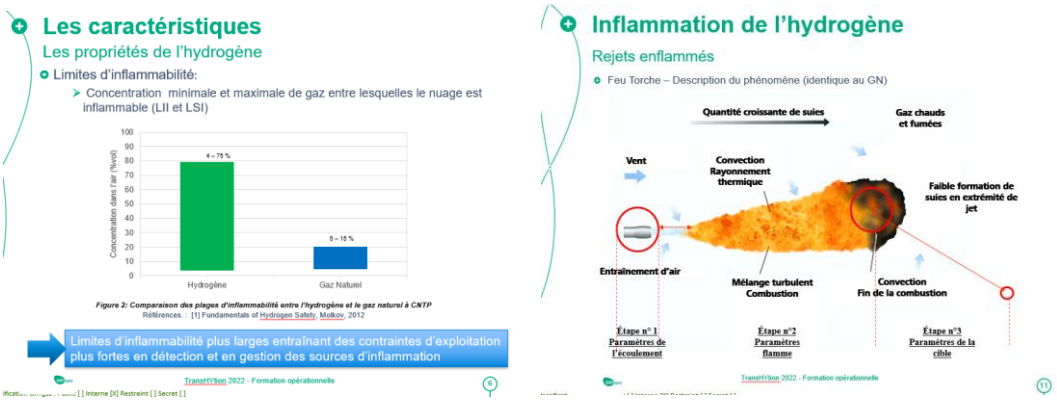

Figure 5 – Example of support used during the theoretical part of the training – Left: flammability limit comparison between H2 & NG; Right: Description of a generic flame

- Practical part:
    - Reminder demonstration of a hydrocarbon flame
    - Hydrogen release demonstration and flame revelation using different means: the trainees are first confronted with a transparent hydrogen flame without any detection means. The demonstration moves forwards to different leak types by adding each time a new visualisation mean (fire extinguisher, thermal camera).
    - Situational exercises: in this second phase of the training, trainees are divided into pairs and must secure the installation on which one or several leaks are located with various leak rates, by using the detection means at their disposal (extinguisher, thermal cameras or both).

Figure 6 – Photography of the training session– Left: Flame visualisation using a thermal camera; Right: Situational exercise including a victim

Situational exercises are held under the supervision of an experienced CNPP trainer who can intervene to protect the trainees if he feels they will put themselves in a dangerous situation. A debriefing is done between each pair exercises to sort out the good behaviour and ways of improvement observed. Particular attention is paid on how the pair communicates with each other and how they follow companies' procedures when arriving at accidental area.

As the objective is to properly train operators with a natural gas experience, the message delivered focuses on highlighting the safety challenges related to hydrogen but in comparison with the knowledge regarding natural gas. Hence the operator will be able to acquire new knowledge but also to understand the main differences between the two gases and adapt its reflexes during an incidental situation.

Test and learn sessions

In the second semester of 2021, a total of six training sessions were held on different categories of personnel of the three sponsoring entities:

- Two sessions in May and June dedicated to the training of GRTgaz FenHyx testing facilities operators, knowing the start-up of the laboratories was taking place in the end of June of the same year.
- A session in July for GRTgaz personnel belonging to different department: Engineering and Project Direction, Technical Direction, Operational Direction, and RICE.
- A session in September for Storengy for a mix of personnel between operators, safety personnel and managers
- A session in early October for GRTgaz operators including J1000 personnel to benefit from their return of experience
- A session in late October for Teréga including a mix of operators, managers, and safety personnel.

Figure 7 – Photography of the first test session of the training module – Left: Flame visualisation using an extinguisher; Right: Situational exercise

A total of 60 persons attended those sessions in 2021. Having personnel not only from the operational direction but also from the engineering, project and technical departments helped us adapting the content thanks to the received feedbacks to ensure it is adapted not only to the operators needs but also in line with the hydrogen philosophies and methodologies in development within the sponsoring companies.

The received feedbacks were positive and helped identifying ways of improvements. Some of the most received comments are as follow:

- The training module offers a good balance between theoretical knowledge and practical exercise enabling to assimilate the key messages regarding hydrogen safety
- The ability to use different models of thermal cameras during the session is a plus for the operators as it allows assessing different equipment on the market and identify the operating criteria that can be acceptable on site (brightness, size, contrast, cost, etc.)
- The key differences between hydrogen and natural gas are well explained
- Adding an additional module to demonstrate the pressure effect in case of an explosion would be a plus.

The last point is one of the key elements on which GRTgaz and CNPP are working to improve the training module as the main consequences effects will shift from thermal to overpressure in case of hydrogen accident compared to a similar natural gas scenario. This task provides several design challenges to ensure the safety of the personnel due to the testing area configuration. This addition is expected to be operational for the training session in 2023.

Running the module and evolution perspectives

Following the tests sessions in 2021, the training has been made available to the three sponsoring companies' employees in 2022 with a priority for the personnel involved in the hydrogen projects. For the time being, eight sessions are scheduled from March to November 2022.

Currently, the training module is in the CNPP technical site in Vernon in the Normandy region in France. Considering the spread of the transmission network within France, the location of the training site implies some challenges for the training of personnel based in regions in the opposite side of the country due to their daily job constraints (maintenance operations, on-call duty, etc.). Therefore, GRTgaz is assessing the possibility to replicate the testing bench on its operating sites to create a mesh network withing France. Two sites are currently investigated, the Alfortville station located in the Paris area and the J1000 station in the South of France. Both sites will allow to couple the training module with visits of the R&D labs and possibly expand the content.

RICE being a R&D Centre with limited staff resources, it will not be able to train the personnel of the different sponsoring companies on the long term. This implies that sponsoring companies need to appropriate the content created and train internal staff to deliver the courses and to ensure that they maintain the training skills and culture over the long term.

Maintaining the safety culture can only be achieved with the support of the management and decision makers, thus a demonstration session is scheduled in 2022 for RICE directory board. This kind of specific acculturation sessions could be extended to the overall GRTgaz directory.

As part of its project development, GRTgaz is interacting with other European gas transmission operators, which have expressed an interest in getting involved in this training initiative and requested the possibility to apply for some training session in 2022 and 2023.

Spreading the hydrogen safety culture, how to widen the target?

Speeding the acculturation process

The developed training module is designed for the Operational Direction staff with priority given to the operators involved in hydrogen projects. However, as expected for a fossil fuel company, personnel are worried about the company's place in the long term and the role it can play in the energy transition. Thus, the interest in the hydrogen acculturation goes beyond the personnel involved in the hydrogen projects and covers all the direction.

To start acculturating in a short term the whole Operational Direction personnel, GRTgaz has turned to new technologies to create a one-hour online quiz. The quiz is hosted by a multi-direction team and provides generic knowledge about the use of hydrogen through history, the means of production, its physical properties and safety considerations, and usage information. The quiz sessions took place in the late 2021 and 240 personnel participated which represents around 21% of the Operational Direction workforce. Similar initiatives will take place in 2022.

As all personnel will not need a practical training, GRTgaz is also working on an internal Massive Open Online Course (MOOC) which would be broadcasted to the whole company personnel via the online training platform. This MOOC is still under current development and will provides categories such as administrative, legal, accounting, etc. with a first knowledge about hydrogen.

To provide some additional materials to these online contents, an explanatory video about hydrogen safety was created. The visual content was filmed during one training session of the hydrogen safety module developed to provide dedicated visuals of the risks and behaviour to follow. This video, produced by CNPP, has been developed jointly by GRTgaz, Storengy and Teréga and is used in their internal acculturation initiatives such as MOOC, intranet articles, team meetings, and so on.

Figure 8 – Extract from the produced explanatory video

Embed the training in the company culture

As stated before, developing, and maintaining a training culture within a company is possible over the long term only with the support of the management and decision makers. Therefore, GRTgaz has engraved in its objectives for 2024 the company's will to prepare for the energy transition and move toward the hydrogen market as well as putting its personnel in the centre of this evolution.

The introduction of hydrogen and other renewable gases in GRTgaz' network will imply a modification of the operating philosophies and practices and the creation of new job categories. The company needs to prepare in the early stages to these changes thus it has been decided to launch in 2022 an internal working group to create an "Ecole du Gaz" (Gas School) which will aim to create a training program to ensure that the employees will have the proper set of skills to operate in a safe and efficient way the installations of tomorrow. The training module presented in this article will be included as one of the modules of this new training cursus.

Conclusions

This article presented the work carried out in the past three years to create a training module on hydrogen safety dedicated to the personnel category operating the installation of the gas value chain. This module was created thanks to the sponsoring of GRTgaz, Storengy and Teréga. RICE. GRTgaz' R&D centre joined forces with CNPP to develop this unique module supplying the trainees with theoretical knowledge about hydrogen safety as well as demonstration of the hazardous phenomena and situational exercises. The module developed focuses on highlighting the differences in terms of safety between hydrogen and natural gas to prepare the natural gas operators transitioning towards a hydrogen economy.

In the process of improvement of this training module, RICE and CNPP are also working together to add an explosion demonstrator to the practical module. GRTgaz is also investigating the possibility to duplicate the test bench on two of its sites, thus creating a web network within France and easing the personnel registration with regards to their daily job constraints. GRTgaz is also collaborating with other gas transmission operators which have expressed an interest in this training module.

Moving from a natural gas to hydrogen implies some changes in the organisation and the need for a sound training of the personnel to ensure a safe operation of the installation. Developing and maintaining training skills and culture over the long term is feasible only with the support of the management and decision makers. Thus, GRTgaz has developed long term company's objectives to ensure that personnel education will guarantee that they will possess the proper skills. Several initiatives were launched internally on top of the module such as online quizzes, explanatory videos or MOOC creation. Finally, the long-term vision involves the creation of a Gas School to prepare the employees for tomorrow's jobs.

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