European Commission

Ensuring safe hydrogen fuel operations: A perspective on regulator oversight and enforcement challenges

Summary of an expert webinar exchange, 14 February 2024

van Wijk, L., Wood, M., Smedberg, E., Moretto, P.

2024

Joint Research Centre

JRC140469

EU Science Hub

https://joint-research-centre.ec.eu-

JRC140469

Ispra: European Commission, 2024

How to cite this report: European Commission: Joint Research Centre, VAN WIJK, L., WOOD, M., SMEDBERG, E. and MORETTO, P., *Ensuring safe hydrogen fuel operations: A perspective on* regulator *oversight and enforcement challenges,* European Commission, Ispra, 2024, JRC140469.

Contents

Abstract

This report summarises the exchanges from the second webinar in the series of webinars on hydrogen fuel risks organised by the European Commission's Joint Research Centre (JRC) in collaboration with the OECD.

As part of strategies to reduce dependence on carbon fuels, energy policy in many countries worldwide has promoted investment in alternative fuels, including hydrogen fuels. Hydrogen is an abundant and highly versatile substance that already plays an essential role as an ingredient for chemical manufacturing and oil refining in today's economy. However, hydrogen poses a flammable and explosive hazard that requires appropriate controls to avoid serious harm when used in high quantities. In this respect, both industry and government will play an important role in minimizing potential negative impacts of new hydrogen fuel uses and infrastructure to workers and the communities where they are located.

For this reason, the European Commission's Joint Research Centre (JRC) organised a webinar for EU and OECD regulators to facilitate exchange on the main challenges linked to hydrogen risks, in light of the rapid escalation of hydrogen fuel projects that are, or will be in future, submitted for review and approval by public authorities. The exchange consisted of an overview of several hydrogen fuel technologies and their applications that were already being proposed and the risk management questions they pose for inspectors, local authorities, and other regulators with permitting and oversight responsibilities. This publication summarises the main highlights of these exchanges. The webinar is the second in a series of exchanges organised by the JRC to support competent authorities in addressing emerging risks associated with hydrogen fuels and other alternative energy sources.

This report summarises the main conclusions from the webinar. It does not necessarily represent the views of the OECD or of the European Commission. The report has not been reviewed by the OECD's Working Party on Chemical Accidents nor the OECD's Chemicals and Biotechnology Committee.

Acknowledgements

The authors are grateful for the availability and openness of all participants in the webinar in Hydrogen Fuel Risks Webinar 2. We particularly appreciate the tremendous support of OECD in bringing perspectives from non-EU countries and experts to the webinar. Moreover, the Technical Advisory Group has been an invaluable resource for advice on structuring webinar programmes for the webinar series to encompass a broad range of important issues. We also have been fortunate for the time and energy spent by Technical Advisory Group members in contributing their national perspectives and tools and information developed to solve particular problems.

1 Introduction

The second webinar on Hydrogen Fuel Risks (Hydrogen Fuel Risks Webinar 2), organised in collaboration with the European Union Joint Research Centre (JRC) and the Organisation for Economic Co-operation and Development (OECD), took place on 14 February 2024. The webinar hosted 198 participants from authorities and research institutes of 23 EU, 28 OECD countries, as well as Argentina, Kenya, Moldova, the Philippines and Singapore. The webinar is the second in a series of exchanges organised by the JRC to support competent authorities in addressing emerging risks associated with hydrogen fuels and other alternative energy sources. The purpose of this webinar was to examine the practical implications of hydrogen fuel-related development in a number of countries, in order to gather information on the risk-related questions that could be expected, as well as to exchange information on efforts already underway to address them.

1.1 The JRC hydrogen fuel risk webinar series

The outcomes of the hydrogen fuel risk webinar series are intended to inform and shape the next four years of work of EU and OECD collaboration on the safety challenges posed by the rapid development of new hydrogen applications. The first webinar in the series took place on 15 September 2023. The purpose of Webinar 1 was for participants to gain an understanding of the scope and variety of hydrogen fuel projects underway or on the horizon. Various authorities from EU and OECD countries described the current situation within their jurisdiction in relation to new projects proposed or being implemented aimed to increase access to hydrogen fuel within their country or region. Additionally, representatives of research organisations gave an overview of technical and scientific areas that were being explored to support safe operation of new or expanded hydrogen fuel facilities. The agenda, presentations, and report from Webinar 1 are available on the event page Webinar 1.

In contrast to Webinar 1, Webinar 2 centred around hydrogen fuel technologies and their applications, with a specific emphasis on matters concerning to safety, inspections, and regulatory frameworks. The webinar highlighted the main challenges linked to hydrogen risks, the rapid development of new hydrogen uses and the decisions faced by public authorities. Furthermore, it underscored the need for effective communication of safety challenges outside the process safety community. For agenda, presentations and reports from Webinar 2, one can visit the event pages for Webinar 2.

1.2 Organisation and content of the second hydrogen fuel risks webinar

Webinar 2 was divided into two parts. The first part of the webinar focused on efforts to identify challenges and solutions associated with regulatory and oversight needs, in particular permitting, accident scenarios and risk assessment, regulations, and standards, in particular noting knowledge gaps and needs for further scientific research within this field. In contrast, the second part of the webinar highlighted work in various countries to clarify safety measures and safety guidelines related to the safe handling and use of hydrogen fuel. This included also land-use planning strategies and recommendations for modelling of distances in order to minimize potential risks and hazards associated with proposals to build or expand hydrogen fuel production, distribution and storage facilities.

To facilitate this discussion, the webinar included several presentations on individual country perspectives hydrogen projects that were underway, under consideration, or expected to be proposed in future. The presentations also included practical experience in overseeing hydrogen sites already in operation, for example, the findings from an inspection campaign on gaseous hydrogen storage and unloading facilities. Other presentations in this line offered a perspective on the complexity of technical regulations and standards applicable to hydrogen facilities. In particular, they provided insight on potential new safety measures and knowledge that may be required of operators of new hydrogen fuel facilities, especially those operators who were neither experienced in managing hydrogen risks or chemical accident risks in general. Other specific topics included examples of risk assessment models developed for hydrogen pipelines, safety considerations for storage of gaseous and liquid hydrogen, the risks presented by potential interaction of hydrogen with different materials, new recommendations regarding guidelines on hydrogen flammability limits, leak hole sizes, and decision criteria for establishing safe distances of new hydrogen fuel facilities in relation to populated areas and the built environment.

There was general agreement across presentations on the need to review and adapt existing standards associated with hydrogen safety to address new risks related to the expansion of hydrogen fuel usage. For example, the specifications of trailer to hose connections could greatly enhance safety during hydrogen filling. Some presentations also emphasized the importance of developing risk assessment models, emergency preparedness measures, inspection practices, and operator training to address additional risk and risk exposure introduced by new hydrogen fuel storage and handling operations.

Concluding the webinar, a discussion took place between presenters focusing on areas where further research and collaboration might be necessary. There was also consensus reached that the next webinar should bring industry speakers to talk with authorities about their hydrogen fuel projects and their vision of how standards and practices should be adapted to meet achieve risk acceptance criteria established in EU and OECD countries.

2 Summary of key discussion points

The webinar built on Webinar 1 that generated a number of conclusions on the range of risk management challenges posed by a wide range of hydrogen fuel applications. (See **Text Box 1**.) There was general agreement in the webinar discussions and presentations that, due to the dangerous properties of hydrogen, the transition towards new hydrogen fuels uses brings several technical and safety challenges and considerations that need to be addressed. This chapter describes these concerns under the following subheadings in which they have been grouped:

- Regulatory frameworks and standardization challenges
- Safety aspects and risk assessment challenges
- Emergency response challenges
- Infrastructure and urban planning considerations
- Research and innovation aspects

Text Box 1 Summary of dangerous properties of hydrogen (Excerpt from the final report of Hydrogen Fuel Risks Webinar 1)

Due to its small molecular size, hydrogen can easily leak through seals and micro cracks. This, combined with a wide flammability range and low ignition energy, increases the risk of accidental ignition in the event of leakage. It also reacts spontaneously and violently with other substances at room temperature such as chlorine or fluorine.

Hydrogen can cause embrittlement in metals, which can lead to material failure. It is important to select materials carefully that are compatible with hydrogen to mitigate this risk.

Two prevalent methods to increase the storage density of hydrogen are liquefaction and/or compression. Liquefaction involves maintaining hydrogen at cryogenic temperatures between its triple point (21.2 K and 0.7 MPa) and critical point (33 K and 1.3 MPa). Compression involves storing hydrogen as a compressed gas at high-pressures (in the range of 900-1,000 bar). The cryogenic temperatures and high-pressure environments pose significant challenges in terms of handling and storage infrastructure requirements.

Existing infrastructure, including pipelines and storage facilities, may not be suitable for hydrogen without significant modifications. This requires careful planning and investment to ensure the safe and efficient integration of hydrogen into existing systems.

The effectiveness and reliability of safety valves and pressure relief devices in hydrogen systems need thorough evaluation to prevent overpressure incidents and ensure the overall safety of hydrogen fuel usage.

The lack of standardized connectors and systems for hydrogen refuelling stations and equipment can lead to safety risks during the refuelling process.

Hydrogen use is expanding from traditional industrial settings into the public domain, including hydrogen fuelling stations and energy supply.

The introduction of electrolysis for hydrogen production, liquid hydrogen storage, and high-pressure hydrogen pipelines presents new scenarios not fully covered by existing safety regulations.

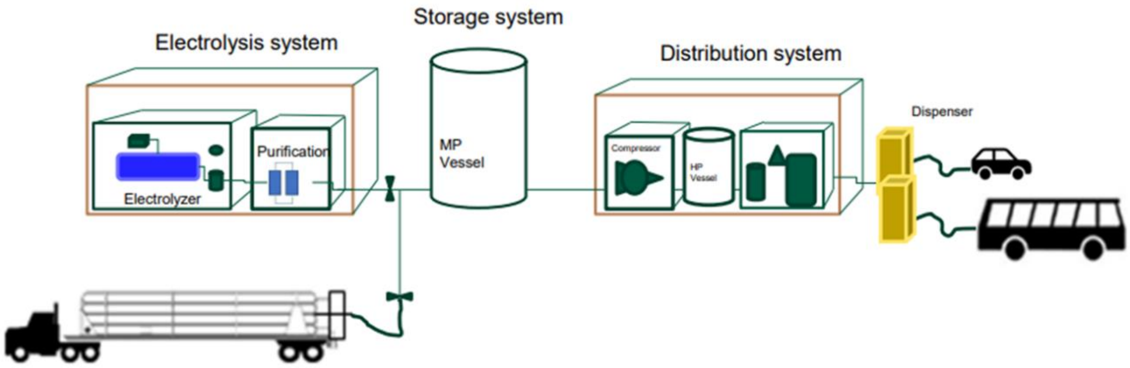
Source: Van Wijk et al., 2024

Since this is a summary document, each of these sections only represents the main highlights from the discussion, consisting of a short introduction followed by an explanation of the principal concerns under this topic. Following these explanations, a final section will give practical examples of how authorities have met various challenges and/or questions that they are seeking to address.

2.1 Safety aspects and risk assessment challenges

Participants stressed the need for better understanding of the main challenges related to hydrogen risks in new technologies and applications. Hydrogen has a wide explosive range, is highly flammable and is notable for invisible flames. It is also a very light molecule and can escape containment if there are any possible openings. These properties together make hydrogen uniquely challenging to manage safely, especially when handled in new contexts involving new technologies, new operators and downstream users. **Figure 1** shows the different parts of the hydrogen fuel infrastructure that will be needed across the life cycle stages (i.e., from production to end use by consumers and businesses). **Text Box 2** lists typical elements of the new infrastructure that will be required to support expanded hydrogen fuel

Figure 1 Challenges and considerations across the hydrogen fuel life cycle



Source: [*B. Debray and B. Weinberger, 2024*]

use along with their most prominent accident risk factors.

- **Risk assessments of hydrogen operations must account for hydrogen's unique properties, including its low ignition energy, high diffusivity, and buoyancy.** A few presenters described methodologies that were in development for assessing these risks for different aspects, such as including qualitative risk assessments, iso-risk contours, and societal risk criteria. Moreover, the importance of identifying overpressure scenarios, calculating safety valve capacities, and ensuring reliable detection and alarm systems was highlighted.
- **Reducing and qualifying uncertainty in assessing risk of hydrogen use should be a priority of research.** Uncertainty in consequence modelling for hydrogen accidents

Text Box 2 Potential new infrastructure elements and risks associated with various EU and OECD national hydrogen fuel strategies

Electrolysis of hydrogen: The permeability of the electrolysis membrane to oxygen and hydrogen can lead to the mixing of hydrogen and oxygen under low-power operating conditions (also known as gas cross-over). This phenomenon poses an explosion hazard.

Storage facilities. With the increasing volume of hydrogen, there is a need for additional storage sites. These must be carefully located to ensure safety, taking into considering the volumes stored and materials compatibility.

Hydrogen pipelines. Hazards are associated with the transportation of hydrogen and hydrogen-natural gas blends through pipelines and integrity of the pipeline. Leakages in pipelines can lead potentially to fire and explosion hazards.

Hydrogen-methane pipelines. There is still research underway to support consequence models for risk assessment and analysis relating to pipeline transportation of H2-Natural gas mixtures (probability of release and triggering in case of loss of containment). In particular, there are uncertainties on the chemical-physical and combustion properties and the risk associated with concentrations of hydrogen exceeding 10%.

Compression and regasification plants. Hazards related to the compression and regasification processes includes leaks, fire or explosion. Hazards related to pressure burst and embrittlement of equipment can occur if materials used are incompatible with hydrogen.

Transportation vehicles (ships, train, and trucks). Hazards can be triggered by road crashes, collisions, or loss of vehicle control during the transportation of liquefied hydrogen (either in pressurized or cryogenic state). Pressure bursts and embrittlement of vessels and containers are potential risks that need to be addressed.

Fuelling stations and dispensers. Challenges exist in determining appropriate locations for fuelling stations, especially in close proximity to urban areas. Factors such as safety and community acceptance should be considered when selecting fuelling station locations. Hazards arise from pressure burst and embrittlement of storage containers.

Collocation with other hazards. Facilities involved in production, distribution and storage of hydrogen may also have other chemical hazards. For example, industrial sites that store hydrogen for their energy needs on site, and fuel stations that also supply petroleum-based fuels, including petrol, diesel and liquefied petroleum gas (LPG) and liquefied natural gas (LNG). On such sites, the harmful consequences of any event resulting from an accidental hydrogen release could increase exponentially should other dangerous substances be involved.

Ammonia used as a hydrogen carrier. It is foreseen that ammonia will be used to carry hydrogen because ammonia is more energy-efficient to transport than hydrogen, especially if long distances are involved. Ammonia is a highly toxic substance and an ammonia cloud can retain harmful properties even several kilometres from the source of release. Transporting hydrogen via ammonia will likely

represents a significant challenge. Different scenarios, quantities, and modelling tools can lead to different results, making it difficult for authorities to assess the reliability of the risk assessments provided by the operators. This uncertainty complicates decision-making regarding safety measures and approvals.

- **Decision processes and tools to support permitting, land use planning and emergency preparedness should adequately take account of current uncertainty in assessing hydrogen risk.** Existing regulations and guidelines, often designed for traditional fuels or chemicals, may not fully address specific aspects of hydrogen. These often focus on liquid chemicals, making them less applicable to gaseous hydrogen.

- **Research and regulatory adaptation to support risk management of distribution networks for methane-hydrogen blends should also be a priority.** The webinar included a presentation highlighting specific challenges associated with the blending of hydrogen with methane into pipelines and the transportation of pure hydrogen. A notable issue is the need to revise the technical regulations to account for the increased presence of hydrogen in methane pipelines.
- **National strategies to promote hydrogen fuel initiatives must take account of new exposure and risk scenarios to optimize the success of investments in this area.** Hydrogen use is expanding from traditional industrial settings into the public domain, including hydrogen fuelling stations and energy supply independence. The introduction of electrolysis for hydrogen production, liquid hydrogen storage, and high-pressure hydrogen pipelines presents new scenarios not fully covered by existing safety regulations. A failure to foresee barriers to and complications in project implementation may undermine economic viability and political support for the strategy.
- **Hydrogen fuel operations that are already underway or soon to be deployed require heightened attention from regulators.** Inspection campaigns have revealed variability in safety measures and maintenance of hydrogen fuel systems, such as inadequate calculations for safety valve capacities, incomplete identification of overpressure scenarios, and gaps in inspection programs for pressure relief devices. Also, the need for regular risk analyses required further investigation and standardization in areas such as for compressors and storage facilities and compatibility of materials with hydrogen.
- **The advancement of liquefied petroleum gas (LPG), compressed natural gas (CNG), and liquefied natural gas (LNG) technologies has led to the application of Seveso criteria to filling stations in certain jurisdictions.** The advancement of liquefied petroleum gas (LPG), compressed natural gas (CNG), and liquefied natural gas (LNG) technologies has led to the application of Seveso criteria to filling stations in certain jurisdictions. Similarly, under the Seveso Directive, urban planning criteria focus on long-established individual risk associated with hazardous facilities. Error! Reference source not found.**2**, shows an example of risk criteria proposed by one jurisdiction for hydrogen filling stations, comparing them to Seveso (EU high hazard) sites and compressed natural gas (CNG)/liquefied natural gas (LNG) filling stations.

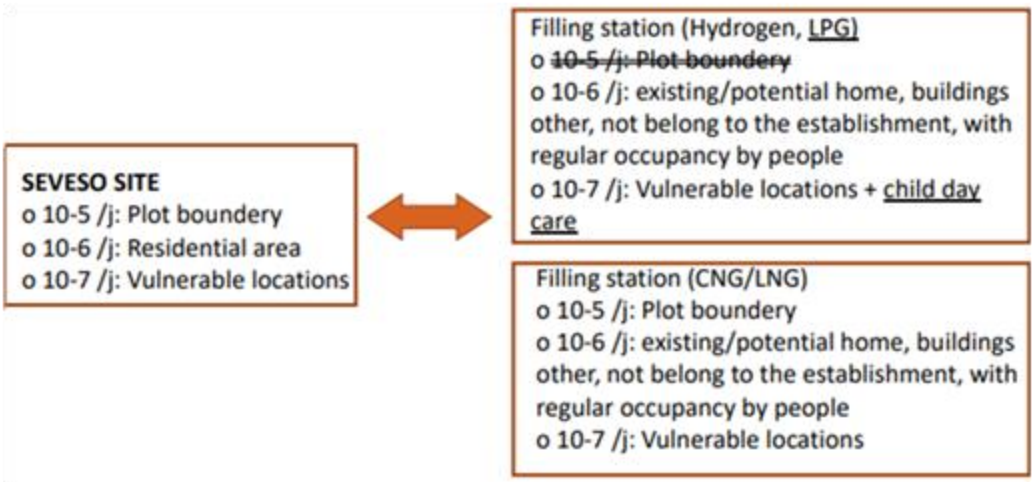
2.2 Regulatory frameworks and standardization challenges

The speakers identified several challenges in the hydrogen fuel domain related to regulatory and standardization. These challenges stem from the diverse regulatory that can vary substantially from country to country in the EU and elsewhere. The safety components of regulation are also evolving but somewhat slowly and uncertainly because they are highly dependent on industry standards that are themselves in the process of evolving to meet new technical and safety needs. In addition, new standards will be required for some uses that operate under different conditions than current technologies in use. Furthermore, many existing and future standards, are dependent on scientific support to test and establish the new parameters that define the standards.

Figure 2 An example of risk criteria proposed by one jurisdiction for hydrogen filling stations

In Flanders, Current efforts are focused on standardizing safety measures across all fuel filling stations. Nearby shops and fast-food outlets may fall within the 10^{-6}, risk contour (see below) and prohibited from locating closer to the site, similar to residential areas. (A risk contour is a zone defined distance by the estimated probability that accident consequences will have serious harm within a certain radius around the site.) In prior years, a more conservative (lower probability) risk contour of 10^{-5} (allowing businesses closer to the site, but not residences) had been established, but this approach was subsequently abandoned for other fuel stations, especially Liquefied petroleum gas (LPG) fuel stations, because it turned out to be impractical. (Allowing the businesses to be located closer to the site means that a slightly higher risk was accepted for these businesses.)

However, more recently, compressed natural gas (CNG) and liquefied natural gas (LNG) installations, primarily new sites, reinstated the stricter 10^{-5} criteria for local businesses. When hydrogen stations were introduced, they initially adopted the more lenient LPG criteria instead of the more stringent LNG/CNG standards. As indicated in the diagram below, the plot boundary should include the 10-5 distance limit for these stations. Now the authorities are reviewing land-use requirements for proposed liquid hydrogen fuel stations. They may be a unique type of fuel station in that they may also be classified as low-tier Seveso installations, necessitating comprehensive safety measures to protect public health. These stations must comply with both Seveso criteria and specific regulations for fuel stations, particularly due to their proximity to truck stops, restrooms, and restaurants, which may attract untrained visitors to potentially hazardous areas. As illustrated in the diagrams below, under current practice, if hydrogen is treated like an LPG filling station, it would not have a plot boundary distance requirement (restricting business operations in that area). The Flemish authorities are now evaluating if such an approach is appropriate for hydrogen fuel stations and/or whether all fuel stations, regardless of substance, should follow the same risk criteria for land-use planning rules.



10^{-5}: Pertains to the plot boundary.

10^{-6}: Relates to residential areas.

10^{-7}: Addresses vulnerable locations, such as hospitals.

Source: B. Reiners, 2024

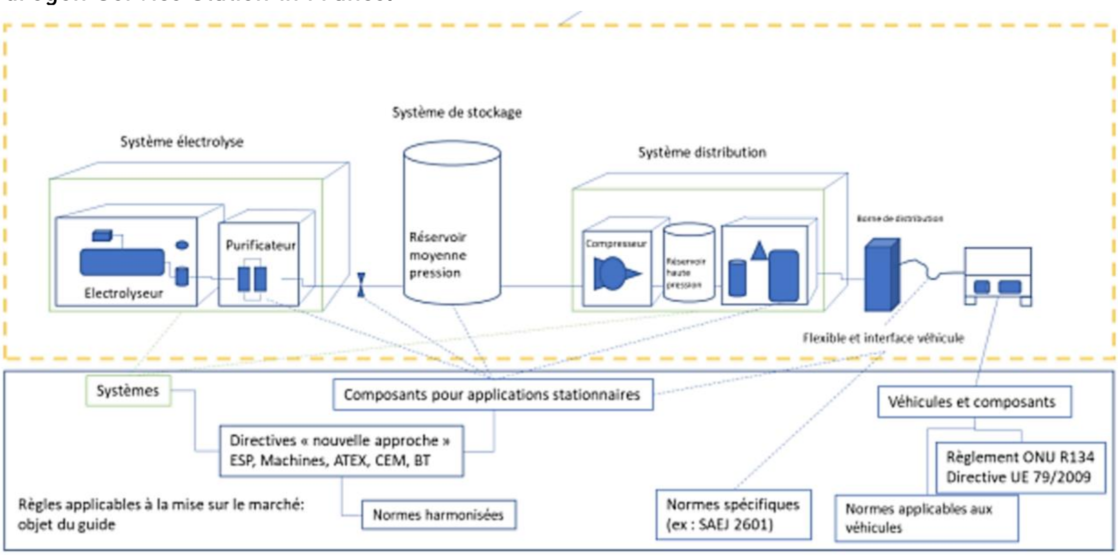
Overall, all countries were in agreement that there is a pressing need to work together to facilitate sound and transparent risk management decisions in exercising permitting, inspections, enforcement and oversight responsibilities, with particular attention to the following issues:

- **Clear and consistent guidance from standardisation organisations will help regulators to establish consistent safety criteria and operators of hydrogen fuel activities to comply with these regulatory requirements.** The complexity and abundance of standards pose challenges for operators, permitting authorities, and inspectors, especially those new to the hydrogen industry. There are over 1,000 industry standards for equipment and processes associated with hydrogen production, storage, handling and distribution, and a significant portion of them are directly or indirectly linked to safety. (VDI, 2024; U.S. Department of Energy, 2024) These standards, in turn, guide safety-related components of regulations and serve as important references for making decisions on whether compliance has been achieved for associated permitting and inspection functions. A number of actors may be creating their own norms, e.g., government, Industry associations, individual companies, at both national and international levels.

  Furthermore, many industry standards for hydrogen technologies are currently under revision or development, adding to the challenges faced by operators and inspectors. They include numerous risk reduction measures, such as criteria to ensure the compatibility of materials used in hydrogen equipment, the safe design of electrolysis plants, and the reliability of risk assessment models for all new use cases (e.g., pipelines, refuelling stations) and contexts (e.g. land-use planning and external emergency planning). (**Figure 3** shows an example of how France is working to apply their existing criteria to new hydrogen fuel stations.)

- **Consistent approaches across countries are needed to reduce barriers to development and growth of hydrogen fuel industries.** One of the recurring themes of the

Figure 3 Illustration of the relationship between the various regulations applicable to a hydrogen service station in France.



Source: B. Debray and B. Weinberger, 2024 webinar was the need for convergence on hydrogen safety regulations and norms of practice. While some countries have set their own regulations and norms for the safety of hydrogen fuel operations, others are still developing their frameworks. Parallel efforts to develop different frameworks in different countries can lead to substantial differences, creating potential obstacles in the spread of hydrogen technologies across borders, as well as unexplained inconsistencies in safety criteria across the various countries. Full harmonization of regulatory frameworks may be a too ambitious objective since risk perception and economic priorities can vary widely among different countries. However, minimizing difference can substantially reduce barriers that operators face in extending their operations beyond the country of origin to achieve economies of scale.

- **National frameworks are required to strengthen government risk management and oversight of new hydrogen fuel operations.** Many countries, do not have risk management legislation that is adequately tailored for risks associated with the new types of hydrogen fuel operations identified in their national strategies. The absence of risk management rules specifically designed for hydrogen fuel operations can leave the government without any mechanisms or even authority, to compel operators of these facilities to meet minimum safety performance requirements and implement appropriate technical and safety management measures. For example, there appears to be no specific standards or guidance to support the application of the EU Pressure Equipment Directive to new hydrogen fuel operations.
- **Government initiatives to promote hydrogen fuel projects should be implemented in tandem and in equal measure with reshaping of the regulatory and standards infrastructures to guarantee their safe operation (and sustainability).** EU Directives are implemented through primary and secondary legislation, encompassing laws and statutory instruments. However, numerous challenges emerge at the national level, particularly concerning tertiary regulations that may be tailored to specific applications and lack consistency across the EU. The fast pace of technological development in the hydrogen sector also outpaces the establishment of standardized regulations and safety practices. This disconnect between economic forces and regulatory forces can lead to regulatory gaps where unregulated new technologies are being deployed without comprehensive safety standards. Furthermore, beyond the national regulatory framework, standards produced by national, European, or international bodies (such as DIN, BSI, CEN, CENELEC, and ISO) complicate the landscape, as governments have limited influence over these standardization organisations.
- **National frameworks need to be adapted to facilitate an efficient regulatory processes for managing risk of hydrogen fuel operations across the life cycle.** A lack of a coherent national framework can also create inconsistent safety performance requirements across jurisdictions. Some projects, depending on their size, for example, may be handled by different levels of jurisdiction, e.g., national vs. regional vs. local. Without a national framework for management and oversight of hydrogen fuel projects, based on common agreed principles, the different jurisdictions may have vastly different approaches to what might be required of the projects within their purview. Moreover, without rules and guidance, jurisdictions that have never managed high

hazard sites will lack the competence (and confidence) to implement risk management responsibilities, including decisions about land-use, permitting and emergency planning.

- **Coordination across jurisdictions can reduce uncertainty and enhance efficiency in project implementation and support effective risk management.** Depending on the country, the responsibility for hydrogen safety is distributed across a number of regulatory bodies with diverse competences, such as environment, energy, transport, industrial development, and occupational safety, etc. The distribution of responsibilities across competences can result in a lack of clarity in decision-making, leading to confusion and frustration for operators, who may receive a variety of different and sometimes conflicting messages from different authorities involved in funding, approval and oversight of new projects.

2.3 Collaboration, knowledge sharing and preservation challenges

Various interventions also emphasized the need to cooperate and share knowledge and experience between regulatory bodies, technical advisory groups, industry associations, standards organizations, and other stakeholders. Regular exchange can help to find common solutions and establish best practices regarding risks, safety measures, and technological developments associated with hydrogen fuels.

- **Regulatory and standardization organizations should work together with the industry to develop standards and guidance documents that address the specific safety considerations associated with hydrogen fuel operations.** As the hydrogen fuel infrastructure extends its economic and geographic reach, the responsibility of safe hydrogen management will also belong to more stakeholders. Knowledge and experience in hydrogen risk management are already present in some industries (e.g., chemical, petroleum refining, and dangerous goods transport) and in authorities in areas that host industrial activities. -It is essential to foster a culture of collaboration where the hydrogen industry actively engages with these established sectors to learn and adapt. By working together, stakeholders can effectively share their accumulated safety knowledge that has been built over many decades of managing hydrogen risks.
- **A conscious effort will be required to identify new stakeholders and engage them in ongoing exchange of risk management practice and lessons learning with the larger stakeholder community.** There are many new players entering the hydrogen fuel market, e.g., in the design of production and distribution equipment, running production operations, managing transport and distribution lines, and building fuel stations and storage facilities. In addition, many hydrogen installations are designed or owned by third parties, which introduces a potential challenge in terms of operators' comprehensive understanding and ownership of these systems. These actors are not necessarily connected to industries and organisations that have the historic experience handling hydrogen risk. In parallel, there is a need for improving understanding and communication of hydrogen risk and safety challenges outside the process safety community, for example, to national policymakers, the media and local government.
- **Preserving and passing on the existing body of knowledge on hydrogen safety is essential for effectively reducing hydrogen fuel risks in the future.** In particular, there should be collective efforts in both the public and private sectors to share training

materials, exchange on good practice and lessons learned, and foster the sharing of knowledge through open-source databases and online information hubs. Likewise, individual organisations should invest in training staff on hydrogen safety and promoting internal exchange on good safety practices and lessons learned, while also networking outside their organisations on these same issues.

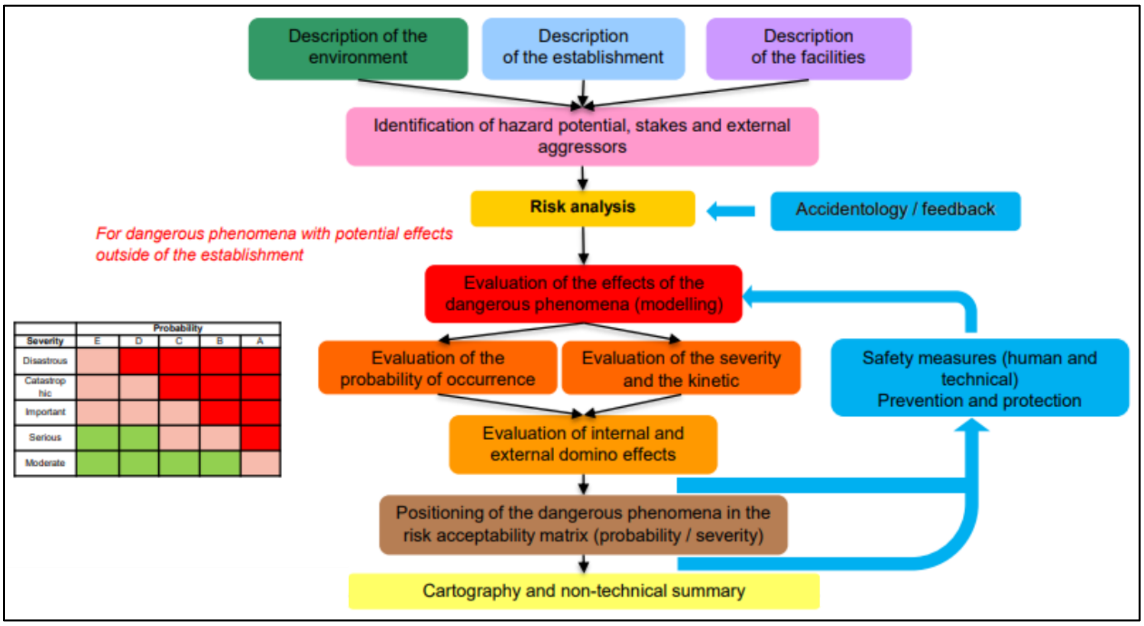
2.4 Infrastructure and urban planning considerations

Participants emphasized land use planning as a critical aspect of chemical accident prevention. The development and expansion of the hydrogen fuel alternative will involve a substantial increase in hazardous activities to support production, distribution and delivery of hydrogen fuel across the EU. Specifically, national strategies for increasing hydrogen fuel use will involve the construction of new infrastructure elements in several countries, including new hydrogen fuel plants, pipelines, distribution plants, fuel stations, and fuel storage sites in new locations. The webinar resulted in identification of a number of challenges that authorities would face in making decisions about whether and where to site new hydrogen-based activities, including:

- **The placement of hydrogen facilities near populated areas as well as the integration of hydrogen technologies into existing infrastructures, requires urban planning** that considers hydrogen's impact on existing risk profiles, and the development of emergency response protocols to minimize impact on public safety. For infrastructure covered by the EU Seveso Directive, the decisions would need to follow the procedures and meet the criteria established at national level for new construction of highly hazardous (Seveso) sites. Making these decisions requires specific expertise in the authorities and also will usually entail detailed discussion with the future operators to produce risk information for making a risk evaluation and incorporate design elements that reduce risk.
- **Land-use planning will require authorities to make risk-based decisions while the science behind the risk is still in development.** Deterministic and probabilistic approaches are used across different regions for evaluating safety distances related to hydrogen installations, in particular, for sites covered by the EU Seveso Directive. The criteria are usually based on substance-specific consequence analysis. For hydrogen, there are knowledge gaps in the science underpinning current consequence models, and research is still needed to understand behaviour of hydrogen in relation to new conditions (e.g., pressure, temperature, equipment) that hydrogen fuel technologies will impose.

- **The interaction between hydrogen systems and existing infrastructure, including electrical systems and cyber security concerns, needs clear guidelines and practices.** As shown in **Figure 4**, the risk evaluation process for authorizing location of a new Seveso site in France takes into account both internal and external influences. This process reflects the EU philosophy of hazardous risk management, embedded in the EU Seveso Directive, which favours a systematic approach to integrating safety considerations into permitting of new development.

Figure 4 The risk management process supporting land-use planning decisions for new Seveso sites in France



Source: B. Debray and B. Weinberger, 2024

2.5 Emergency response challenges

Participants discussed various challenges related to emergency response capabilities challenges of hydrogen facilities. These challenges are linked to issues with safety equipment, inspection programs, material compatibility, incomplete identification of overpressure scenarios and concerns about the fire resistance of materials and components used in hydrogen systems. Some areas of particular concern included:

- **The effectiveness of gas detection systems**, particularly in outdoor settings, and the adequacy of emergency response plans have been questioned. For instance, the colourless flame makes it difficult to detect leaks and fires.

- **The variation in emergency shutdown capabilities** (e.g., hydrogen tube trailers) and the effectiveness of gas detection systems in different settings pose challenges for emergency response teams.

- **The inspection and maintenance of safety valves and pressure relief systems need to be updated to address new specifications and operating conditions.** Also, the identification of overpressure scenarios and precise calculation of safety valve capacities were areas of concern. Detection and alarm systems for enclosed spaces where hydrogen accumulation may occur were often found to be inadequate.

Moreover, as research reveals more information about the behaviour of hydrogen under certain conditions, there may be a need for new emergency response strategies to address specific situations.

2.6 Research and innovation aspects

Attendees pointed at the necessity for further research and standardization efforts to identify and develop strategies to ensure mechanical integrity of different operations. New uses will create new operating conditions and parameters for safe operation will need to be adjusted accordingly. Creation of a scientific basis to inform decisions on design, maintenance, and equipment life cycles, will help ensure the safe and reliable operation of hydrogen service. The following areas of research were mentioned specifically as needing attention:

- The compatibility of materials in hydrogen service is a concern, particularly in relation to the potential embrittlement of metals in pipelines and storage systems when exposed to hydrogen.
- There is a need to focus on the development of detection technologies that can effectively detect hydrogen leaks and other potential hazards that can compromise the safety of hydrogen systems.
- The current safety measures in place do not provide sufficient assurance of the overall integrity and reliability of hydrogen systems. Guidelines and standards for safety protocols, emergency response procedures, and risk management practices, should be developed to ensure their safe handling and use.

2.7 Practical examples

The participants discussed several practical examples to illustrate the challenges and considerations faced in the hydrogen fuel domain. These examples highlight the need for safety and risk assessments, standardized regulations, and collaborative efforts to ensure the safe production, transportation, and use of hydrogen.

2.7.1 Hydrogen and methane mixtures transportation in pipelines

Some countries are exploring the safe transportation of hydrogen and methane mixtures through existing pipelines, particularly with hydrogen concentrations that exceed current allowable limits. For example, in Italy the permitted volume of hydrogen is limited to 2%. The challenges include evaluating material compatibility to prevent embrittlement, the impact of hydrogen concentrations on safety scenarios, safety distances, and updating existing safety standards. Field tests and studies are conducted to assess the feasibility of increasing hydrogen percentages in terms of integrity and safety, with experiments conducted at 5% hydrogen blending, in the natural gas network as well as for residential and industrial heating systems. Extensive tests are being conducted in Germany with volumetric hydrogen concentrations of up to 20%, further exploring the potential for higher blending levels in various applications.

2.7.2 Hydrogen refuelling stations safety

The practical challenges in ensuring safety of the refuelling stations, particularly those involving tube trailers and storage, both for gaseous and liquid hydrogen, were discussed. Participants emphasized the necessity of developing standardized connections to prevent incorrect connections and the importance of identification systems for hydrogen-related equipment, such as trailers and process control systems.

Aspects that need attention include the inconsistency of emergency shut-off mechanisms on trailers and the absence of gas detection systems in some older facilities. In general, the critical role of emergency shutdown systems and gas detection equipment was underscored. It was also noted that standards should address the hydrogen higher flow rates associated with tube trailers (which are filled at 200, 300, and 500 bars) and refuelling dispensers (these can range from 60 to 120 g/s for heavy duty vehicles), as well as consider ventilation requirements.

Some countries have developed a guidebook for the safe production, use, and storage of hydrogen to address the lack of specific hydrogen legislation. This guidebook aims to provide clear requirements and recommendations for operators seeking permission for new hydrogen projects, including refuelling stations. Some countries are also updating their legislation to incorporate specific risk factors relevant for hydrogen fuel stations. One country has also developed a methodology for reviewing risk assessment and associated safety measures of a hydrogen fuel station based on the existing process for reviewing safety reports from EU Seveso (high hazard) sites. (See **Figure 4**.)

2.7.3 Small electrolysers in residential areas

The advancement of electrolyser technology for small-scale hydrogen production, including in residential areas, brings with it a set of safety and technical challenges that need to be addressed. For example, this technology presents new scenarios not fully covered by existing safety regulations. The complexities in applying current legislation to these emerging applications, and the absence of explicit guidelines for such installations, requires a case-by-case approach to safety assessments, ensuring each situation is individually evaluated for potential risks.

2.7.4 Land use planning for hydrogen facilities

The need for simplified and standardized approaches to land use planning for hydrogen facilities was emphasized. As an example, one country (Germany) presented the development of guidance for determining safety distances for installations with gaseous hydrogen. The guidance aims to provide simplified criteria based on standardized parameters for evaluating safety distances in land use planning.

2.7.5 Inspection campaign findings

The findings from an inspection campaign (conducted in Belgium) that focused on nineteen selected sites, encompassing both hydrogen production and usage (storage and unloading) facilities, were presented. The campaign underscored the inconsistency in safety measures across different sites, highlighting the importance of comprehensive risk analysis and emergency preparedness.

The inspections uncovered several issues such as insufficient periodic control over safety valves, along with inadequate inspection programs. Pressure relief valves, particularly those on storage equipment, were found to have deficiencies. For compressors, it was noted that not all interlocks were in place to safeguard against high pressure, high temperature, and excessively low pressure at the inlet of the compression. Furthermore, incomplete identification of overpressure scenarios, and absence of calculations for the capacity of installed safety valves were identified. Also, inconsistencies were noted in emergency planning resources.

The campaign also highlighted the challenge of ensuring that hydrogen installations, often designed or owned by third parties, adhere to safety standards. It also emphasized the difficulties faced by new local authorities who may be dealing with hydrogen sites for the first time. These authorities, tasked with permitting or oversight responsibilities, often lack prior experience with hydrogen sites, which adds complexity to their roles.

3 Conclusions

The second JRC Hydrogen Fuel Risks webinar addressed a range of topics related to managing hydrogen risks, including technical regulations and standards, operational practices, risk assessment methodologies, and practical experiences from ongoing hydrogen projects. It emphasized the need for continued collaboration, research, and standardization efforts, and knowledge sharing among stakeholders to enhance hydrogen safety and integrate it into the green energy transition and development. Overall, the successful development, scaling, and implementation of hydrogen technologies requires a coordinated effort among industry stakeholders, competent authorities, regulatory bodies, and research institutions to develop comprehensive standards, improve infrastructure compatibility, and ensure the safety of operations involving hydrogen fuels.

Several key conclusions were drawn, highlighting the areas where improvements are needed for safe and effective integration of hydrogen technologies into existing frameworks and new applications.

- There is a need to update industry standards to ensure the safe deployment of hydrogen technologies (e.g. trailer connections) and applications (e.g. refuelling stations). The evolving nature of hydrogen use requires timely development of standards to keep pace with the rapid deployment of hydrogen technologies (e.g. electrolysers) and adapt corresponding risk management components of government regulation and oversight. Standards and regulations will need to be continuously reviewed and adjusted as hydrogen applications expand into new sectors and the scale of projects increases.
- Current risk assessment methodologies will also need to be adapted to adequately address the risks associated with hydrogen technologies and installations. Scientific research should support the modification of quantitative and qualitative risk assessment models to predict the behaviour of hydrogen under new conditions imposed by technological developments. Hydrogen safety and safety distances for hydrogen installations should incorporate the modelling advances as necessary into decision-making processes for land use and emergency planning.
- Regulatory bodies, industry stakeholders, and research institutions need to establish effective collaborations and foster the exchange of experience, knowledge, best practices, research findings, and lessons learned in the domain of hydrogen safety. Active engagement with industries possessing extensive expertise in the field of hydrogen should be promoted among operators who are new to hydrogen technologies to augment risk analyses capabilities and reinforce safety measures implementation.
- Education and training programs must be developed and implemented for operators, emergency responders, and inspectors to ensure they acquire the necessary skills and knowledge to identify and mitigate potential hazards. The new uses will require an enhancing understanding of hydrogen's properties and risks in relation to new uses and technologies. Government and industry institutions should also collect and disseminate knowledge on the implementation of safety protocols and measures that will be required to fulfil their respective roles in ensuring that hydrogen risks are properly controlled within hydrogen fuel operations.

- Inspection protocols, checklists and compliance criteria should be updated to ensure safe and efficient operation, such as overpressure protection, inspection programs, material compatibility, and emergency response protocols. Safety valves, the site inspection and maintenance practices will need to incorporate risk factors that are relevant for their operations. Mitigation and emergency response measures should be based on accident scenarios that are tailored to their hydrogen risks and potential consequences.
- Continued research and development efforts are needed to understand the behaviour of hydrogen in various scenarios and to address the evolving nature of hydrogen technologies as to identify innovative solutions for managing risks. This includes reviewing test data and developing testing facilities for long-term exposure tests as well as exploring new materials, detection technologies, and models as well as developing best practices, and safety measures to further enhance the safety and efficiency of hydrogen systems.

Overall, by implementing these improvements, industry stakeholders, competent authorities, regulatory bodies, and research institutions can work together to establish a robust framework for hydrogen safety. This coordinated effort will be instrumental in advancing the successful development, scaling, and implementation of hydrogen technologies.

References

Corbane, C., Eklund, G., Gyenes, Z., Lentini, A., San-Miguel, J., Durrant, T., Boca, R., Maianti, P., Liberta`, G., Oom, D., Branco, A., De Rigo, D., Suarez Moreno, M., Ferrari, D., Roglia, E., Scionti, N., Broglia, M., Hrast Essenfelder, A., Toreti, A., Salamon, P., D`Angelo, C., Dworak, T., Berglund, M., Santini, M., Proietti, C., Tsionis, G., Wood, M., Guagnini, E., Pla Freixa, P., Magrotti, G., De La Rosa Blul, J.C., Guglielmelli, A., Krausmann, E., Menoni, S., Faiella, A., Gazzola, V., Boni, M.P., Ruiz Moreno, A., Colpo, P., Spagnolo, L., Rembold, F., Baruth, B., Van Wijk, L., Koutelos, K., Valsamos, G., Jungwirth, R., Robuchon, M., Dubois, G., Di Girolamo, F., Schvitz, G., Galariotis, I., Linge, J., Kotseva, B., Krzysztofowicz, M., Jensen, K., Muench, S., Roeslin, S., Bountzouklis, C., Sibilia, A., Rodomonti, D. And Salari, S., Cross-border and emerging risks in Europe, Publications Office of the European Union, Luxembourg, 2024, doi:10.2760/55638, JRC137818, https://publications.jrc.ec.europa.eu/repository/handle/JRC137818

Debray, B. and B. Weinberger, 2024, Origins of the current regulation on HRS in France, challenges regarding its evolution, Prepared for the EU+OECD Hydrogen Fuel Risks Webinar, Organised by the European Commission Joint Research Centre, 14 February 2024, https://minerva.jrc.ec.europa.eu/en/shorturl/minerva/debrayorigin_of_french_regulation_on_hrspdf

Marrazzo, R, 2024, Hydrogen as an energy carrier: transport in methane mixtures, Prepared for the EU+OECD Hydrogen Fuel Risks Webinar, Organised by the European Commission Joint Research Centre, 14 February 2024, https://minerva.jrc.ec.europa.eu/en/shorturl/minerva/marrazzohydrogen_energy_carrier-italyr_marrazzopdf

Reiners, B., 2024, Hydrogen projects in Flanders: Situation and risk assessment at the moment, Prepared for the EU+OECD Hydrogen Fuel Risks Webinar, Organised by the European Commission Joint Research Centre, 14 February 2024, https://minerva.jrc.ec.europa.eu/en/shorturl/minerva/reinerspresentation_flanders-bruno_reinersreducedpdf

Van Wijk, L., Wood, M., and Moretto, P., The hydrogen fuel alternative:, Perspectives on risk management challenges and solutions, European Commission, Ispra, 2024, JRC138242., https://minerva.jrc.ec.europa.eu/en/shorturl/minerva/h2_webinar1_finalsummary_reportpubsyv2pdf

List of boxes

List of figures

Getting in touch with the EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

Finding information about the EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

EU open data

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of da-