European Commission

The hydrogen fuel alternative: Perspectives on risk management challenges and solutions

Summary of an expert webinar exchange, 15 September 2023

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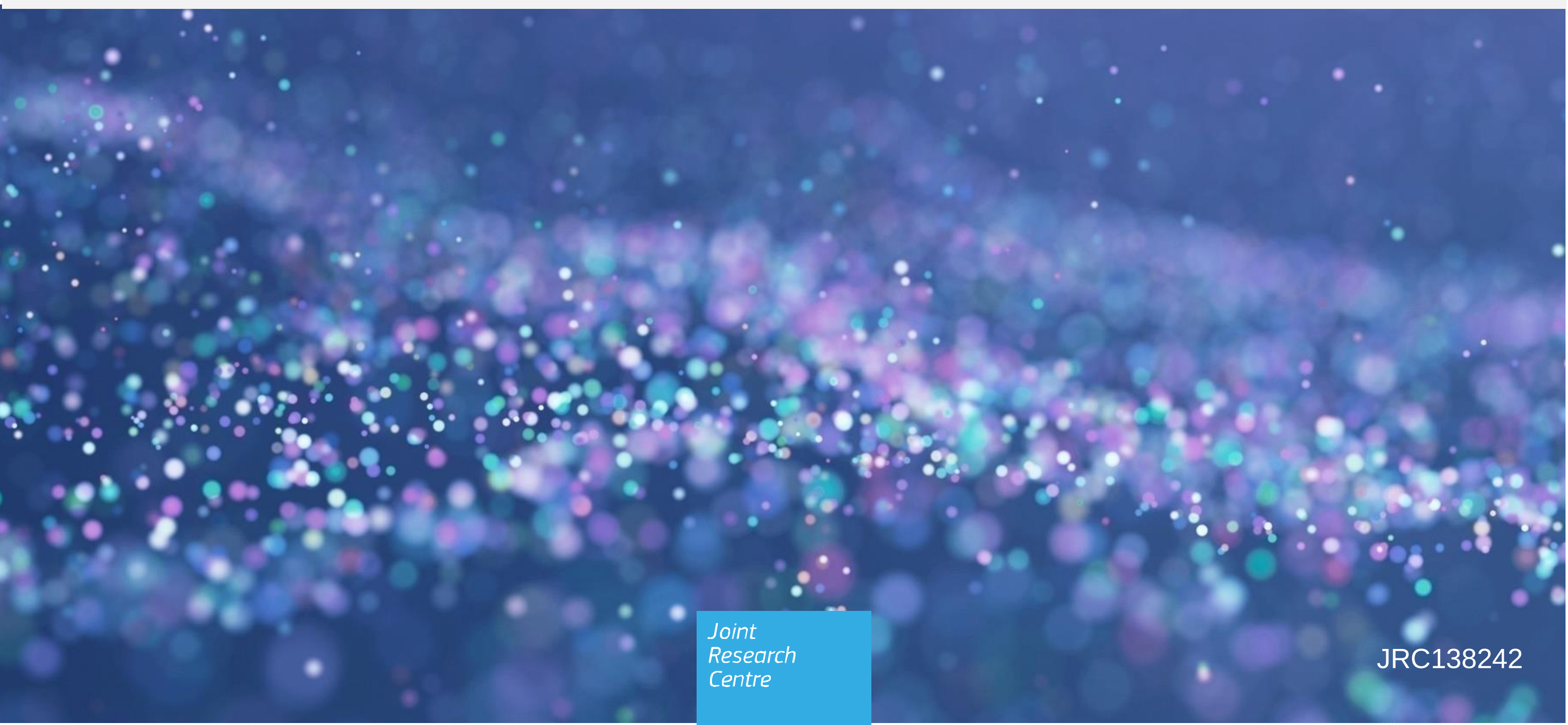

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Abstract

Many countries around the world have adopted strategies to decrease their carbon footprint, which includes diversifying energy sources to low carbon or carbon-free alternatives. As such, the use of hydrogen to deliver energy solutions has become an important element of many national strategies. 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 the context of the Seveso Directive, and as part of its collaboration with partners in chemical accident risk management in OECD, the JRC's Major Accident Hazards Bureau (MAHB) started looking at potential implications of this energy transition in an industrial risk as well as a safety and health hazards context. In the past few years, many experts and authorities also have been posing questions to the JRC and in various networks about how current knowledge about hydrogen risks could evolve into practical approaches for managing the new types of hydrogen risks that may emerge with implementation of their national strategies.

In this context, the JRC proposed a series of webinars on different aspects of hydrogen fuel risk management. This first webinar was intended to exchange of knowledge and experience between EU and OECD experts and authorities who were engaged, or would be engaged in future, in assessing risks associated with new or expanded operations promoting use of hydrogen-based fuels. The purpose of the webinar was to identify the range of technologies and infrastructure that were foreseen across the various EU and OECD countries and to discuss common challenges and potential solutions with experts in hydrogen risk

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.

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1 Background

In the foreseeable future, hydrogen is expected to play a prominent role in various sectors of the economy and within society. This will lead to an increase in hydrogen fuel production and utilization, as well as the scaling up of distribution, storage, and transport infrastructure, coupled with the emergence of novel hydrogen applications. One of the key challenges, given the risks involved, lies in ensuring secure solutions for all these systems and processes across technical and regulatory aspects. Furthermore, the Green Deal incentivizes the entry of new and less-experienced players into the market, which adds an additional element of risk.

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. All the same, hydrogen is considered a dangerous substance. Although it is not toxic to humans or the environment, its physical properties make it highly flammable and also complicate efforts to manage it safely. Fire and explosive risk are considered chemical accident risks when they are caused by a raw material, such as hydrogen. Thus, hydrogen use and supporting infrastructure pose a chemical accident risk.

Several countries worldwide have already received proposals and initiated projects related to hydrogen fuel. As the European Union and other countries actively pursue strategies to transition away from carbon-based fuels, the JRC's Major Accident Hazards Bureau (MAHB) has initiated a study of the potential implications of the hydrogen transition on industrial risk. Specifically, MAHB aims to understand how this transition impacts the oversight and monitoring of chemical accident risks within the framework of the Seveso Directive (2012/18/EU) by the EU chemical competent authorities.

The handling of hydrogen is primarily the domain of a limited number of experienced companies, such as petroleum refineries and air products companies. Still, current experiences may not comprehensively represent the risks associated with large-scale hydrogen generation, transportation, distribution, and utilization. These processes involve multiple interactions, creating opportunities for containment failure and loss. Many plans for hydrogen generation, transportation, and distribution may still be considered "futuristic" due to unresolved challenges.

Hence, a major concern for the future lies in the combination of untested hydrogen applications, widespread adoption of these applications, increased production and storage capacities, and the entry of numerous first-time operators responsible for managing hydrogen facilities. Effectively addressing and mitigating these risks is of paramount importance to minimize potential negative impacts on sectors of the economy, the environment, industry, and society as a whole.

Chemical disasters can have impacts on workers, communities and the environment and as such, the management of these risks is a multi-disciplinary policy area. For this reason, the potential risk of new or expanded hydrogen fuel-related activities may have relevance for a number of competent authorities, including environmental protection, permitting and land-use planning, safety, public health, emergency response, civil protection, and industrial policy. Likewise, the science of chemical process safety is an integration of many scientific disciplines. Therefore, solutions that mitigate hydrogen fuel risks in future will depend on contributions from a number of scientific areas, including chemical engineering, mechanical engineering, and thermodynamics, as well as social sciences, in particular, those associated with human behaviour, risk decision-making, and sustainability..

At present, there is a pressing need to share existing knowledge about safety concerns associated with the growing hydrogen usage among countries and relevant authorities responsible for overseeing and permitting these facilities.

1.1 The ad hoc EU+OECD Hydrogen Fuel Risks Exchange Initiative

EU and OECD countries have been actively promoting the increased use of hydrogen fuel as part of the overall strategy to move their economies away from carbon-based fuels as a way to combat climate change. As such policies have gained momentum, experts in chemical accident risk management, particularly in government and academia, have begun discussing the limitations associated with some uses because of safety concerns. In the international community, the OECD has largely positioned its Working Party on Chemical Accidents (WPCA) as a forum for these discussions, especially in the wake of an intervention by the JRC highlighting hydrogen risk considerations in a WPCA meeting in 2020.

Indeed, over the last several years, more and more countries have added a hydrogen component to their future energy strategy, fostering the emergence of a wide range of proposals for producing and storing green hydrogen and delivering hydrogen fuel. The pace and nature of these proposals have reportedly posed administrative and technical challenges in some countries. For example, several EU Member States have indicated to the JRC, bilaterally and within the EU's Technical Working Group for Seveso Inspections, a lot of proposals for new hydrogen-based activities were in development, many involving new technologies or new uses, sometimes in close proximity to population centres or in industrial parks. Inspectors, in particular, were being asked to input on permitting and siting decisions. In large part, the inspectorates were not confident that existing risk controls and analytical tools supported the decision-making needs in these cases, and thus struggled with giving advice on whether and where to allow such operations.

In October 2022, the OECD hosted a special session covering energy transition risks within the annual meeting of the WPCA in which several OECD countries highlighted similar challenges. Following that meeting, and after more discussions with EU Member States, the JRC determined that it was becoming urgent to understand and organise the questions about the safety and feasibility of new hydrogen activities. Once defined and mapped, it might eventually be possible to find, or begin working on, the answers.

For this purpose, the JRC conceived of a series of EU level exchanges, or webinars to allow EU Member States to exchange experiences with each other and with hydrogen experts, as a starting point for understanding the scope and nature of the problem. In May 2023 the JRC asked a subset of EU inspectors and experts to form a technical advisory group (TAG), on an ad hoc (i.e., as long as needed) basis, to help the JRC planning this initiative. In addition, the JRC asked the OECD to partner with it on the initiative, given that it had already taken a proactive stance on the topic, and that other OECD countries were having similar experiences. It was also timely, in that a proposal was already being circulated within the OECD WPCA to incorporate safety issues associated with the energy transition in a new project slated to begin in 2025. The so-named ad hoc EU + OECD series of hydrogen fuel risk webinars could help in defining the scope and give some input on potential priorities for that project.

1.2 Description of the event

Together with the TAG, the JRC held a half-day webinar on 15 September 2023 to initiate discussion between EU and OECD inspectorates and experts on the potential risk implications associated with the expanded use of hydrogen-based fuels. A main objective of this first exchange was to define the scope of hydrogen risk challenges and to identify additional knowledge, tools and structures that might be needed to address them. Given the exploratory nature of the topic, it was decided that the webinar would be by invitation only, with a limited number of inspectors from each EU and OECD country participating along with hydrogen specialists within government institutes, or closely affiliated universities or industry associations.[1] It was expected that insights from this diverse group would help in framing a general picture of the landscape of new hydrogen fuel activities (proposed or already in development) and the risk management challenges that they presented. This report summarises the outcomes of those exchanges.

Over 60 participants from 24 EU and OECD countries took part in the webinar, mainly representing inspectorates associated with environment, labour, or civil protection authorities, with competence in oversight and monitoring of hazardous sites. In addition, participation included a number of scientific organisations providing scientific support to managing future hydrogen fuel risks, several of whom gave presentations in the latter half of the agenda.

The webinar agenda and presentations are publicly available and can be found at the following link: Hydrogen Fuel Risks Webinar 1. The webinar agenda was divided in two parts. The first part consisted of presentations from eight EU and OECD countries (Czech Republic, Finland, Germany, Ireland, Italy, Japan, and the Netherlands) on the range of projects associated with hydrogen fuel-related projects currently foreseen or already in development. A follow-up webinar was also held on 14 February 2024 for a general audience of EU and OECD authorities that included presentations elaborating on technical tools and case studies relevant to the topics in this report. The presentations from this webinar will not be summarised in a report. However, they can be found at this link: Hydrogen Fuel Risks Webinar 2. A third webinar on this topic is planned for autumn 2024 and is expected to focus on industry challenges and initiatives.

2 Summary of key findings

The agenda of the webinar was divided into two topics and a prolonged period was allowed for discussion at the end. In the first part, several countries described the status of new hydrogen activities in their country (proposed or underway), the questions that these projects raised relative to safety and sustainability (from a risk management, and sometimes practical, perspective), and if and how the inspectors had dealt with these issues. The second part of the webinar consisted of presentations from various hydrogen experts on how standards, research, and modelling tools could provide some answers to the questions. The end of the webinar featured an exchange between inspectors and experts on areas where more research and collaboration might be needed.

The webinar largely fulfilled its expectations to define the range of hydrogen fuel projects envisioned across the various countries. It also brought into focus a number of questions and practical needs related to risk management that would have to be addressed as proposals move from the conceptual stage to development and implementation. These findings are summarised in this section.

2.1 Hydrogen hazards and safety

The wide flammability range, ranging from 4% to 75%, and explosive characteristics of hydrogen-air mixtures present significant safety concerns throughout its production, storage, and transportation

[1] The distribution of representatives across various organisations was as follows: 42 from government institutions, 9 from international organisations, 7 from research institutions and universities, and 3 from industry.

processes. Due to its small size, hydrogen can easily permeate, corrode and embrittle containment materials, leading to potential structural failures, leakages and possible accumulation of hydrogen in confined spaces.

To minimize and mitigate the risks of fires, explosions and hydrogen leakage, hydrogen compatible materials and appropriate safety measures, such as leak detection systems, ventilation, and explosion-proof equipment, need to be in place. Risk control measures also include following safety protocols and training of personnel involved in the hydrogen industry.

Furthermore, the storage and transportation of hydrogen entails high-pressure or cryogenic conditions that can introduce additional safety challenges. Therefore, it is crucial to ensure the proper design and maintenance of such systems to prevent leaks or ruptures. Cryogenic storage, in particular, requires specialized insulation material and techniques to maintain the required conditions.

2.1.1 Hydrogen consequence modelling

The field of hydrogen modelling faces challenges due to the special properties of hydrogen, and a lack of data on hydrogen behaviour under different conditions. Its unique dispersion and reactivity characteristics create particular modelling uncertainty under all circumstances. Moreover, there is a lack of data regarding the specific behaviour of cryogenic hydrogen in high-pressure systems (e.g., > 700 bar) and liquid hydrogen. More research and data collection are necessary to support development of consequence models that, in turn, could facilitate the assessment of emerging risks associated with new hydrogen scenarios and the implementation of effective safety measure. In some cases, modelling solutions exist to a certain extent, but they involve complex algorithms, processing capacity, and expertise to run them properly. To capture this knowledge for practical use, Seveso inspectors and regulatory authorities need simplified models, decision criteria, or other practical tools, for assessing the risks associated with new uses of hydrogen.

2.1.2 Hydrogen risk assessment and safety

The classification of hydrogen installations under the EU's Seveso Directive, and similar regulatory frameworks in OECD countries, and the emergence of new accident scenarios creates a requirement for new risk management strategies and scenario planning for hydrogen-related activities. This work would entail envisioning potential initiating events, the range of circumstances in which they occur, and possible domino effects. On this basis, appropriate safety measures could be developed based on these scenarios and additional tools could be developed to support government decisions on siting or extending hydrogen-related activities and permit approval.

Moreover, the webinar exchange highlighted that addressing the risks associated with different types of equipment is essential to the success and sustainability of new hydrogen fuel infrastructures. The risk potential of many new technologies needed to support these projects, such as high-pressure and cryogenic systems, as well as electrolysis and fuel cell technologies, is still not well understood. Similarly, the increase and elevated risk associated with hydrogen use at existing hazardous installations, including power plants and hydrogen fuel stations, as well as increased risks associated with transfer operations, needs to be evaluated.

Transportation modes for liquid hydrogen, such as sea transport and pipeline networks, are also of concern, as exemplified by a case, noted in the webinar free discussion, of a pipeline intended to transport ammonia from Rotterdam to Flanders.[2] The associated regulatory frameworks (e.g., the Seveso Directive[3]) may need to be reviewed to account for the increasing number of small-scale hydrogen production and fuelling stations.

For all these situations, there is a need for a better understanding of the various accident scenarios that could arise. At the same time, the location of new hydrogen-related activities, such as liquid hydrogen production, storage and transportation, especially if they are in port areas or close to other industries or populated areas, should be considered with a view to what potential domino effects could be unleashed.

2.1.3 Experience, competence and knowledge gaps

Experience, competence, and knowledge gaps exist among various stakeholders who are or will be in charge of operation and oversight of hydrogen-related activities. The expansion of hydrogen fuel production and use brings in a host of new actors in industry and government that, until now, have almost no experience in working with hydrogen risks and, as a result, lack a comprehensive understanding of risks associated with production, storage, handling and infrastructures surrounding these uses. Notably, these new actors entering the hydrogen sectors may not have any prior experience with processing, engineering, or the process industry. The absence of competency and experience may significantly reduce their ability to manage safety effectively in association with hydrogen-related activities. Of particular concern is the real possibility that local authorities, fire departments and emergency responders may not possess the competence and expertise required to handle hydrogen-related facilities and manage the risks associated with these installations. This lack of knowledge may impede their ability to plan for emergencies and respond appropriately in case of an emergency.

In tandem with the changing hydrogen landscape, resources will be required to educate new actors on hydrogen-related risks, and how to manage those risks, as well as on compliance with safety regulations. Also, as knowledge is obtained on new hydrogen-based uses and technologies, experts and authorities should work together on enhancing the fundamental risk control framework and decision processes, so that they are apt to meet the new challenges that new and expanded uses of hydrogen may bring. An evaluation and revamping of such control measures as land use planning, regulatory structures, and safety standards, may be necessary. As these controls are developed, there will be a need to invest in training programmes to build competence in applying them within authorities and the related industries.

Moreover, control of hydrogen risks, like any other type of chemical accident risk, requires building a strong reference knowledge base that is regularly reinforced and improved by research and experience. For this purpose, government and industry should establish programmes to support regular analysis and exchange of incidents, experiences and good practice, to maintain active attention on dangers associated with hydrogen use and to improve and support effective implementation of risk control measures.

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[2] This initiative was discussed but not presented during the webinar. More information on the project can be found at the website of the Port of Rotterdam. In addition, it has been well publicized in news source, for example, SPGlobal.

[3] Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances

2.2 Hydrogen infrastructure challenge

Integrating hydrogen production, storage, and transportation processes and systems into existing infrastructure is a critical step in the transition to a hydrogen fuel economy. In particular, this transition comes with significant technical and safety challenges in regard to the safe handling of hydrogen, prevention of hydrogen leaks, and effective management of the highly flammable nature of hydrogen. Scaling up, adapting or repurposing existing infrastructure, such as natural gas pipelines, is deemed necessary to support large-scale hydrogen consumption. However, the practicability and feasibility of re-purposing of infrastructure originally intended for containment of vastly different substances needs to be faced realistically. If, in some circumstances, it is a reasonable option, the transition needs to be well assessed in terms of management of change. Moreover, it requires careful planning and sufficient investment to ensure that hydrogen is handled safely and sustainably across the life cycle. Therefore, the scaling up or repurposing of existing infrastructure, such as natural gas pipelines, demands meticulous planning and strong financial commitment.

Notably, there are significant challenges associated with development of delivery infrastructure for residential and business areas. Implementing safety protocols, land-use planning criteria, and a proper legislative framework to enforce them, will be required to mitigate risks and ensure the safe integration of hydrogen into existing infrastructure without exposing surrounding communities to new risks.

- ***Production systems.*** Hydrogen production involves various methods, including electrolysis, steam methane reforming, and coal gasification, that each has its own risks for potential leaks, explosions, and other failures. While steam methane reforming and coal gasification are well-known, electrolysis is less familiar. Moreover, electrolysis eventually is supposed to use renewable energy sources to produce hydrogen. There is currently not enough renewable energy available to produce hydrogen in this way on a large scale. As such, the electrolysis is either powered by carbon-based sources ("brown hydrogen") or uses scarce renewable resources that make it a high-cost option due to the significant amount of electricity required. As such, it is still a question as to whether producing "green hydrogen" through electrolysis and successively burning it to generate electricity will be economically viable. As technology improves, more efficient and cost-effective electrolysers may reduce the hydrogen production costs, but this realisation is still well in the future.
- ***Storage systems***. Liquefied hydrogen is stored at high pressures (up to 900 bar) and/or extremely low temperatures (-253°C) to maintain its liquid state. These storage conditions present challenges and risks related to leaks or spills, ruptures in storage tanks or pipelines, which can lead to the formation of flammable or explosive mixtures with air. In addition, the cryogenic temperatures required for storage can pose challenges in terms of equipment integrity and insulation. Hence, proper design, construction, and maintenance of storage facilities are essential to minimize the risk of accidents and ensure the safe storage of liquefied hydrogen.
- ***Transportation systems.*** Transporting and distributing liquefied hydrogen requires infrastructure and equipment that can maintain the low temperatures and high pressures necessary for its transport. As the world's lightest molecule, hydrogen in its natural form will take up a lot of space. Hence, economical transport and distribution of hydrogen necessitates a dramatic compression of hydrogen gas using higher pressures and lower temperatures than for other gases currently transported by rail, road and pipeline. Usually, hydrogen is transported in specially designed cryogenic tanks or trailers. Hydrogen requires specialized

equipment for loading and unloading to accommodate its particular temperature and pressure conditions. Risks associated with hydrogen loading, unloading, and transportation include potential leaks or spills, as well as the formation of flammable or explosive mixtures. To ensure the safe delivery of liquefied hydrogen, proper safety measures and protocols must be in place to design, operate, and maintain transportation systems that minimize the risk of accidents.

Research and tests are also being conducted to facilitate transport of hydrogen through pipelines blending concentrations of 5%-10% hydrogen with natural gas. Both hydrogen and methane are inflammable gases that are a high risk of fire and explosion. Current research is not yet conclusive in terms of the leak and explosive potential of hydrogen blended with natural gas. Moreover, different countries and industries are experimenting with different % blends. At the moment no technical standards for distribution of blended hydrogen gas have been defined, including limits associated with acceptable risk.

2.3 Regulatory and safety standard challenges

The fast pace of hydrogen-related facilities and associated infrastructure development has outpaced the regulatory framework. This discrepancy poses challenges for policymakers and inspectors in order to keep up with these advancements and ensure that safety regulations are up to date for the design, operation, and maintenance of hydrogen-related applications to ensure their safe deployment.

The classification of hydrogen-related facilities and the obtaining of permits have emerged as significant concerns. For instance, in Flanders, the process of acquiring permits for sites with liquid hydrogen storage has raised concern that a hydrogen fuel station will enter the Seveso Directive regime. If the capacity of the fuel station equals or exceeds the 5 tonne threshold qualifying quantity, assigned in Annex I of the Seveso Directive, it will lead to an increase in high hazard sites, potentially in locations where there has never been a Seveso site. A new location can present additional challenges related to establishing public awareness and acceptance of high hazard sites in the area, as well as the need to build competence in oversight and enforcement of Seveso high hazards sites within the local authority.

Moreover, the classification in the EU of hydrogen fuel stations under the Seveso Directive, that may handle other fuels like LPG, gasoline, or diesel, has gained attention since they could also become lower-tier Seveso sites. Even if a fuel station carries less than 5 tonnes of hydrogen, together with hydrogen, the total quantity of flammable gases (e.g., hydrogen, liquefied petroleum gas and liquefied natural gas) may exceed the Seveso threshold quantities for that category. This situation raises the question as to whether the inclusion of such sites is aligned with the intentions of Seveso policy decision makers.[4] This classification additionally poses new challenges for inspectors and policymakers, as they must ensure that safety regulations are in place for these multi-fuel stations.

[4] In Seveso, the thresholds for carbon-based fuels are purposely set to be high enough to exclude fuel stations offering petroleum-based products from Seveso coverage for pragmatic reasons, i.e., the high number of sites that would be covered and the regulations which already applied to fuel filling stations. This decision reflected a judgment that the Seveso Directive was not a pragmatic solution for risk management of the thousands of fuel stations in the EU. (Reference: Smeder, M., 1998, Substances covered by Part 1, Annex I, of the Seveso II Directive, Major Accident Hazards Bureau, European Commission Joint Research Centre

The complexity of managing the risks associated with hydrogen, especially in residential areas and in homes, represents another challenge faced by hazardous site inspectors.

Consequently, there is a need for regulatory bodies to collaborate and establish common standards and guidelines across EU and OECD countries to ensure a consistent and comprehensive approach towards the development of appropriate permits, safety standards, and regulatory frameworks for hydrogen-related facilities. Efforts are underway at international and European level to develop harmonised standards for hydrogen systems, including electrolysers, connection devices, fuelling stations, and vehicle components. Existing hydrogen standards have been issued by organisations like ISO and CEN.

2.4 The role of communication and dialogue in addressing challenges

Open and transparent dialogue among technical experts, policymakers, and politicians are critical for ensuring informed decision-making on investment in new hydrogen technologies and uses. Frank discussion of safety concerns and practical feasibility should be encouraged so that dangerous and unsustainable aspects are foreseen and properly addressed prior to implementation. Local communities are also stakeholders that should be informed and assured about the safe and effective use of hydrogen in their localities.

In these exchanges, some important points should be taken into account:

- ***Political and policy considerations:*** Discussions surrounding hydrogen fuel often have a political dimension that goes beyond carbon reduction goals. Energy choices also can significantly impact energy security, environmental health, trade relations, consumer energy costs, and potential job opportunities and economic growth. Analysis and open discussion of how alternative scenarios involving hydrogen fuel use can help to drive towards successful integration of hydrogen fuel-based systems into the socio-economic fabric. A well-reflected view of the intricate relationship between energy and the global landscape will help in developing effective strategies for expanding the use of hydrogen fuels without causing serious disruptions to daily life and the economic well-being of citizens
- ***Industry engagement.*** Policymakers need to engage industry stakeholders in discussions about limitations and advantages of different technologies as policy decisions are being formed. A particular effort to reach out and gather various industry actors for such dialogue may need to be part of this effort, given that many of the new actors are not affiliated with the traditional hydrogen-using industries. These new actors should be encouraged to organize in professional associations to facilitate intra-industry collaboration for risk management research and exchange of good practice, as well as to provide an open channel for dialogue with government authorities
- ***Public involvement.*** Involving the public in decisions about hydrogen fuels in their local area not only provides an opportunity to address concerns regarding safety and feasibility but also allows for a constructive dialogue on the viability and acceptance of various options. In particular, early engagement with the public can generate feedback on the willingness of the public to accommodate certain changes and lead to development of incentives that might ease the transition. This involvement can be achieved through educational campaigns and targeted outreach programs that facilitate discussion on benefits and limitations of the hydrogen-related activities under consideration, the associated safety challenges, and the control measures in place to manage them.

3 Conclusions

EU and OECD countries are actively promoting the transition to hydrogen fuel as part of their efforts to promote renewable energy sources and achieve a more sustainable energy system. Hydrogen is seen as a potential key component of the energy transition strategy due to its ability to be produced from renewable sources and used as an alternative energy carrier to fossil fuels.

Nonetheless, the transition to hydrogen introduces new risks and safety challenges, particularly in terms of technological uncertainties, hydrogen production, storage, transportation, and infrastructure development. Proper safety measures, such as leak detection systems and explosion-proof equipment, need to be in place to address the hazards and safety concerns associated with hydrogen. Integrating hydrogen production, storage, and transportation into existing infrastructure poses technical and safety challenges. Scaling up or repurposing existing infrastructure, such as natural gas pipelines, requires careful planning and investment.

The fast pace of hydrogen-related development has outpaced the regulatory framework. Collaboration is needed to establish common standards and guidelines for safety regulations and permits.

To address the risks and ensure the safe and sustainable use of hydrogen, a supportive regulatory framework, investment in research and development, and collaboration with industry stakeholders are necessary. Tools, guidance documents, and risk assessment strategies need to be developed to help inspectors, policymakers, and industry stakeholders make informed decisions.

Stakeholders involved in hydrogen-related activities may lack comprehensive understanding and experience. Training, knowledge sharing, and industry engagement are crucial for safe handling and compliance with safety regulations.

Open and transparent communication among technical experts, policymakers, and industry stakeholders is crucial to address safety concerns, assess feasibility, and make informed decisions about the implementation of hydrogen technologies. Ongoing communication and discussions among stakeholders are necessary to address potential risks and ensure the safe and effective use of hydrogen.

Engaging in effective dialogue with policymakers is essential, as discussions surrounding hydrogen often have a political dimension, such as energy security, environmental benefits, international collaboration, job opportunities, and economic growth. Strategies need to be developed to overcome barriers that may hinder the widespread adoption of hydrogen.

It is vital that the general public is informed, in an open and transparent manner by industry and regulators, of the hazards associated with hydrogen together with the risks. Increasing public awareness and understanding can promote the safe utilization of hydrogen as an energy resource through educational campaigns, targeted outreach programs, and clear communication of safety measures.

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