Institute for Sustainable Process Technology

Green Hydrogen Inherent Safety Practices on large industrial scale

H2 Safety

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TKI19-Safety

DNV, Shell, YARA, TNO, NOBIAN, Ørsted, Royal HaskoningDHV, Institute for Sustainable Process Technology

Format final report

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Researchers (name & title thesis)	
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KPI	Omschrijving
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6. Projectsucces	Keuze uit : 1. Het project is afgerond conform de oorspronkelijk scope. Alle mijlpalen zijn behaald;
7. Vervolg	Safety standardisation of green hydrogen electrolyzers, H2Safety2 project
8. Aantal gerealiseerde peer-reviewed publicaties	1 Download: Safety Aspects of Green Hydrogen Production (ispt.eu)
9. Aantal verwachte peer-reviewed publicaties	0
10. Aantal gerealiseerde niet-peer-reviewed publicaties	0
11. Aantal aangevraagde patenten	0

KPI	Omschrijving
12. Aantal verleende licenties **13. Aantal prototypes** **14. Aantal demonstrators** **15. Aantal spin-offs/ spin-outs**	0 0 0 0
16. Aantal nieuwe of verbeterde producten/ processen/ diensten geïntroduceerd **17. Impact**	1 Het project draagt bij aan de Integrale kennis en innovatieagenda, MMIP8 en het realiseren van economische kansen door het veiliger maken van groen waterstofproductie.

PUBLIC Summary

The public and executive summary can found through this link Report: (ispt.eu). The text is given below.

The need to ensure process safety of large-scale green hydrogen production

Green hydrogen production is expected to scale up at an unparalleled pace in the coming years. In the Netherlands, 500 MW of large-scale green hydrogen plants are scheduled for completion in 2025, producing nearly 0.5 million tonnes of hydrogen per year. The REPowerEU Plan reveals that the EU aims to produce 10 million tonnes of domestic renewable hydrogen, in addition to 10 million tonnes of imported renewable hydrogen, by 2030.

This ambitious production ramp-up poses an important challenge to the industry. Large-scale industrial water electrolysis plants typically use hydrogen and oxygen inside the same equipment, separated by a membrane/diaphragm. Safeguarding process safety in the design, implementation and operation phases is a complex task. While experience with operations and maintenance is available for small plants, it is lacking for large-scale production.
The lack of historical data and validated models of failure frequencies and consequences means that electrolyser systems suppliers, asset owners and authorities have only limited data and knowledge on specific fire and explosion hazard scenarios. Due to the lack of a common understanding and standardised risk and design approach, different stakeholders may make different choices. This may then lead to delays in design and authorisation processes. It could potentially also lead to underestimation of the risks involved. The exchange of information on technical safety practices between all stakeholders will therefore be a cornerstone for enabling the hydrogen economy.
This public report aims to stimulate awareness about required safety levels regarding large-scale green hydrogen production. A special focus is placed on fire and explosion risks associated with the combination of oxygen and hydrogen in equipment and buildings. This project is a first step towards achieving a uniform and consistent risk assessment methodology for large-scale green hydrogen plants. In this way, we want to help the industry and stakeholders understand explosion risks and enable them to create safe designs for large-scale water electrolysis systems.
The report summarises the results of a year-long project involving extensive cooperation with safety experts from HyCC, Ørsted, Shell, Yara, DNV, Royal HaskoningDHV and TNO. This process was managed by the Institute for Sustainable Process Technology (ISPT). Interviews were held with electrolyser suppliers so that their input and feedback could be included in the project results.

Two top events that lead to explosions

Two typical scenarios were identified for events that might lead to an explosion or fire:
o in-equipment mixing of hydrogen and oxygen (in an electrolyser stack, pipe or separator);
o mixing of hydrogen and oxygen (from the air) as a result of loss of containment inside an electrolyser building.
Potential causes, consequences, safeguards and opportunities for inherently safe design were identified for both scenarios.

Main conclusion

The process/chemical industry has well-established tools to assess the safety of processes involving hydrogen, including GW-scale electrolyser plants. However, there is a lack of historical and validated data on failure frequencies, probability of failure on demand and probability of ignition at GW scale. In addition, data and corresponding models on deflagration and detonation are not as well developed for hydrogen as they are for hydrocarbon systems. This will require a conservative approach in assumptions and models for the design and operation of upcoming large-scale deployments.

Safety aspect of large-scale water electrolysis plants

Several points illustrate the importance of addressing safety aspects specific to large-scale green hydrogen production:

o Hydrogen's properties are different to those of hydrocarbons, resulting in different characteristics such as higher probability of ignition and potentially more severe consequences of explosions.
o The introduction of hydrogen as an energy carrier will lead to hydrogen being handled in a different production process and by a much wider range of stakeholders. Moreover, these stakeholders could be less familiar with process safety than the present actors in the chemical, oil and gas industries.
o In an electrolyser system, both oxygen and hydrogen are present inside the installation.

As a consequence, an explosive mixture could potentially occur inside the equipment or inside the building due to deviations in operating conditions, membrane/diaphragm failure, design flaws, human error or other causes.
o Large-scale hydrogen facilities differ considerably from small plants because of their combinations of modular constructions. This introduces a necessity to understand the impact of potential interaction between modules as well as failure rates for many successive components. These failures and domino effects play an important role in understanding and controlling plant safety.
o Green hydrogen production will largely follow the availability of renewable electricity. This will lead to frequent starts and stops, stand-by and load changes, which can potentially affect safety-related aspects.
o Technology is still under development, meaning that new technologies and materials, such as thinner membranes, push the performance limits. This has an impact on gas crossover and potential membrane/diaphragm assembly failures.
o Analysis of major historical accidents helps to identify hazards and their causes. The investigation revealed the need to devote sufficient attention to operation and maintenance.

Risk assessment approach

The risk management strategy is to avoid explosion scenarios and to apply risk control measures to achieve a tolerable level of risk. Risk matrices are often used for this purpose. Because there is no nationally or internationally agreed risk matrix, many companies have developed their own. This is illustrated in the risk matrix of Figure S.2. An unacceptable risk is indicated by the colour red while green indicates a risk that is generally accepted. Risks in the area between red and green are only accepted when sufficient risk reduction measures have been taken in accordance with company criteria.
We emphasise the need for scenario-based thinking in combination with the common process safety methods and tools used in the process industry (HAZID-HAZOP-SIL-LOPA). We call for an inherently safer design approach that eliminates possible causes of incidents, as well as the installation of effective safeguards where inherent safety is not possible.

The chain from cause to consequence with Independent Protection Layers (IPL) is shown in Figure S.3. The frequency of the final consequence is reduced by every IPL, which is indicated by a reduction in the thickness of the arrows after each IPL.

Frequency rates and probability of ignition

There is a clear lack of data on failure modes and probabilities for the safety assessment of electrolysis systems. For example, failure frequencies are not available for unit operations such as the current and new generations of electrolyser stacks. Understanding of failure mechanisms of hydrogen-specific equipment is lacking, especially with respect to electrolyser membrane/diaphragm failures. A loss of containment or a degradation of the internal separation between the gases could cause hydrogen to mix with oxygen or air. In that case, another set of probabilities comes into play, namely the probability of ignition. Compared to hydrocarbons, the minimum ignition energy required for hydrogen-air mixtures is low, and even lower for hydrogen-oxygen mixtures. The related probability assessment is complex and more experimental, and data and clear guidelines on this topic would be advantageous. Therefore, ignition probability, either immediate or delayed, is often simply equated to 1. No clear guidelines have been found on how to handle these probabilities. It must be noted that such risk assessment for hydrocarbons is equally difficult.

Effect models

Effect calculation models are often used in risk analysis to calculate the impact of events. This includes the shockwaves resulting from the dispersion and ignition of gradients of explosive hydrogen and oxygen mixtures. There is a clear difference in properties between hydrocarbons and hydrogen. More empirical models, which have been validated mainly for hydrocarbons, have been updated with hydrogen-specific data sets, but these models are only applicable to outdoor scenarios for far-field calculations. Only limited data is available for confined and congested areas, such as buildings or containers.

CFD modelling makes it possible to obtain results for some well-defined geometries of installations inside buildings as well as outside in near-field situations. For more confined geometries, this approach is labour-intensive as it requires computation involving a large number of parameters.

In the Netherlands, authorities impose the use of SAFETI-NL as the Quantitative Risk Assessment (QRA) software program of choice for external safety. It uses empirical models. This QRA program is applicable for hydrogen vapour cloud explosions including detonations.

All of these considerations show that there are uncertainties in the application range of the model, the results and the validity of the risk contours. An effect-based approach is often applied as an alternative, but has the obvious drawback of potential overestimation. Risk-based assessment of credible scenarios therefore needs to be considered with care.

Inherently safer design, barriers and good practices

The project has resulted in a list of examples of possible inherently safer designs of green hydrogen plants and protection layers, to eliminate or reduce risk. It illustrates the principles of preventive and mitigating barriers and good practices. Nevertheless, the validity of protection layers must be assessed for each individual design. In addition, the project identified good practices, most of which are already common practice in the process industry. Within this framework, it should be considered that electrolysers are a class of systems with a broad range of embodiments. Standardisation and classification of different types of systems will be useful for the development of large-scale green hydrogen systems.

Next steps

The approach for assessment and reduction of explosion risks in large-scale green hydrogen production plants is presented in this report. A follow-up project on standardisation with this consortium, selected electrolyser suppliers and the Netherlands Standardization Institute (NEN) has been started, building on the results in this report. The project will aim to create more accurate scenario descriptions (initial events, final consequences and barriers) in order to make recommendations for standards for the design and operation of water electrolysis plants. It will also enhance understanding between owner-operators, engineering companies, technology providers and authorities. This is important in order to reduce the risks of incidents that would have a negative impact on the whole sector.