Building a compliant and safe green hydrogen plant

Green hydrogen is skyrocketing, and this is necessary if we are to have any chance of effectively combating global warming. The chemical, transport, and energy sectors require legally compliant and safe facilities for hydrogen production, storage, transport, and utilisation. Only by adopting a structured and goal-oriented approach to a hydrogen project can one achieve a safe and compliant installation and instil the necessary confidence among investors and users of hydrogen plants to truly make hydrogen a cornerstone of a sustainable economy.

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The core of any green hydrogen plant is an electrolyser. Depending on the electrolyser technology chosen (alkaline, PEM, SOEC, AEM), specific risks arise, necessitating a carefully selected approach for risk identification.

Occupational safety vs process safety

For each process, risks can be divided into the following three domains:

- **Process-related risks** concern deviations from the operational window in relation to factors such as the properties of the electrolyte compared to the design intent. These risks are typically assessed in a Hazard & Operability Study (HAZOP).
- **Equipment-related risks**, typically assessed through a Failure Mode Effect Analysis (FMEA), pertain to equipment and components such as rectifiers and electrical safeguards for electrolyser cells.
- **Human interface risks** are associated with the complexity of equipment operability, such as the design of the electrical supply network. For electrolysers, the electrical supply is insulated and galvanically isolated from the rest of the system (i.e., IT network). Due to the presence of an extended static magnetic field of the electrolyser, special consideration is required for human interface handling. These risks are typically assessed through an Event Tree Analysis (ETA) or Fault Tree Analysis (FTA).

The standard 'straightforward approach' to tackle these process safety risks for the three domains is to identify the domain where the predominant risks occur and select the specific risk analysis technique accordingly. The risks related to the domains with less prominent risks are incorporated into the chosen risk analysis technique through expert judgement.

Given that the risks for the electrolysis process are evenly distributed across the three domains mentioned earlier, the standard approach explained above cannot be easily followed in all cases. Consequently, performing the risk analysis techniques for the three domains requires a significant amount of effort in terms of resources and time. Therefore, it is advisable to develop a methodology specifically related to the risks associated with the electrolysis process.

In general, risks related to the three domains will lead to:

- **Occupational health requirements** related to the health, safety, and wellbeing of the employees, involving measures either technical or organizational in nature.

- **Process safety requirements** linked to the conceptual measures that aim to prevent major accidents caused by the release of energy, chemicals, or other hazardous substances. Such accidents may lead to significant casualties and potentially result in plant loss.

The differences between the two aspects are illustrated in Figure 1.

The outcome of the risk analysis for electrolysers will in many cases lead to technical requirements such as, for example:

- Selection of specific materials to ensure:
  - Compatibility with oxygen (when applicable)
  - Resistance to hydrogen penetration
- Management of electrostatic accumulation
- Implementation of an electrolyser management control system

To properly identify and manage these process risks, risk identification techniques are often combined with risk management techniques such as the LOPA (Layers Of Protection Analysis). The risk identification study identifies potential deviations from design intent through brainstorming, while LOPA assesses the effectiveness of the Independent Protection Layers against these deviations and can provide a detailed analysis to determine for which of the identified risks additional safeguards are required.

With a LOPA, it is also possible to identify the required Safety Instrumented Level (SIL Classification).

Managing risks in hydrogen plant design

To draw conclusions, a selection of challenging risks are addressed below. It should be noted that in addition to these risks, there may be other relevant risks when designing a hydrogen plant.

Explosion safety: ATEX or no ATEX?

One of the most challenging issues when considering hydrogen is managing the explosion risk.
The following aspects are of utmost importance:

- **Identifying the unmitigated risk** based on dedicated and well-defined evaluation criteria for hydrogen. It is important to note that the evaluation criteria for hydrogen are completely different from those used for other gasses such as methane, where rules of thumb may provide an easy solution.
- When **mitigating the risk, the prevention hierarchy** should be followed:

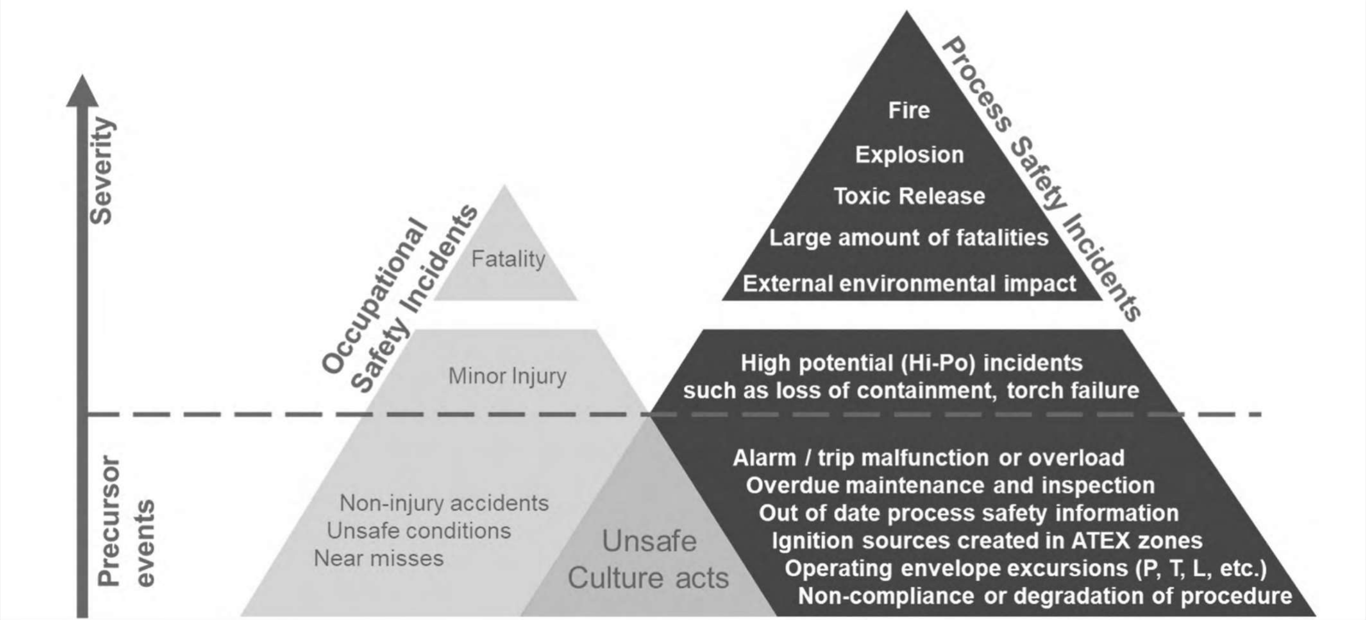


Fig. 1. Process and occupational safety hazards associated with electrolysers

- Application of primary prevention in the conceptual design
- Secondary prevention measures, such as mastering ignition sources, if primary prevention cannot be implemented.
- Employing suppression systems to master the consequences of hydrogen explosion wave(s).

Application of primary prevention in the conceptual design means choosing an operational window outside the explosive ranges of hydrogen (Lower Explosion Limit [LEL], Upper Explosion Limit [UEL], Lowest Oxygen Concentration [LOC]).

Due to the low ignition energy of hydrogen and its electrostatic accumulation properties, mastering ignition sources for hydrogen applications remains critical and challenging.

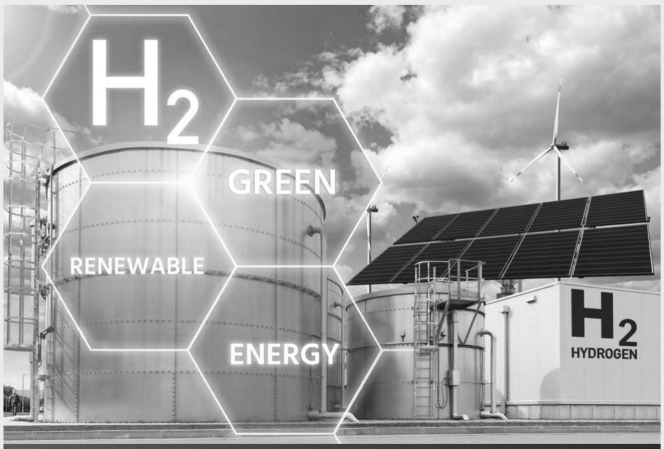
When addressing the ATEX Directives, it is important to mention that the focus of these directives is on accidental releases of hydrogen with a limited release rate, meaning that they deal with explosion risks and expected equipment malfunction during normal operation.

Consequently, and due to all the considerations discussed earlier, solely relying on ATEX-certified compliant equipment does not always provide the complete answer to explosion safety.

Proper material selection compatible with a small molecule like hydrogen, especially in high-pressure applications, is another key aspect of explosion protection.

Care must be taken when considering hydrogen at (very) high pressure within the scope of commonly known standards that address explosion characteristics, such as API 505, NFPA 497, NPR 7910-1, and IEC 67910-1.

To formulate a well-founded approach for handling explosion safety for hydrogen, one should have reliable data based on research and development, prior usage data, Risk-Based Inspection (RBI), and other sources. However, such data may not always be available.



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In the meantime, modelling with Quantitative Risk Analysis (QRA) software and implementing rigorous testing protocols and intervals are necessary for the specific purpose.

The results obtained from these tests and R&D data should feed into a continuous improvement PDCA loop (Plan-Do-Check-Act) and RCA (Root Cause Analysis).

In conclusion, the risk of gas explosion is one of the most significant hazards in a hydrogen plant. Proper installation design plays a crucial role as a primary prevention measure. It is strongly advised to incorporate natural ventilation, as it can effectively mitigate numerous potential difficulties.

Electromagnetic risk

To perform an electrolysis process, it requires not only the conversion from AC (alternating current) to DC (direct current) but also a substantial amount of power initiated by high current and low voltage.

Typically, when high power is needed, it is supplied through higher voltage and lower current. In general, an electric field is generated by high voltage and a magnetic field by high current.

The combination of DC application with high current consumption leads to the generation of an extended static magnetic field around the electrolyser, making safety considerations in electrolysis processes very specific. If sensitive equipment or living material is located within the extended static magnetic field, unexpected consequences can occur.

For instance, by interacting with metals, high magnetic fields can interfere with flux-based applications such as (implanted) medical devices, sensitive measuring equipment or other devices containing metallic materials. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) provides the following guidelines on limits of exposure to static magnetic fields (see *Health Physics* 96.4 [2009]: 504–514):

- For workers: 2 T for the head and 8 T elsewhere
- For the public: 400 mT for all parts of the body
- For implanted electronic medical devices: 0.5 mT

The 2013/35/EU European Directive for the protection of workers advocates the same values as the ICNIRP. Moreover, in occupational environments, exposure up to 8 T is tolerated for the entire body if the environment is controlled and work practices are adapted to reduce the speed of execution and movements in such fields.

Considering the specific characteristics of the electrolysis process mentioned earlier, it becomes evident that a standard 'straightforward approach' to tackle process safety risks may not be necessarily sufficient and adequate.

Technology readiness level

In the IEA report 'Electrolysers', published in 2022, the readiness level of electrolyser technologies was assessed (see Figure 2). Based on this report, one can conclude that only for the PEM technology has the 'market uptake' level 9 recently been achieved, while for SOEC, only the 'demonstration' level (level 7) has been attained.

Because of the current readiness level of a chosen technology, the proposed measures for the obvious risks explained in the previous paragraphs on electromagnetic and explosion risks should be regularly reassessed. This reassessment should consider the rapidly changing readiness level of the technology, the rapid development of new standards, and any legislative framework of concern.

The method to manage this complex challenge is through compliance and conformity assessment, as explained in the next section.

Building a compliant plant

Currently, there is no standard or straightforward way to achieve a legal compliance for an electrolyser or hydrogen plant.

To attain a legally compliant hydrogen plant, one must consider various aspects that involve different responsibilities for different

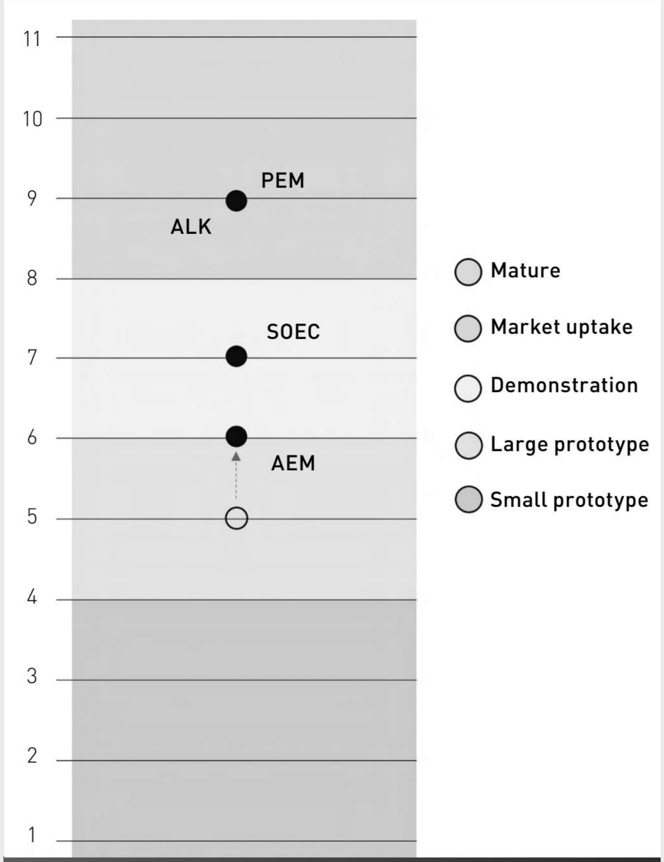

Fig. 2. Technology readiness levels of electrolyser technologies. Source: IEA

stakeholders. This complexity makes achieving compliance quite challenging.

This complex issue can be simplified by performing a dynamic ‘compliance and conformity assessment’ (C&C), which consists of the following steps:

Creating a clear inventory of applicable legislation and the scope of each legislation.

- Creating a clear inventory of inspections, certificates, documents, or any other requirements that need to be performed or fulfilled for each individual functional system.
- Creating a clear inventory of inspections, certificates, documents, or any other requirements that need to be performed or fulfilled for the overall hydrogen plant.
- Identification of the roles and responsibilities of the different stakeholders such as the OEM, the EPC contractor, and the end user by means of completing a RACI (Responsible, Accountable, Consulting, Informed) matrix.

Conclusion

Handling hydrogen safety during the design process can be particularly challenging in a rapidly changing technical and legal environment.

At Vinçotte, as part of the KIWA Group, we have a highly skilled process safety team with experienced experts who can assist clients in solving these challenges smoothly. We provide tailor-made solutions for a specific hydrogen plant design within the legal applicable framework.

However, it is important to note that such tailor-made solutions are strongly influenced by the rapid changes in the technological readiness level until the technology becomes mature and proven.