STATUS OF HYDROGEN SAFETY STANDARDS

for Residential Applications in Sweden

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Abstract

This technical report provides a review of the status of hydrogen standards in Sweden, with a focus on safety aspects related to residential hydrogen applications that involve production, storage, distribution, and utilisation. It identifies the main standards within the field and their specific areas of focus, while also pointing out the risk of addressing safety aspects of components and subsystems in isolation, rather than considering the hydrogen application as a whole. It underscores the importance of addressing safety risks that span the entire hydrogen application lifecycle, rather than limiting concerns to individual components or system segments.

Keywords: hydrogen, residential application, safety, standardisation

I. Introduction

The emerging hydrogen industry is expected to play an important role in shaping a sustainable future [1], [2], [3]. As the world seeks alternatives to fossil fuel and a transition to cleaner energy sources, hydrogen presents a solution to decarbonise multiple energy intensive sectors. Hydrogen is a clean energy carrier that provides important solutions to many of today's energy challenges, such as energy storage [4]. However, hydrogen also raises new safety concerns because of its unique physical and chemical properties, such as high flammability and low ignition energy [5].

To address these safety challenges, the need for dedicated hydrogen standardisation has gained both national and international recognition [2], [3]. However, in a rapidly evolving sector characterised by frequent technological advances and a wide diversity of applications, the standardisation landscape requires continuous development. It is essential that standardisation bodies remain adaptable to this dynamic environment to minimise the risk of standardisation gaps. At the same time, it is equally important that the standards developed are well-suited to the broad variety of hydrogen applications, ensuring they do not become a bottleneck for future innovation and development.

Objective: This report aims to provide an overview of the key sources of regulatory and standardisation requirements for residential hydrogen applications in Sweden. It examines national legislation, regulations, and applicable international standards, with a focus on their implications for the distinct areas of hydrogen application: production, storage, distribution, and utilisation.

Scope: This report highlights Swedish national legislation, regulations, and applicable standards related to hydrogen safety in residential stationary applications from the standardisation bodies International Organisation for Standardisation (ISO), European Committee for Standardisation (CEN), International Electrotechnical Commission (IEC), and Swedish Institute for Standards (SIS). The scope is limited to standards concerning stationary residential applications, and areas such as transport and mobility, including refuelling infrastructure and road and rail vehicles, are not addressed.

In addition, the report seeks to identify potential gaps in the current standardisation landscape for residential hydrogen applications in relation to Swedish legislation and regulations, and points to areas where further work may be needed.

II. Swedish Legislation and Regulation

Swedish legislation regarding hydrogen applications is still in its early stages. Current regulatory frameworks for hydrogen are based on general laws governing flammable and explosive materials, notably the **Act 2010:1011** [6] and Ordinance **2010:1075** [7]. In addition, safety and safety handling guidelines are provided through regulations issued by the Swedish Rescue Services Agency (SRV), specifically **SRVFS 2004:7** [8].

Additional national guidelines exist, which developers of hydrogen applications aimed for the Swedish market and requiring permission from relevant authorities are required to consider. These include:

- **AFS 2016:4**: Equipment for potentially explosive atmospheres [9].
- **MSBFS 2010:4**: Classification of goods as flammable or explosive and associated amendments in **MSBFS 2018:2** [10].
- **MSBFS 2013:3**: Permits for the handling of flammable gases and liquids [11].
- **MSBFS 2020:1**: Handling of flammable gases and flammable aerosols [12].
- **SRVFS 2004:7**: Explosive atmospheres during the handling of flammable gases and liquids [13].
- **ELSÄK-FS 2016:2**: Electrical equipment and protection systems intended for use in potentially explosive atmospheres [14].

Permits based on the above-mentioned laws, regulations, and guidelines are issued by regional and local authorities, in collaboration with the Swedish Civil Contingencies Agency (*Myndigheten för samhällsskydd och beredskap*, MSB). In this context, regional and local authorities refer to local administrative bodies, such as the fire and rescue services (*räddningstjänsten*), which are responsible for assessing safety risks and ensuring compliance with safety standards across different regions of the country. These authorities work closely with MSB to ensure that hydrogen production, storage, and utilisation are conducted safely and in accordance with national regulations.

For a hydrogen residential application targeted at the Swedish market, developers are required to obtain multiple permits from various local authorities, each governing different region. Since different regions may interpret and apply laws and regulations in diverse ways, navigating the permitting process can become complex and require coordination between several authorities. This can lead to a costly process, where, in the worst case, different safety measures may be required for different local regions, further complicating the implementation and increasing the overall cost of the project.

III. Hydrogen Safety

Safety considerations are integrated throughout the entire hydrogen lifecycle, that is, production, storage, distribution, and utilisation. Given the breadth of this field, safety is often addressed with respect to these distinct stages of the lifecycle, where each stage is considered a separate area with its own specific safety concerns [3], [5], [15]. In this report, we follow this approach, examining safety standardisation specific to each stage of the hydrogen lifecycle, consisting of:

Production: Within the scope of residential applications, hydrogen production is limited to **electrolysis**, that is, splitting water into hydrogen and oxygen using electricity. Associated risks are flammable and explosive gas mixture of hydrogen and oxygen due to gas crossover, leaks, and insufficient ventilation [15].

Storage: Hydrogen is primarily stored as a **compressed gas**, often at pressure up to 700 bar, in current residential applications. Associated risks include hydrogen leakage, high-pressure rupture, and material embrittlement [15].

Distribution: In residential applications hydrogen is transported via **pipelines**. Pipelines intended for hydrogen carriage face challenges such as sealing, welding, and metal embrittlement [15].

Utilisation: In residential applications, hydrogen is primarily used for the production of electricity through electrochemical conversion in **fuel cells**. Safety concerns include hydrogen leakage, and electrical currents [15].

In addition to the four stages of the hydrogen lifecycle, **functional safety** of integrated computer-based hydrogen applications deserves special attention. Integrated applications involve safety risks that span the entire hydrogen lifecycle, and ensuring safety in such systems requires a systematic approach that goes beyond the individual concerns of each lifecycle stage [16]. For example, safety measures during production may require physically separating the electrolyser and its utility equipment from the hydrogen storage area, managed by control systems, appropriate piping and controllable volts. This safety concern alone spans production equipment, distribution pipelines, and storage functionality. It is therefore crucial that the safety management of integrated applications includes functional safety considerations that are addressed at the system level, taking into account the full lifecycle of the application and its interdependencies across all stages of the hydrogen lifecycle.

IV. Hydrogen Production

The production of hydrogen through electrolysis involves various risks, including flammable gas leaks and electrical safety aspects [5]. Safety standards in this area are designed to minimize the risk associated with those hazards and ensure safe and reliable operation. The following standards and technical specifications fall within this category:

1. **ISO 22734:2019** – Hydrogen generators using water electrolysis - Industrial, commercial, and residential applications. This standard defines requirements for hydrogen production via water electrolysis for industrial, commercial, and residential use, focusing on safety, performance, and operation of electrolysers [17]. This standard has been adopted as a Swedish standard under the designation **SS-ISO 22734:2022** by the Swedish Institute for Standards [17].
2. **IEC 60364-4-41:2005** – Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock [18]. This international standard specifies requirements for protecting people and equipment against electric shock in low-voltage installations. It covers protective measures such as insulation, protective earthing, and the use of residual current devices (RCDs).
3. **IEC 60364-4-42:2024** – Low-voltage electrical installations – Part 4-42: Protection for safety – Protection against thermal effects. This international standard addresses protection against fire caused by electrical faults, including overcurrent, short circuits, and arcing [32].

4. **IEC 60364-5-52:2009** – Low-voltage electrical installations – Part 5-52: Selection and erection of electrical equipment – Wiring systems. This international standard outlines how to correctly select and install wiring systems, taking into account factors such as current-carrying capacity, environmental conditions, and mechanical protection [20].
5. **IEC 60364-5-53:2019** – Low-voltage electrical installations – Part 5-53: Selection and erection of electrical equipment – Isolation, switching and control. This international standard provides requirements for disconnecting, isolating, and switching devices, including emergency shut-offs [21].

These documents address safety in hydrogen production for small scale and residential applications. They specifically focus on the safety aspects of individual components within a larger context but do not cover the overall safety management, including risk assessments, operational procedures, or regulatory compliance required for comprehensive safety management of the overall hydrogen production systems.

V. Hydrogen Storage

The storage of hydrogen in compressed gas cylinders presents various risks that can ultimately lead to hydrogen leaks, such as high-pressure containment failures and material degradation over time. Even small leaks pose significant safety concerns, as hydrogen is highly flammable, has a low ignition energy, and burns with an almost invisible flame. Additionally, in confined spaces, hydrogen can accumulate and create an explosive atmosphere, posing a serious safety threat [5]. Safety standards in this area are designed to mitigate these risks, ensuring secure containment, proper handling, and reliable long-term storage. The following standards, technical specifications, and reports fall within this category:

1. **EN 17533:2020** – Gaseous hydrogen - Cylinders and tubes for stationary storage [22]. This European standard, issued by CEN, provides requirements for cylinders and tubes used for the stationary storage of gaseous hydrogen, with a focus on design, construction, and testing. It ensures that these storage vessels meet safety requirements under high-pressure conditions, ensuring their safe operation and integrity throughout their service life. This standard has been adopted as a Swedish standard under the designation **SS-EN 17533:2020** by SIS [23].
2. **EN 12245:2022** – Transportable gas cylinders - Fully wrapped composite cylinders [24]. This standard, issued by CEN, specifies minimum requirements for the materials, design, construction, prototype testing and routine manufacturing inspections of fully wrapped composite gas cylinders for compressed, liquefied and dissolved gases. This standard has been adopted as a Swedish standard under the designation **SS-EN 12245:2022** by SIS [25].
3. **ISO 7866:2012** – Gas cylinders -- Refillable seamless aluminium alloy gas cylinders -- Design, construction and testing [26]. This international standard, issued by ISO, specifies the minimum requirements for materials, design, manufacturing, and testing of refillable seamless aluminium alloy gas cylinders (0.5 to 150 litres), intended for compressed, liquefied, and dissolved gases. This standard has been adopted as a Swedish standard under the designation **SS-EN ISO 7866:2012** by SIS [27].
4. **ISO 11119-1:2020** – Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes — Part 1: Hoop wrapped fibre reinforced composite gas cylinders and tubes up to 450 l [28]. This standard has been adopted as a Swedish standard under the designation **SS-ISO 11119-1:2020** by SIS [29].
5. **ISO 11119-2:2020** – Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes — Part 2: Fully wrapped fibre reinforced composite gas cylinders and

tubes up to 450 l with load-sharing metal liners [24]. This standard has been adopted as a Swedish standard under the designation **SS-ISO 11119-2:2020** by SIS [31].

6. **ISO 11119-3:2020** – Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes — Part 3: Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450 l with non-load-sharing metallic or non-metallic liners or without liners [32]. This standard has been adopted as a Swedish standard under the designation **SS-ISO 11119-3:2020** by SIS [33].
7. **ISO 11119-4:2016** – Gas cylinders — Refillable composite gas cylinders — Design, construction and testing — Part 4: Fully wrapped fibre reinforced composite gas cylinders up to 150 l with load-sharing welded metallic liners [28]. This standard has been adopted as a Swedish standard under the designation **SS-ISO 11119-4:2016** by SIS [35].

Together, these standards focus on reliable storage of hydrogen across various storage technologies and material. They primarily address the design, construction, testing, and performance of storage components for pressurised gas.

While these standards provide important reliability aspects and safety guidelines for hydrogen storage vessels, they do not address the broader safety management of complete hydrogen application or system. This includes system-level aspects such as installation and its integration into infrastructure, or regulatory compliance at a system-wide level. The standards listed serve as a foundation for safe hydrogen storage but do not replace overall risk assessments, operational procedures, or system-wide safety strategies required for a system integrating hydrogen storage.

VI. Hydrogen Distribution

For fixed, stationary installations, hydrogen distribution involves transporting hydrogen through pipelines between different parts of the system. This may include shorter distances, such as between system components located in the same compartment, or longer distances between different physical locations, for example, from production units to storage facilities.

Given the scope of this report, this chapter focuses specifically on non-industrial, pipeline-based distribution, and does not address the safety concerns associated with other distribution mechanisms, such as tube trailers, and liquid hydrogen transport, which are commonly used in the automotive and rail industries.

Current hydrogen safety standardisation related to piping primarily addresses the prevention and management of hydrogen leakages with limited consideration given to external hazards such as mechanical impact from vehicles, falling objects, or other environmental threats that may compromise system integrity. The focus is instead placed on considerations such as material compatibility, mechanical durability, pressure regulation, leak detection, and emergency isolation. The following standards address these aspects, providing guidance on both general pipeline safety and hydrogen-specific risks.

1. **EN 15001-1:2008** – Gas Infrastructure - Gas installation pipework with an operating pressure greater than 0,5 bar for industrial installations and greater than 5 bar for industrial and non-industrial installations - Part 1: Detailed functional requirements for design, materials, construction, inspection and testing [37]. The standard has been adopted as a Swedish standard under the designation **SS-EN 15001-1:2023** by the Swedish Institute for Standards [38].

2. **EN 15001-2:2023** – Gas Infrastructure - Gas installation pipework with an operating pressure greater than 0,5 bar for industrial installations and greater than 5 bar for industrial and non-industrial installations - Part 2: Detailed functional requirements for commissioning, operation and maintenance [38]. The standard has been adopted as a Swedish standard under the designation **SS-EN 15001-2:2023** by the Swedish Institute for Standards [39].
3. **EN 1775:2007** – Gas supply - Gas pipework for buildings - Maximum operating pressure up to and including 5 bar - Functional recommendations [40]. The standard has been adopted as a Swedish standard under the designation **SS-EN 1775:2007** by the Swedish Institute for Standards [41].
4. **EN 12732:2021** – Gas infrastructure - Welding steel pipework - Functional requirements [42]. The standard has been adopted as a Swedish standard under the designation **SS-EN 12732:2021** by the Swedish Institute for Standards [43].
5. **EN 10226-1:2004** – Pipe threads where pressure tight joints are made on the threads - Part 1: Taper external threads and parallel internal threads - Dimensions, tolerances and designation [44]. The standard has been adopted as a Swedish standard under the designation **SS-EN 10226-1:2005** by the Swedish Institute for Standards [45].
6. **EN 10226-2:2005** – Pipe threads where pressure tight joints are made on the threads - Part 2: Taper external threads and taper internal threads - Dimensions, tolerances and designation [46]. The standard has been adopted as a Swedish standard under the designation **SS-EN 10226-2:2005** by the Swedish Institute for Standards [47].
7. **EN 10226-3:2005** – Pipe threads where pressure tight joints are made on the threads - Part 3: Verification by means of limit gauges [48]. The standard has been adopted as a Swedish standard under the designation **SS-EN 10226-3:2005** by the Swedish Institute for Standards [49].
8. **ISO 11114-1:2020** – Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 1: Metallic materials [50]. The standard has been adopted as a Swedish standard under the designation **SS-EN ISO 11114-1:2020** by the Swedish Institute for Standards [51].
9. **ISO 11114-2:2021** – Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 2: Non-metallic materials [52]. The standard has been adopted as a Swedish standard under the designation **SS-EN ISO 11114-2:2021** by the Swedish Institute for Standards [53].
10. **ISO 14687:2025** – Hydrogen fuel quality — Product specification [54]. This standard specifies the minimum quality parameters for distributed hydrogen fuel, including the context of residential, commercial and stationary applications.

Piping plays an essential role in a hydrogen application and is crucial to account for during system safety analysis to mitigate the risk of hydrogen leakages. This risk, and its mitigations, are well addressed through the standardisation listed in this chapter. However, piping is not only a potential source of leakage, but it also serves a vital function in fragmenting the system into functional zones through piping and safety valves. This allows system designers to define distinct areas for safety assessment, such as applying different ATEX zoning classifications for explosive atmospheres, as specified in **IEC 60079-10-1:2020** [55]**,** and to implement targeted risk mitigation strategies accordingly.

Such segmentation is critical for managing hazards effectively and ensuring the system complies with applicable safety, regulatory, and performance requirements. It can be argued that this aspect of piping is more closely related to the system's overall functional safety, and should be documented as such, yet its relevance is missing in current hydrogen standardisation efforts.

VII. Hydrogen Utilisation

The utilisation of hydrogen in residential applications has, at the time of writing, been largely limited to fuel cell technology. That is, the production of electricity through an electrochemical process in which hydrogen and oxygen react to produce electricity, water, and heat. Other types of utilisations, such as hydrogen combustion, have not yet been commercialised nor addressed by standardisation to the same degree. However, the technology has shown promising potential and standardisation initiative is already started and, in some cases, finalised with released standards.

For example, the EN standardisation for gas-fired central heating boilers, **EN 15502-2-1:2022** [56], has been extended to support gas mixtures with up to 20% hydrogen, **EN 15502-2-1:2024** [57]. For example, the EN standard for gas-fired central heating boilers, **EN 15502-2-1:2022** [56], has been extended to support gas mixtures with up to 20% hydrogen, as reflected in **EN 15502-2-1:2024** [57]. Given that hydrogen utilisation is currently dominated by fuel cell technology, the remainder of this chapter will focus on that area.

The main safety hazards involved in fuel cell technology include the risk of fire and explosion, due to hydrogen leakage, as well as electrical hazards from power generation components [5], [58]. Thermal effects may pose additional safety-related concerns, although they are generally less critical and not addressed to the same degree. The following standards represent current efforts from standardisation bodies to address these risks in a centralised and structured manner:

1. **IEC 62282-2-100:2020** – Fuel cell technologies - Part 2-100: Fuel cell modules – Safety [59]. This standard specifies safety requirements for fuel cell modules, as a standalone unit, across its different operational modes. The standard has been adopted as a Swedish standard under the designation **SS-EN IEC 62282-2-100** by the Swedish Institute for Standards [60].
2. **IEC 62282-3-100:2019** – Fuel cell technologies - Part 3-100: Stationary fuel cell power systems – Safety [61]. This standard specifies the safety requirements for a fully integrated fuel cell power system. The standard has been adopted as a Swedish standard under the designation **SS-EN IEC 62282-3-100** by the Swedish Institute for Standards [62].
3. **IEC 62282-6-107:2024** – Fuel cell technologies - Part 6-107: Micro fuel cell power systems - Safety - Indirect water-reactive (Division 4.3) compounds [63]. This standard specifies safety requirements for micro fuel cell hydrogen power systems. While this standard is not typically applied to fixed hydrogen installations, it may become relevant in the foreseeable future as innovative hydrogen solutions emerge. The standard has been adopted as a Swedish standard under the designation **SS-EN IEC 62282-6-107:2025** by the Swedish Institute for Standards [64].
4. **IEC 60335-1:2020** – Household and similar electrical appliances - Safety - Part 1: General requirements [65]. The standard specifies electrical safety requirements for residential and commercial applications, operating at up to 250V, single phase, or 480 V, multi-phase. The standard has been adopted as a Swedish standard under the designation **SS-EN 60335-1** by the Swedish Institute for Standards [66].

Furthermore, **IEC 60204-1:2016**, Safety of machinery - Electrical equipment of machines - Part 1: General requirements [67], can be considered for equipment operating above the voltage limits specified in **IEC 60335-1:2020**. Though the scope of **IEC 60204-1** is intended for stationary industrial machinery and is therefore not appropriate for typical residential or commercial applications.

The standards presented in this chapter provide an overview of the current safety standardisation available for the use of hydrogen in residential and commercial applications, limited to fuel cell technology. While this standardisation is important for the components involved in fuel cell systems, it is important to note that these components are always part of a larger integrated system that includes, at minimum, hydrogen storage and distribution in some form. The safety requirements associated with such integrated applications are not covered by the standardisation listed in this chapter.

VIII. Hydrogen Functional Safety

Functional safety refers to system functionality, carried out by electrical/electronic/programmable electronic (E/E/PE) control systems, that are involved in mitigating safety risks [68]. Functional safety is typically not isolated to a single component or subsystem but concerns the system and its context as a whole. In hydrogen systems, functional safety involves addressing risks that may span several stages of the hydrogen lifecycle, including production, distribution, storage, and utilisation, rather than treating each stage in isolation. Functional safety specific to hydrogen, typically includes control system functionality for leak detection, system segmentation, ventilation, and safe state implementation.

Functional safety standards are often defined within the broader context of the overall system and its safety concept. This is typically achieved by specifying sector-specific requirements within a more generalised safety framework. For example, in the process industry, the functional safety standard **IEC 61511** [69] is based on more general safety framework of **IEC 61508-1** [70], which outlines the overall safety lifecycle in generic terms. A comparable functional safety standard, specific for hydrogen applications, is currently absent from the existing hydrogen standardisation landscape. This lack of a dedicated functional safety standard presents challenges during risk assessment and can be considered a gap in the current hydrogen safety framework, as identified in the European Clean Hydrogen Alliance Roadmap [71]. However, the roadmap only highlights the need to improve general risk assessment methodologies and does not explicitly address the need for hydrogen-specific functional safety standardisation.

The most important hydrogen-specific safety document currently provided by hydrogen standardisation bodies that may be relevant to functional safety is **ISO/TR 15916:2015** [72]. This technical report outlines fundamental safety principles for hydrogen systems, including general hydrogen hazards and corresponding risk mitigation strategies. The report has been adopted as a Swedish standard under the designation **SIS-ISO/TR 15916:2022** by the Swedish Institute for Standards [73]. It should be noted, however, that **ISO/TR 15916** is a technical report, not a standard with clearly defined requirements, and therefore cannot be used as a basis for system-level safety assessment.

IX. Conclusion

This report indicates that the standardisation for residential hydrogen applications in Sweden is well developed at the component level, with well-established standards for production, storage, distribution, and utilisation. However, the absence of hydrogen-specific functional safety standardisation with a broader system lifecycle perspective represents a significant gap in the current hydrogen safety framework. This is especially the case when it comes to assessment, which, in the absence of standardisation, must rely on generic national laws and regulations. This imposes considerable risk of misinterpretation and misunderstanding, which may lead to high development costs, safety threats, and overall hindrance to innovation. Therefore, to support efficient and safe development of residential hydrogen applications, future standardisation efforts must recognise the need for both functional and overall safety considerations supporting the entire system lifecycle.

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