THE GERMAN STANDARDIZATION ROADMAP HYDROGEN TECHNOLOGIES

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Abstract - On behalf of the German Ministry for Economic Affairs and Climate Action the major rule setters of Germany are working on the Standardization Roadmap for Hydrogen Technologies since January 2023.

The activities are divided into five areas along the value chain of hydrogen

- Production
- Infrastructure
- Application
- Quality Infrastructure
- Training, Certification and Safety Management

Since July 2024 an analysis report [1] is available to the public, that presents the status of existing and analysis of gaps of technical regulations. Another result of the program is a directory of technical regulations [2] that are applicable to hydrogen with over 850 entries.

This paper will provide an overview of the structure of the program and which subject areas it covers. It also explains how interested users find access to further information of the program. Using a few selected examples, the work results and identified areas of action and open questions are presented.

Index Terms — Regulations & New Standards, Standardization Bodies, Hydrogen Production, Hydrogen Infrastructure, Safety Management, Safe Design Principles, Training, Incident Database.

I. INTRODUCTION

The energy transition is a decisive step towards a sustainable and climate-friendly energy supply. Hydrogen will play in future an important role as an energy carrier and is a promising option for reducing dependence on fossil fuels and cutting greenhouse gas emissions.

In order to successfully realize the up scaling of the hydrogen market, a reliable and congruent set of technical rules is required. Thus, the continuous development of technical standards and specifications at national, European and international level is of enormous importance.

With this background the German Federal Ministry for Economic Affairs and Climate Action (BMWK) has set-up a number of actions and in specific the program for the Standardization Roadmap Hydrogen Technologies.

Over 600 experts from rule setters, institutes, industry and the public sector are involved in this program that started in year 2023 and will continue until end of year 2025. Project partner in the program are the following rule setters:

- DIN - German Institute for Standardization
- DVGW - German Technical and Scientific Association for Gas and Water
- DKE - German Commission for Electrical, Electronic & Information Technologies
- NWB - Association for Standardization and Development of the Railway System
- VDA - German Association of the Automotive Industry
- VDE - German Scientific-Technical Association for Electrical Safety
- VDI - The Association of German Engineers
- VDMA - Machinery and Equipment Manufacturers Association

II. INTERNAL AND EXTERNAL ORGANIZATION STRUCTURE OF THE PROGRAM

A. Standardization Landscape

In terms of fully consensus-based standardization ISO (International Organization for Standardization), IEC (International Electrotechnical Commission) and ITU (International Telecommunication Union) are the relevant (standardization) organizations at international level.

The corresponding standardization organizations at European level are CEN (European Committee for Standardization), CENELEC (European Committee for Electrotechnical Standardization) and ETSI (European Telecommunications.

In addition to DIN and DKE, there are other recognized German rule-setting institutions that have the task of creating technical rules for their sector based on their expertise and in the spirit of industrial self-regulation.

This mandate is often reinforced by the legislation. As example, the DVGW is the legally recognized rule-setting institution for gas and hydrogen within the meaning of the German Energy Industry Act [3], just as the VDE is responsible for setting technical rules in the electricity sector under the same Act.

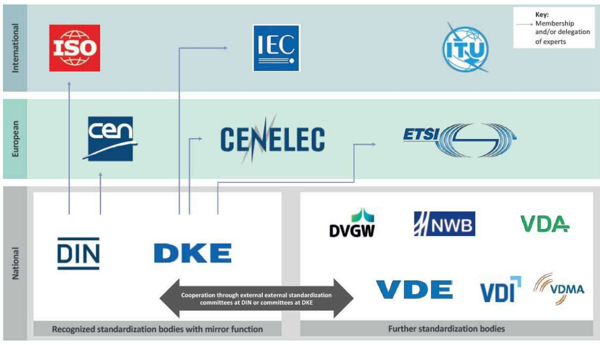


Fig. 1 Overview of the Standardization Organization
Source: [1]

The German program is of course not the only initiative that deals with an assessment of standards and open topics regarding the standardization in the area of hydrogen technologies. A number of assessments have been carried out in various countries at national level, but also by the European and International standardization bodies. At this point, the following programs are mentioned as a representative example:

- Technical Committees ISO/TC 197, Hydrogen Technologies
- HyDelta. A Dutch national research program and collaboration focused on the large scale implementation of hydrogen in the Netherlands.

And also to be mentioned in this context is the European analysis report "ROADMAP ON HYDROGEN STANDARDISATION", [5].
The coordination and exchange of information between the various programs, to the extent that official standardization bodies are involved, is guaranteed through the appropriate networks at national and international levels. See Fig. 1.

B. Working group structure for the program

The work has been organized in 5 top level clusters along the hydrogen value chain and a total of 39 associated working groups to focus on specific areas according to the following scheme:

a) Hydrogen Production
   1. Electrolysis
   2. Other Production Methods
   3. Total System Integration
   4. Hydrogen Composition
   5. Verification and Sustainability Aspects

b) Hydrogen Infrastructure
   1. Piping
   2. Transmission Pipelines
   3. Plant Engineering
   4. Distribution Networks
   5. Stationary and Mobile Pressure Vessels
   6. Underground Gas Storage
   7. Liquefaction

c) Hydrogen Applications
   1. Fuel Cells
   2. Power Plants, Turbines, CHP Plants
   3. (Petro)chemical Industry
   4. Power-to-X
   5. Thermoprocessing Equipment
   6. Steel Industry
   7. Domestic Applications
   8. Controls
   9. Commercial Applications
   10. Filling Systems (for mobility)
   11. Road Vehicles
   12. Railway Vehicles
   13. Shipping
   14. Aviation
   15. Special Vehicles

d) Quality Infrastructure
   1. Gas Analysis
   2. Hydrogen Measurement Technology and Billing Methods
   3. Metallic Materials
   4. Composites and Plastics
   5. Components for Infrastructure
   6. Components for Application and Technologies

e) Training, Safety, Certification
   1. Safety Design Principles
   2. Cyber Security
   3. Explosion Protection
   4. Safety and Integrity Management
   5. Product Certification
   6. Training

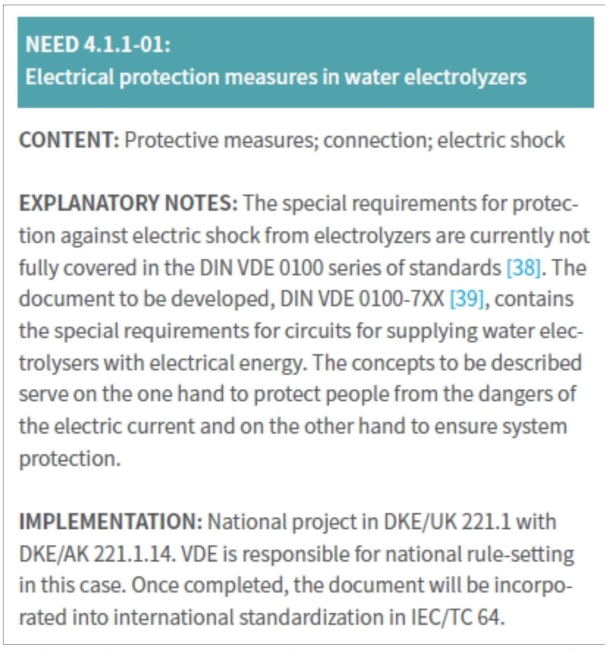
III. ACCESS TO THE ANALYSIS REPORT AND FURTHER INFORMATION

The access to the program information and the project results in German language is via a website hosted by the DIN at
https://www.din.de/de/forschung-und-innovation/themen/wasserstoff/normungsroadmap-wasserstoff
and corresponding in English at
https://www.din.de/en/innovation-and-research/hydrogen/standardization-roadmap-for-hydrogen-technologies.

The website provides also access to the main contact person at DIN for the hydrogen standardization roadmap program, Ms. Lydia Vogt.
The analysis report [1] provides also comprehensive information about all experts (name, company) that participated in the program, the technical heads of each working group and the other persons involved in the program organization. Based on this information you can find your way for further contact data to gather specific information that you are interested in.

IV. ANALYZED GAPS AND NEEDS

The analysis report [1] exhibits a total number of 180 needs. Each need is defined based on a compact summary with a defined structure and a specific ID for the explicit identification. Fig. 2 depicts one example for illustration of the structure of information.


NEED 4.1.1-01:
Electrical protection measures in water electrolyzers

CONTENT: Protective measures; connection; electric shock

EXPLANATORY NOTES: The special requirements for protection against electric shock from electrolyzers are currently not fully covered in the DIN VDE 0100 series of standards [38]. The document to be developed, DIN VDE 0100-7XX [39], contains the special requirements for circuits for supplying water electrolysers with electrical energy. The concepts to be described serve on the one hand to protect people from the dangers of the electric current and on the other hand to ensure system protection.

IMPLEMENTATION: National project in DKE/UK 221.1 with DKE/AK 221.1.14. VDE is responsible for national rule-setting in this case. Once completed, the document will be incorporated into international standardization in IEC/TC 64.

Fig. 2: Structure used in the analysis report [1] to define needs.

The data presented and discussed in the following paper reflects the status at the time of the publication of the analysis report in summer 2024. As the program is still active some of the published needs may have meanwhile a changed status. In summer 2025 an updated report will be published by the DIN.

V. ANALYSIS OF PRIORITY AREAS FOR STANDARDIZATION NEEDS

To gain further insights into the status of standardization and the focus areas for identified gaps the author collected and analyzed all key information from the analysis report [1].

A. Challenges in the analysis of data and information

At first it seemed possible to draw conclusions about the focus areas for open standardization tasks based on the amount of needs defined by each working group. But this has proven to be irrelevant. On the one hand, a very low number of requirements from a working group can indicate that this specific area is already very well covered by technical standards. However, it can also be an indication that the field is still very new and in a very early phase of technological/industrial implementation. This relation is sketched in Fig. 3.

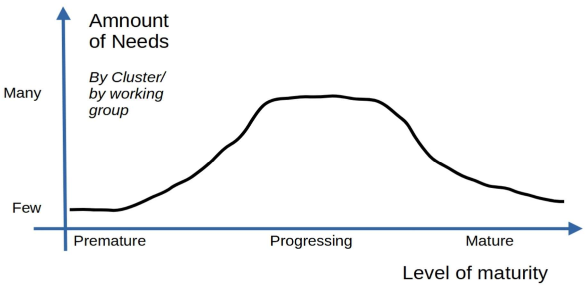


Fig. 3 Hypothetically assumed distribution of the number of needs depending on the maturity level of each domain

It also became obvious that the working groups took different approaches to define needs. For example, one working group summarized the need for revision of entire series of standards as one single need, and in another working group the individual standards of a series of standards that needed to be revised were identified as individual needs.

In some cases needs are formulated in the form of “Consideration of hydrogen in the standards of ISO/TC xxx”. This type of outcome of the working group is pretty generic and does not allow closer assessment of the required scope of work.

Therefore, looking at the number of identified needs does not allow conclusions about the key areas of identified gaps and the need for action.

Given this background, a manual review of the 180 needs is necessary in order to generate a useful overview of the main areas of gaps and actions.

In order to gain insights into the scope and complexity of work associated with a need, they should be classified. Unfortunately, there was no classification system defined for the analysis report. Based on the description that is provided in the analysis report for each individual need, the following most frequently used terms can be identified and can be used to classify the needs:

- New technical rule required
- Revision of an existing technical standard
- Adjustment of an existing technical standard
- Extension of an existing technical standard

The logical order of workflow and meaning of these classes according to the author’s interpretation is shown in the Fig. 4.

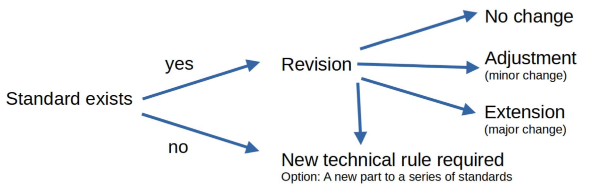


Fig. 4 Classification and relation of needs

B. Distribution of the needs to the key rule setters

The diagram in Fig. 5 shows the assignment of the needs to the key rule setters.

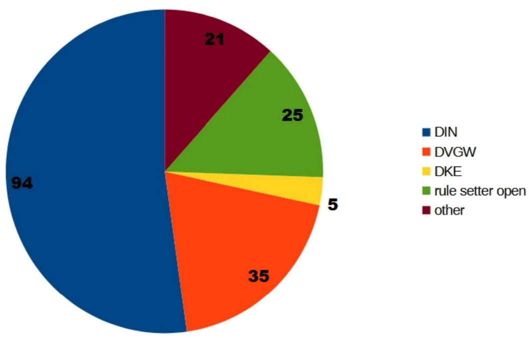


Fig. 5 Assignment of needs to the rule setters

The major portion falls into the responsibility of DIN and covers national (23), European (CEN, 43) and international standards (ISO, 28).

In the area of DKE only 5 needs are identified. This shows that there is little need for adjustment to the status of electrical standards due to developments in hydrogen applications.

The DVGW is by German legislation the technical rule setter for the gas infrastructure and therefore heavily involved in the rule setting for our future hydrogen infrastructure and for domestic appliances. Most of the needs assigned to the DVGW are outcome of one of the following working groups:

- Transmission Pipelines
- Plant Engineering
- Distribution Networks
- Domestic Applications
- Components for Infrastructure

The DVGW publishes the standards mostly in German, but some are also available in English. Coordination of the DVGW standards with European and international standardization bodies, where applicable, is coordinated by the DIN.

35 needs are related to the DVGW. Hereof 27 needs require an adjustment, 5 a revision and 3 a new technical rule. From this data it can be concluded that most of the necessary standards for the gas infrastructure are in place and require only minor adjustments to cover the requirements for future hydrogen use.

C. *Type of work to be performed*

According to the diagram in Fig. 6 approx. 40% of all needs are related to a new technical rule that is required.

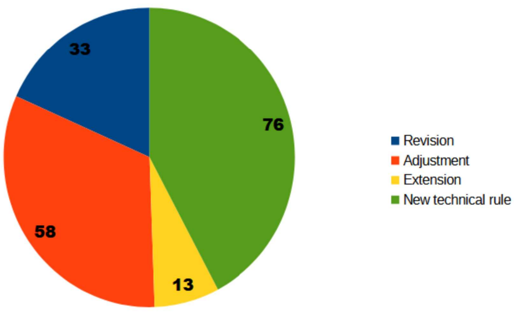


Fig. 6 Distribution of the type of work to be performed

The requirement for a new technical rule often corresponds to needs, where also the rule setter is not yet identified. The focus for the identified needs for new technical rules are related to the working groups:

- Underground Storage
- Liquefaction
- Railway Vehicles
- Shipping
- Aviation
- Metallic Materials
- Composites and Plastics

VI. ANALYSIS AND DISCUSSION OF THE IDENTIFIED NEEDS BY CLUSTER

A. *Hydrogen Production*

This cluster consists of the 5 working groups Electrolysis, Other Production Methods, Total System Integration, Hydrogen Composition, Verification and Sustainability Aspects.

For Electrolyzer a large number of technical standards exist. But there are still some gaps and challenges as follows

- no standards for the determination of efficiency
- lack for harmonization of international markets
- differences in US and European standards
- missing definition of water quality.

And as a further challenge electrolyzer technology trends are still under dynamic development.

For the working group Other Production Methods the analysis for needs could not be completed and the technical development must be continuously monitored.

Also for the working group System Integration the analysis is still in progress. The main fields of consideration are the grid codes, the Smart Grit Architecture Model, interface to gas supply and gas storage.

Hydrogen Composition was found to be well included in technical rules at national, European and international level. There are already established verification systems for the transmission and trading of gases (including hydrogen), such as mass balancing, guarantees of origin and other certificates. The EU's Union Database is intended to ensure that there is no double marketing or double counting in future. Criteria for renewable hydrogen and its derivatives are defined by the Renewable Energy Directive, RED II. As need the following topic was identified: Sustainability criteria for hydrogen and hydrogen derivatives as energy carrier which requires a new technical rule.

D. *Hydrogen Infrastructure*

This cluster consists of the 8 working groups Piping, Transmission Pipelines, Plant Engineering, Distribution Networks, Stationary and Mobile Pressure Vessels, Underground Gas Storage and Liquefaction

The first 4 working groups have essentially already been discussed in the previous sections. Technical rules for this types of gas infrastructure are largely in place and only require minor adjustments. The DIN is the main rule setter for the needs identified for piping while DVGW is the main rule setter for the other gas infrastructure.

For Pressure Vessels there are a historically large number of standards and technical rules, some of which have to be adapted to the new requirements of a mass market. But on the other hand, the increasing economic importance of hydrogen is leading to new technologies that need to be standardized in order to gain market access.

In the field of Underground Storage, there are many standards on the storage of natural gas but these are not applicable to hydrogen. This requires the definition of new technical rules and a further analysis of standardization gaps.

For Liquefaction there are a large number of standards and technical rules that applicable to cryogenic hydrogen (LH2). Most of the standards are exclusively of international origin and therefore outside the direct sphere of influence of German and European technical rule-setting bodies. Therefore the European and German activities for standardization in this filed must be established. The key issue here is the lack of experts. The number of experts involved in this working group was limited to three to four persons.

E. Hydrogen Application

This cluster consists of a large number of 15 working groups. Their outcome is summarized by working group in the following sections.

Note: Some of the following summary statements are a direct citation from the analysis report [1] and are indicated accordingly, some are formulated and/or adapted by the author.

1) Fuel Cells

"With around 30 published standards, the topic of fuel cell energy systems is already well covered." One need was identified to standardize the general safety requirements for fuel cells.

2) *Power Plants, Turbines, CHP Plants*

"In 2023, the existing main standards for hydrogen quality, safety and control equipment … were compiled." Thus, only one need for adjustment has been identified.

3) (Petro)Chemical Industry

Here no specific needs are identified since hydrogen and hydrogen-containing media are known as the main products or by-products in this area. The working group found the industry to be well positioned and standardized.

4) Power-to-X

"PtX plants produce gaseous, liquid or solid chemical base materials, often using production processes already known and established in the chemical industry. Therefore, PtX plants can already be designed quite comprehensively with the existing technical rules."

5) Thermoprocessing equipment

"Industrial thermoprocessing equipment is covered by standards series at European level and international level (standards series ISO 13577)."

6) Steel industry

"Significant conversions of production plants show that the existing standards are suitable for implementing ongoing construction activities. Nevertheless, the bottom-up approach may reveal gaps in the future."

7) Domestic Applications

"A major advantage of technical rule-setting in this area is that it is already largely known and can be derived from the conventional "world of gas". This is also because Section 113 et seq. of the German Energy Industry Act considers the relevant DVGW technical rules to be generally recognized rules of technology for hydrogen distribution. "

8) Controls

"The working group determined that, with regard to controls, the existing technical rules only need to be supplemented to include hydrogen or hydrogen mixtures."

9) Commercial Applications

"...this [standardization] work is already largely known from the natural gas sector and can be transferred from that sector."

10) Filling Systems (for mobility)

"...most of the existing technical rules have so far been developed in the USA or at ISO level." Most cryogenic standards have been adopted to national standard DIN EN ISO. For gaseous hydrogen this is still missing.

11) Road vehicles

"A large number of standards and technical rules are already known in the field of road vehicles. Around 87 technical rules were identified, most of which were developed at European (CEN) and international (ISO) level..."

12) Railway Vehicles

"...standardization work in this area is still in its infancy."

13) Shipping

"...existing codes are reviewed, supplemented and further developed for the extension of hydrogen (gaseous, liquid) and its derivatives for use as a fuel."

14) Aviation

"As there are currently hardly any standards and technical rules for this sector, there is a need for standardization in several areas, such as refueling, test methods and cleanliness."

15) Special vehicles

"Identifying needs is a key challenge that has not yet been fully resolved"

F. Quality Infrastructure

This cluster consists of the 4 working groups Gas Analysis, Hydrogen Measurement Technology and Billing Methods, Metallic Materials, Composites and Plastics, Components for Infrastructure and Components for Application and Technologies.

For Gas Analysis there are only minor gaps identified. For the 4 other working groups the outcome of the analysis is similar and can be summarized with the following citation from the report [1]: "There are a large number of standards and technical rules that are currently applicable to natural gas but that need to be revised or adapted for operation with hydrogen."

G. Training, Safety, Certification

This cluster consists of the working groups Safety Design Principles, Cyber Security, Explosion Protection, Safety and Integrity Management, Product Certification and Training.

No or minor gaps were identified by the working group for Cyber Security, Explosion Protection, Product Certification and Training.

The results of the other two working groups Safety Design Principles and Integrity Management shall be discussed more in detail in the following section.

VII. NEEDS IDENTIFIED BY THE WORKING GROUP SAFETY DESIGN PRINCIPLES

The situation in this field of activity of the working group is pretty complex. On one hand, there are many technical standardization documents available and more than 80 of theses have been listed in the database. However, often these standards are non-European standards, that are not generally applicable or accessible and are not in line with European directives.

Here a wide range of international harmonization of technical rules and industry codes is required, which is also a main topic identified for most of the other working groups in this program. Were available and applicable the harmonized European standards provide common technical guidelines for manufacturer. But in contrast, the requirements for European operators and approval procedures vary greatly between the European states. These needs have not been elaborated in detail in the scope of this working group.

Although many international standards exist, it requires complex studies of a wide range of standards, to gather the context and transfer the safety requirements to a specific application. Nine ongoing and/or completed research projects were identified, that focus on the definition of safety design principles. In the legal German framework 17 documents were identified, that specify objectives for the safety, but not the technical implementation of safe design principles.

In general hydrogen is a well-known gas and safety-related experience exist, but mainly in specific industrial areas. The transformation to a hydrogen economy entails many changes, which nevertheless create new risks.

Because of the complexity of existing standards and the dynamic market and technical development is was a challenge to identify rule setters that can and are willing to take over the identified needs and define further standardization projects. The defined needs and the status as per September 2024 is summarized in Table I.

TABLE I
Needs for Safety Design Principles

Need	Status (Sep. 2024
Manual on accidents and incidents at hydrogen plants	On hold. No specific standardization project foreseeable. Ref. to Safety and Integrity Management
Ready-to-use systems – general requirements	Potential coordination with committees in discussion
Vent stacks and flare stacks, exhaust systems	Search for a potential rule setter and definition of the scope of required standardization
Release models/impact assessments	This topic has been taken over by the VDI
Catalytic recombiners	This topic has been taken over by the PTB for a potential research project
Requirements for gas tightness	The plan is to prepare an IEC/TS and to harmonize it by CEN/TC 305

VIII. NEEDS IDENTIFIED BY THE WORKING GROUP SAFETY AND INTEGRITY MANAGEMENT

The progress of work in this working group is summarized in the analysis report [1] with following key statements:

"15 standards and technical rules were identified that deal with technical requirements and the organization of functional safety within the scope of the working group. This can be roughly divided into three areas. First, standards and technical rules are named that deal generically with risk management, i.e. how risks can be systematically recorded and evaluated, and measures for risk reduction derived. The supply infrastructure is a focal point here. Second, specific technical plant components, such as fuel cells and electrolyzers, are considered in their places of use. A third part deals with the management of the organization, which is responsible for placing safe products on the market through appropriate measures."

Another area of activity was on the analysis of incident and event databases. These have been established to share lessons learned with the related stakeholder. Based on this information manufacturers or operators can review and improve their systems. However, the solutions available to date are still very limited in their benefits.

In a specific expert group an assessment of strength and weaknesses of existing incident databases has been realized. Based on this analysis a proposals for a "perfect" database system and for a further international project to improve the situation have been elaborated. The outcome of this work will be presented at the upcoming conference ICHS 2025 in October 2025 under the title "Considerations on incident databases to support the safe introduction of hydrogen in the energy sector and new applications".

IX. LEVEL OF STANDARDIZATION MATURITY

An assessment of the maturity levels is only possible with some uncertainties due to the highly summarized reports from the working groups. As discussed in the chapter V. a specific field may have few identified gaps, because the standardization is already very mature. But the situation can also be very different. As example the technological level in a specific field may be very premature by its nature and/or if there was no sufficient expert participation in a working group due to various obstacles. Also it has to be kept in mind, that the task setting of the program was the identification of gaps in German standardization. If a large number of gaps in standards has been identified by a working group, this may simply mean that only the relevant national standards are missing, but international standards are available.

Based on the statements in the analysis report [1], the following maturity assessment can be derived.

TABLE II
Evaluation of the level of maturity of standardization based on the analysis report [1] from German perspective

Production 4.1	4.1.1 Electrolysis	some gaps
	4.1.2. Other production methods	Premature
	4.1.3 Total system integration	Premature
	4.1.4 Hydrogen composition	some gaps
	4.1.5. Verification and sustainability aspects of hydrogen	some gaps
Infrastructure 4.2	4.2.1 Piping	minor gaps
	4.2.2 Transmission pipelines	minor gaps
	4.2.3 Plant engineering	minor gaps
	4.2.4 Distribution Networks	minor gaps
	4.2.5 Stationary and mobile pressure vessels	some gaps
	4.2.6 Underground Storage	Premature
	4.2.7 Liquefaction	Premature (National standards)
Application 4.3	4.3.1 Fuel Cells	minor gaps
	4.3.2 Power plants, turbines, CHP plants	minor gaps
	4.3.3. (Petro)chemical industry	no gaps
	4.3.4 Power-to-X	minor gaps
	4.4.5 Thermoprocessing equipment	minor gaps
	4.3.6 Steel industry	no gaps
	4.3.7 Domestic applications	some gaps
	4.3.8 Controls	some gaps
	4.3.9 Commercial applications	some gaps
	4.3.10 Filling Systems	some gaps
	4.3.11 Road vehicles	some gaps
	4.3.12 Railway vehicles	Premature
	4.3.13 Shipping	Premature
	4.3.14 Aviation	Premature
	4.3.145 Special vehicles	Premature
Quality Infrastructure 4.4	4.4.1 Gas analysis	minor gaps
	4.4.2 Hydrogen measurement technology and billing methods	some gaps
	4.4.3 Metallic materials	some gaps
	4.4.4 Composites and plastics	some gaps
	4.4.5 Components for infrastructure	some gaps
	4.4.6 Components for application and technologies	some gaps
Training, Safety and Certification 4.5	4.5.1 Safety design principles	some gaps
	4.5.2 Cyber security	no gaps
	4.5.3 Explosion protection	no gaps
	4.5.4 Safety and integrity management	some gaps
	4.5.5 Product certification	minor gaps
	4.5.6 Training	minor gaps

X. FURTHER SPECIFIC ASPECTS OF INTEREST

A. Release of hydrogen to the atmosphere

The release of hydrogen to the atmosphere was discussed in various meetings of different working groups. This includes the desired release, for example during process-related purging procedures, but also the undesired release due to leaks, failures in filling processes or incident scenarios. In the author's opinion, such releases were too often classified as unproblematic with blanket statements, since it is assumed that hydrogen clouds would quickly dissipate in such cases and in outdoor applications.

Firstly, the damage scenarios should be taken into account especially for mobility applications, because the release of hydrogen clouds as example over the roof of a railway vehicle in the event of a fault is by no means safe when damage scenarios, such as an overturned railway carriage, are taken into account.

Above all, it must be noted that hydrogen is not directly a greenhouse gas, but does have a significant greenhouse effect through indirect effects in the atmosphere. According to a study published by the German Öko-Institute (Institute for Applied Ecology) the indirect greenhouse gas potential (Global Warming Potential, GWP) for hydrogen is estimated at 6 to 16 over a period of 100 years (GWP100) and 18 - 50 over a period of 20 years (GWP20) [6]. As known the reference greenhouse gas is CO_2 and associated with a GWP of 1.

Therefore, in all applications, the predominant interest should be to avoid hydrogen releases into the atmosphere, e.g. by using passive catalytic re-combiners, which can be found in concrete applications as example in the nuclear industry and in sealed lead-acid batteries. And even small leakage losses that do not pose a safety risk should not simply be accepted carelessly for reasons of climate protection.

To be mentioned in this context: Water vapor also has a strong greenhouse effect, but water vapor does not represent an anthropogenic greenhouse effect because the atmosphere only absorbs a certain amount of water vapor, depending on its temperature. And water vapor only stays in the atmosphere for a very short time, about 10 days. In this respect, flaring of H2 is preferable to its direct release to the atmosphere.

B. Ignition of hydrogen clouds through partial discharges

There were also some discussions in various working groups regarding the standards for lightning protection. The question was whether more extensive regulations were needed for lightning and explosion protection for hydrogen systems and the dangers posed by lightning during thunderstorms. The opinion of the experts in the working group Explosion Protection was that everything regarding lightning protection was adequately regulated.

In this context, this primarily refers to the electrical standards for lightning protection. These serve to divert dangerous lightning discharges and protect the electrical installation from dangerous over voltages. With the implementation of a proper building lightning protection, the prerequisites for the safe operation of electrical devices with, for example, ATEX certification are met.

However, in the author's opinion, the danger of partial discharges may be overlooked. The risk potential from partial discharges is not limited to the scenario of a thunderstorm. Partial discharges also occur on high-voltage lines and equipment, and corona discharges are also a phenomenon that can occur in the preliminary phase of a thunderstorm where there is no actual lightning activity.

It is generally known that such partial discharges represent an ignition source, but there are no known cases of damage in which such a partial discharge would have ignited a hydrocarbon gas or vapor. This is because such partial discharges generate too little energy to ignite hydrocarbon gases or vapors. But in the case of hydrogen clouds, the necessary ignition energy can certainly be achieved through partial discharges.

These phenomena have not yet been comprehensively investigated and prepared for use in technical regulations. So there are no regulations that state which safety distances must be considered from a potential hazardous area, for example an outdoor filling station, and high-voltage devices and/or possible discharge points on the top of buildings and infrastructure.

This example shows that it can easily happen that based on previous application experience, in this example the question regarding lightning and explosion protection in hydrogen systems, the regulations used are rated as sufficient in the expert review, but that certain phenomena that are relevant to hydrogen are not yet covered.

XI. CONCLUSIONS

The numerous activities to analyze the existing standards and close gaps in standardization at the various national and international levels are very systematic and of high intensity. The participation of many hundreds of experts ensures a comprehensive assessment of the technical regulations. And the international networking of the standardization bodies also ensures international coordination.

Nevertheless, there are some risks associated with hydrogen transformation, namely:

- applications in new industries and as a storage technology
- innovative system concepts
- usage at a bigger industrial scale
- new materials and components
- an extended non-professional group of people, e.g. employees and users
- the consideration of non-atmospheric conditions (outside of: 0,8 bar to 1,1 bar, –20 °C to +60 °C and oxidizing agents other than air);
- use in public spaces

The work on the technical regulations makes a lot of sense, but against this background of changes and innovations they cannot ensure for 100% that all necessary standardization aspects related to hydrogen are recognized and taken into account.

In order to reduce risk, in addition to the review and adjustment of standards and creating new standards, it is particularly important that the relevant user groups receive good training about hydrogen and its safety aspects.

And it also seems urgent that information about undesirable incidents is made known to the world's experts as quickly and transparently as possible so that we can move through the learning curve quickly and, if possible, without serious cases of damage. As already mentioned before, this will be the topic of a specific paper at the ICHS 2025.

XII. ACKNOWLEDGMENTS

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XIV. VITA

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