STANDARDIZATION ROADMAP
FOR HYDROGEN TECHNOLOGIES

STANDARDIZATION ROADMAP HYDROGEN TECHNOLOGIES 2024

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FOREWORD

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Dear Reader,

The energy transition is a decisive step towards a sustainable and climate-friendly energy supply. Hydrogen plays an important role as an energy carrier of the future and is a promising option for reducing dependence on fossil fuels and cutting greenhouse gas emissions. In order to successfully realize the upscaling of the hydrogen market, a reliable and congruent set of technical rules is required. Standards and technical rules create a uniform understanding across specialist areas and enable hydrogen technologies to be scaled up. They are groundbreaking guidelines for technologies, infrastructures and quality standards, and create trust in technologies that are "Made in Germany".

The publication of this Standardization Roadmap Hydrogen Technologies, which you are holding in your hands, presents the status quo of the analyses of existing and required standards and technical rules in the field of hydrogen technologies.

The results of these analyses serve as a coordinated roadmap and uniform standardization strategy for Germany's hydrogen economy. These results are to be seen as tools for successfully representing German interests on the European and international stages.

In order to cover the detailed range of the entire hydrogen value chain this Standardization Roadmap, funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK), is jointly organized by the nationally responsible organizations for rule-setting and acknowledged standardization organizations. This provides a platform that enables stakeholders in the hydrogen economy to engage in a comprehensive exchange on the topic of standardization and technical rule-setting, to contribute their needs in a targeted manner and to advance projects to expand the technical rules.

The project partners involved consider the importance of the Standardization Roadmap Hydrogen Technologies as follows:

Christoph Winterhalter (DIN): "Hydrogen is a key building block for a sustainable, safe, secure and affordable energy supply. For us as a standardization organization, it is important that we have succeeded in bringing together all involved and interested parties in the development of the Standardization Roadmap Hydrogen Technologies in order to create a recognized roadmap, combined with a strong commitment to joint implementation."

Michael Teigeler (DKE): "Hydrogen clearly has the potential to sustainably change many value chains and trade relations internationally. We must use safety standards to ensure that this technology is accepted more quickly and, of course, positively by society."

Prof. Dr. Gerald Linke (DVGW): "The topic of hydrogen affects all branches of industry, whether they be concrete, steel, glass or mobility, but of course the energy industry itself as well. We therefore need this synergetic process and the expertise from all sectors that we are contributing to this Standardization Roadmap."

Marko Kurt Schreiber (NWB): "In rail transport, alternative propulsion concepts make a significant contribution to climate protection, especially for the use on non-electrified lines. Standards are an essential success factor for manufacturers, approval authorities and operators in order to obtain planning security for the development, approval and operation of the important energy carrier hydrogen. The Standardization Roadmap Hydrogen Technologies is an ideal platform for pooling expert knowledge and shaping a sustainable future."

Hildegard Müller (VDA): "The Standardization Roadmap Hydrogen Technologies can serve as a model for other countries to jointly develop standards and specifications. There is also the hope that technical rules initiated as part of this project will be adopted in Europe or even worldwide."

Dieter Westerkamp (VDI): "This requires the involvement of a large number of partners, i.e. manufacturers, infrastructure providers, end users and representatives of society as a whole. In participating, we can define the content of the standards together with others and thus shape the scaling-up of the hydrogen economy."

Hartmut Rauen (VDMA): "In mechanical engineering, we are positioned with our technologies at the centre of the hydrogen economy, we represent manufacturers of machinery and equipment for hydrogen production, conversion and use, e.g. in the product worlds of electrolysers, fuel cells, H_2-ready gas turbines or mobile machinery as users of e-fuels – as well as manufacturers of production equipment for the fuel cell stack, for example."

We would like to thank everyone who contributed to this version of the Standardization Roadmap Hydrogen Technologies. We would especially like to thank the more than 600 authors and contributors who developed this Standardization Roadmap collaboratively and by consensus, thus making this project possible in the first place.

We hope you enjoy reading this Roadmap and look forward to your active support in implementing the Standardization Roadmap, as it does not mark the end, but rather the start of the implementation of the recommendations for action in the technical standardization bodies of all partners involved.

We are convinced that standardization and technical rule-setting will create the framework conditions for a successful scaling-up of the hydrogen market. Let’s take on this challenge together!

Your

Christoph Winterhalter

Michael Teigeler

Prof. Dr. Gerald Linke

Marko Kurt Schreiber

Hildegard Müller

Dieter Westerkamp

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INTRODUCTION BY THE FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND CLIMATE ACTION

Dr. Franziska Brantner
Parliamentary State Secretary at the Federal Ministry for Economic Affairs and Climate Action

Dear Readers,

intelligent and innovative approaches are still needed to ensure that the energy transition can be successfully implemented. Hydrogen as an energy carrier of the future offers a promising solution for contributing to sustainability and counteracting climate change.

Germany's goal is to achieve climate neutrality in all sectors by 2045. A special focus is on the decarbonization of the energy sector. By 2030, at least 80 % of electricity is to come from renewable energies. Climate-neutral electricity forms the basis for making heat supply and mobility climate-neutral. Hydrogen can be used for this purpose, particularly in areas that are difficult to electrify. Hydrogen power plants will also play an essential role in ensuring security of supply to compensate for times when no wind or solar energy is available.

The importance of hydrogen is also underlined by the National Hydrogen Strategy. The German government wants to use this strategy to promote the use of climate-friendly hydrogen technologies in order to make an important contribution to achieving greenhouse gas neutrality. In addition, the European Commission presented the EU Hydrogen Strategy in July 2020 as part of the implementation of the European Green Deal. This strategy also aims to decarbonize hydrogen production and replace fossil fuels.

In addition to hydrogen's potential as an energy carrier, safety aspects should not be neglected. This requires framework conditions and guidelines that support and promote the establishment of hydrogen technologies on the market.

Against this background, the continuous development of technical standards and specifications at national, European and international level is of enormous importance. This is also addressed in Germany's National Hydrogen Strategy, e.g. with regard to the development of quality and sustainability standards, as well as the international harmonization of standards for mobility applications for hydrogen and fuel cell systems.

Through timely standardization, German industry can also position itself in this context at European and international level by defining key measurement methods and requirements during the development of new products and processes. Against this background, this Standardization Roadmap Hydrogen Technologies coordinates a national approach.

However, we must also strengthen Germany's strategic role in international standardization. The Federal Ministry for Economic Affairs and Climate Action (BMWK) has therefore convened the German Strategy Forum for Standardization, a body of leading figures from companies, associations, science, standardization organizations and the public sector, which – since the beginning of 2023 – has been advising the federal government on strategic issues relating to standardization and the recruitment of urgently needed experts. When it comes to the central topic of hydrogen, the recommendation for a successful market ramp-up is clear: Standardization and rule-setting players must coordinate more closely in order to strategically pool our resources and activities and align them with international standardization.

The Standardization Roadmap Hydrogen Technologies is an important step for the future viability of our sustainable economy and climate protection. It will help ensure that standards and specifications for hydrogen technologies are uniform and reliable. This is an important prerequisite for companies and research institutions to be able to plan and work successfully in this area. We are convinced that the implementation of the recommendations for action identified will help to make the best possible use of the potential of hydrogen technologies and at the same time minimize the risks.

I would like to thank all the experts involved and everyone at DIN, DKE, DVGW, NWB, VDA, VDI, and VDMA for their outstanding work. In addition to the implementation projects that have already been initiated, it is now also important to realize the identified needs for action. All stakeholders involved in standardization are called upon here. Get involved and seize the opportunity to help shape the rules of the game for hydrogen technologies.

Your Franziska Brantner

Dr. Franziska Brantner

Parliamentary State Secretary at the Federal Ministry
for Economic Affairs and Climate Action

STEERING COMMITTEE

The members of the Steering Committee include high-ranking representatives from industry, politics, science and civil society. The Steering Committee guides the content and gives the strategic direction of the Standardization Roadmap Hydrogen Technologies, provides impetus for the bodies of the Roadmap, and recommends prioritized standardization projects to be funded.

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The members of the Steering Committee are listed on page 221.

SUMMARY

On behalf of the Federal Ministry for Economic Affairs and Climate Action, work on the Standardization Roadmap Hydrogen Technologies began in early 2023 under the leadership of the project partners DIN, DKE, DVGW, NWB, VDA, VDI, and VDMA.

The aim of the joint project is to develop a strategic roadmap for a rapid and targeted expansion and adaptation of technical rules in the field of hydrogen technologies and to efficiently close the identified gaps. This is being done in close cooperation with the national organizations for standardization and technical rule-setting, as well as in joint collaboration with a network of experts from industry, politics, science, and civil society.

The project thereby complies with the expert recommendation of the Hydrogen Research Network to "draw up a standardization roadmap to describe a framework for action that strengthens German industry and science in international competition and creates innovation-friendly framework conditions for the technology of the future (status quo and needs analyses)" [1]. In addition, the demand for uniform standards to support the scaling-up of the market will be taken up by updating the National Hydrogen Strategy.

This Strategy is being developed in 39 working groups with the participation of more than 600 experts. There are five major topic areas that cover the entire value chain:

→ Production
→ Infrastructure
→ Application
→ Quality infrastructure
→ Training, certification, and safety

As an important milestone, the status quo of standardization was determined, which is presented in the public and freely accessible Standards Database for Hydrogen Technologies with more than 850 entries. Based on this, needs were identified, recommendations for action were derived and specific projects for standardization and technical rule-setting were recommended.

A total of around 180 needs and recommendations for action for technical rule-setting were identified. Many of these are aimed at adapting and further developing European and international technical rules.

The rapid and efficient implementation of these recommendations is an important factor and, for the high-priority projects, is specifically supported by funding. In total, the joint project is currently supporting the development of more than 20 standardization and technical rule-setting projects at national, European and international level in areas such as generation, transport, storage, infrastructure, industry and mobility.

This first publication of Standardization Roadmap Hydrogen Technologies provides an overview of the activities and results of the joint project to date. To this end, Section 1 classifies the role of hydrogen as an energy carrier in the context of the energy transition and for Germany in particular. The Roadmap explains how technical rule-setting can enable and support the planned market ramp-up of the future technology and, in Section 2, provides an overview of the standardization landscape and the stakeholder environment of the Standardization Roadmap. Section 3.1 illustrates the difference between the Standardization Roadmap and standardization work itself. Then, Section 3.2 describes the objectives and tasks, and Section 3.3 explains the procedure and methodology used in the project.

The main focus of this publication, however, is on the results obtained to-date (Section 4). Subdivided according to the respective fields of action, this section shows which technical rules can already be applied to hydrogen, which challenges currently exist in the various areas and must be faced before the necessary technical rules are available in full, and which steps the project has already taken to follow this path.

Finally, the status quo is presented and an outlook is given for the further work on the project until the end of 2025 (Section 5).

1 Introduction

Climate change is one of the most pressing and complex problems of our time. The rise in the global average temperature is accompanied by far-reaching changes that affect ecosystems, the economy, society and people's quality of life.

2023 was the warmest year since weather records began [2], while greenhouse gas emissions from the combustion of fossil fuels have reached an all-time high [3], [4]. The increasing frequency of extreme weather events such as droughts, heat waves, and heavy rainfall, as well as the global rise in sea levels and the significant loss of biodiversity, clearly demonstrate the far-reaching effects of anthropogenic climate change.

The energy transition plays a decisive role in limiting the extent of climate change and keeping global warming below 1,5 °C [5]. This transition not only affects the energy sector and the associated moving away from fossil fuels and the expansion of renewable energies such as solar, wind and hydropower. The defossilization of the industrial, transport, and heating sectors is also essential to achieve the global climate targets. As an energy carrier, storage medium, and an element of sector coupling, hydrogen is considered a central component for this desired transformation, especially in the difficult-to-electrify sectors of buildings, (heavy-duty) transportation and industry [6]. In addition, environmentally-friendly generated hydrogen forms the basis for the synthetic production of ammonia, methane, and methanol and is therefore used in a wide range of applications beyond electrification.

An overview by the World Energy Council [7] clearly shows that a large number of countries around the world are pursuing or currently developing national hydrogen strategies. This overview is presented in Figure 1.

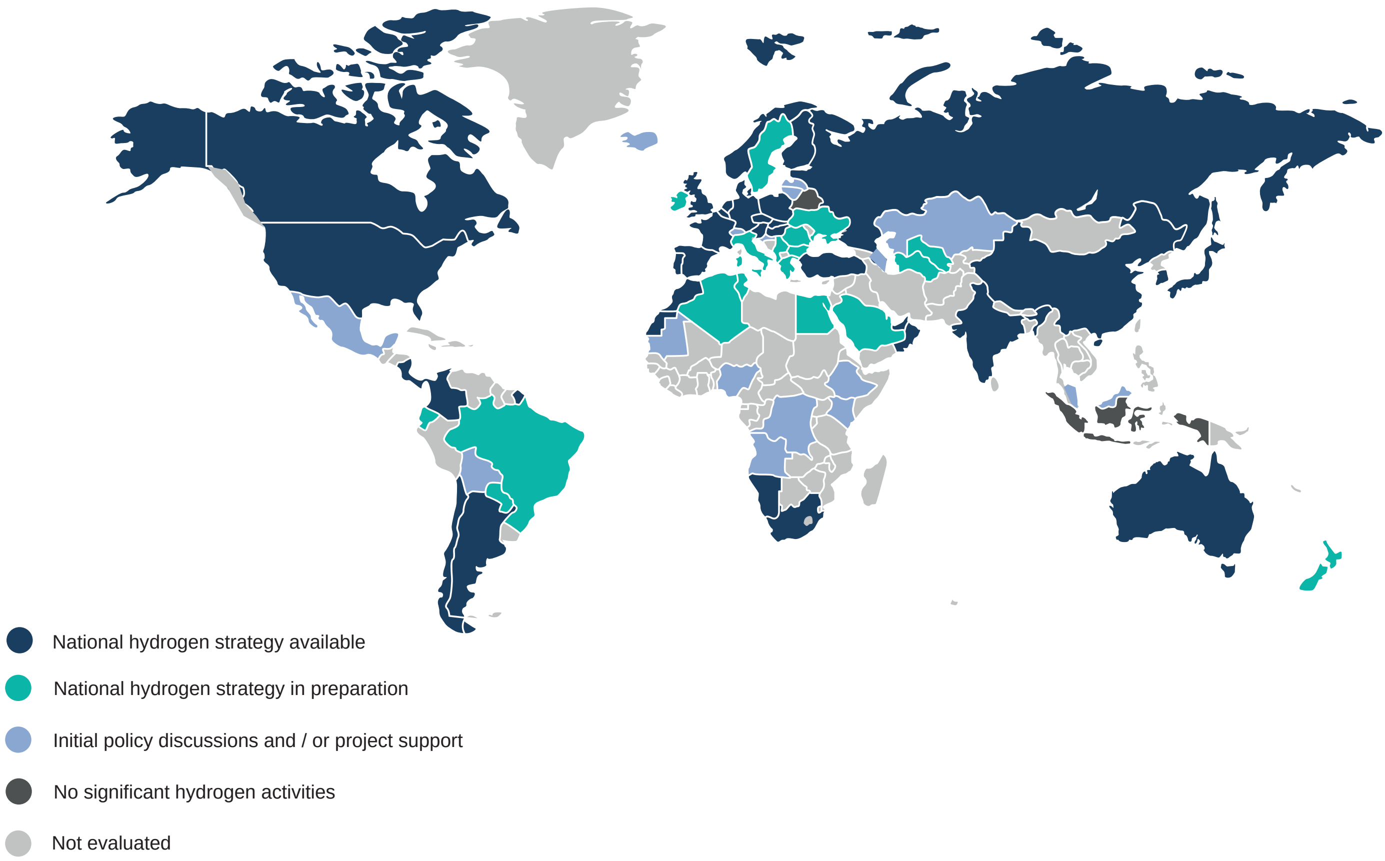

Figure 1: Overview of global national hydrogen strategies (Source: own illustration along the lines of [7])

In 2020, the European Hydrogen Strategy [10] was adopted as part of the European Green Deal [8] and the Fit for 55 Package [9] to achieve climate neutrality by 2050. The National Hydrogen Strategy (NWS) adopted by the German government, which was confirmed and continued in 2023 [6], aims to accelerate the market scaling-up of hydrogen technologies and establish the development of a domestic market in Germany for this purpose.

Standardization and technical rule-setting, together with the legal framework, form the basic framework for the successful implementation of these hydrogen strategies and thus also for a sustainable upscaling of the hydrogen technologies market. They define requirements for products, services or processes and thus promote rationalization and quality assurance in industry, technology, science and the public sector. By setting technical rules, a uniform understanding is created across specialist areas in order to break down technical barriers and ensure greater market security.

For example, compliance with standards and technical rules ensures the safe handling of hydrogen, defines reliable and reproducible measurement methods, and specifies materials that are suitable for the use of hydrogen. Standards and technical rules also define uniform interfaces to enable the interaction of market players and create a common economic basis.

“Coherent regulatory conditions at national, European and, if possible, international level will support the market ramp-up [of hydrogen]. They will primarily include […] uniform standards and certification systems […]”. With these words, the German Federal Government emphasizes the need for standardization and technical rule-setting in the field of hydrogen technologies in the update of the strategy [6].

The European Clean Hydrogen Alliance (ECH2A) report from October 2021 also emphasizes the importance of uniform standards and technical rules, and cites the lack of these as one of the key hurdles to the introduction of hydrogen technologies and applications [11].

Standards and technical rules therefore provide a basis for creating a uniform understanding and rules of the game across sectors, borders and market participants so that the future hydrogen economy can mesh seamlessly. In this way, a coherent value chain can be established that meets the highest standards of safety and security, economy, efficiency and climate protection.

2
Standardization and technical rule-setting in the hydrogen sector

Various bodies already exist at national, European and international level for standardization and technical rule-setting in the field of hydrogen technologies. There are also bodies at all three levels for existing standards and technical rules that were not explicitly developed in the field of hydrogen, but which can be transferred to the field of hydrogen technologies. In addition, there are projects and initiatives by other stakeholders and interest groups that contribute to consensus-building and the exchange of interests regarding hydrogen technologies. Building on these activities, the objectives and content of the Standardization Roadmap Hydrogen Technologies serve as guidelines for standardization and technical rule-setting.

2.1 Standardization landscape

Thanks to the large number of existing standardization and technical rule-setting bodies in the field of hydrogen technologies, there is already a broad basic framework of standards and technical rules. The basic structure and organization of the standardization bodies are shown in Section 2.1.1. The relevant bodies, standards and technical rules for hydrogen technologies are discussed in Section 2.1.2.

2.1.1 General information on standardization and technical rule-setting

Technical rules are developed in various organizations at national, European and international level in self-administration by the stakeholders. At the beginning there is always a need of the stakeholders. Standards and technical rules also play an important role as instruments for supporting and implementing legal regulations and provisions. 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 Standards Institute). The respective national standards organizations are members of ISO, IEC, ITU, CEN, CENELEC and ETSI (see Figure 2). In Germany, these national organizations are DIN and DKE. The national standards organizations send delegations to the European or international standards bodies to represent the interests of the individual countries on a particular topic.

In addition to DIN and DKE, there are other recognized national 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 legislator, who cites these institutions directly in laws. Thus, the DVGW is the legally recognized rule-setting institution for gas and hydrogen within the meaning of the Energy Industry Act (EnWG), just as the VDE is responsible for setting technical rules in the electricity sector under this Act.

Standards and technical rules are the result of national, European or international specifications by experts in the respective field. They are drawn up by technical bodies in accordance with defined principles, procedures and rules of presentation. All interested parties, such as manufacturing companies, consumers, the trades, universities, research institutes, authorities, testing institutes, associations etc., can participate in the work of the committees.

Standards are developed by consensus. This means that experts come to agreement on the state of the art and on standards contents that take the interests of all parties into consideration. European and International Standards ensure a common understanding among market players worldwide and thus support the removal of barriers to trade. European Standards are always adopted at national level in Germany. Any existing national standards that contradict the content of a European Standard must be withdrawn and are therefore no longer valid. A large number of European directives exist that are to be supported and implemented by European and national standardization (harmonized standards). This is an essential building block for ensuring the free movement of goods and the functioning of the European single market. International standards, on the other hand, do not have to be adopted as national standards.

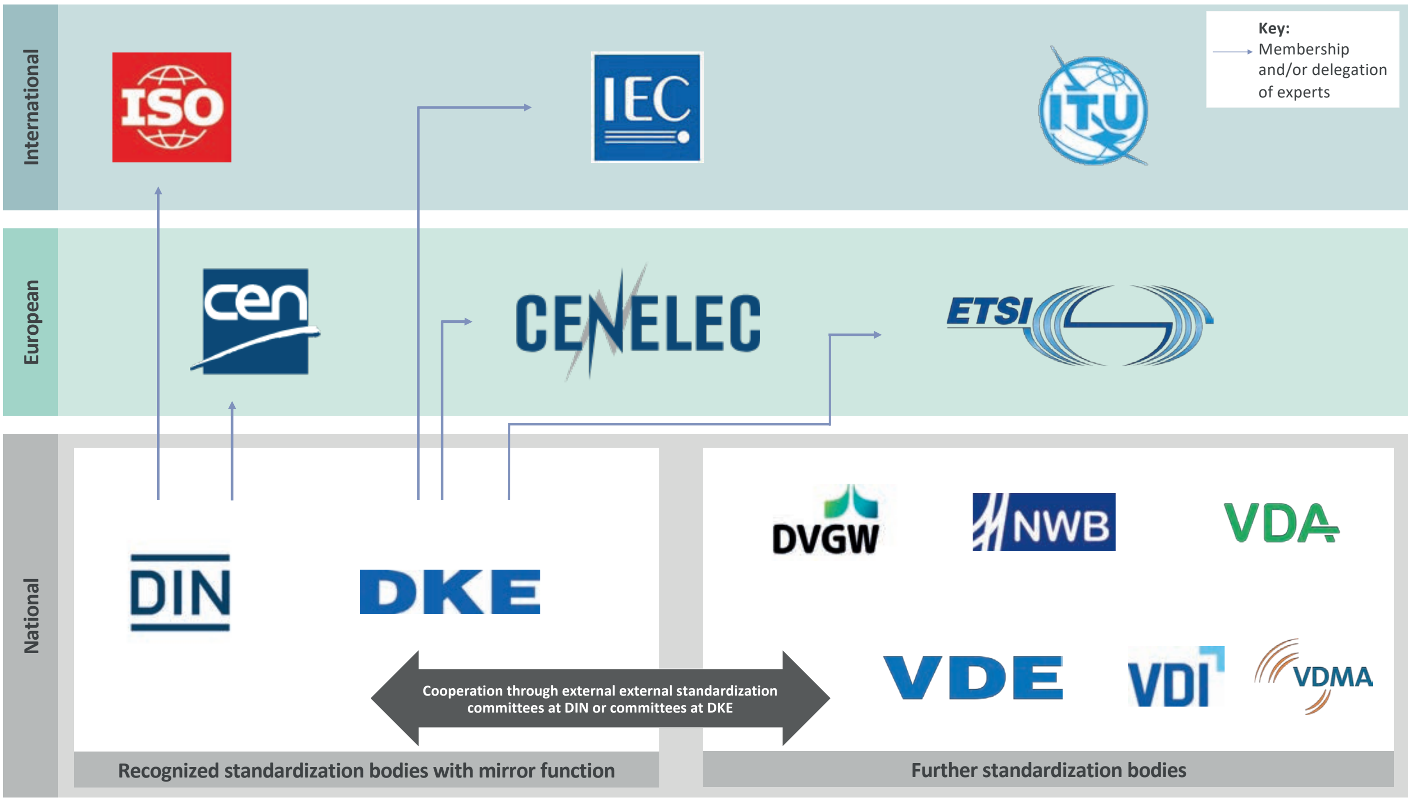

Figure 2: Overview of standardization organizations and technical rule-setting institutions (Source: own illustration)

As a rule, the use of standards and technical rules is voluntary. However, they can be made binding by referencing them in a law or in a contract. If work is carried out based on a standard or technical rule, this can be invoked in case of doubt. They therefore provide security for those who use them.

Within the scope of this Roadmap, standardization documents of the national standardization organizations, the European standardization organizations (CEN/CENELEC/ETSI) and the international (standardization) organizations (ISO/IEC/ITU) are considered, as well as a large number of other technical rule collections. These technical rules include DVGW technical rule – codes of practice and guidelines, technical reports (TR), technical specifications (TS), VDE application rules (VDE-AR), VDI standards, etc. Other documents considered with a regulatory character include specifications such as pre-standards, consortia standards, technical recommendations, DIN SPEC, VDE SPEC, VDI expert recommendations or VDMA Specifications. Standards are documents published by recognized national standards organizations such as DIN or DKE in Germany or, for example, ANSI (American National Standards Institute) in the U.S., as well as the above-mentioned European and international standards organizations.

2.1.2 Currently relevant standardization bodies for hydrogen technologies

Various standards and technical rules relevant to hydrogen technologies have already been established along the entire value chain. A wide range of aspects of hydrogen technology are covered at national level in Germany. Standards and technical rules – from safety standards for handling hydrogen, to various infrastructure topics such as transport and valves, to the characterization of hydrogen as a fuel and its use in various applications – are being developed in over 100 national bodies.

At European level, standards relating to hydrogen as an energy source and carrier are being developed within the CEN- and CENELEC bodies to ensure interoperability and safety throughout the EU. These standards relate, for example, to the storage, transmission and use of hydrogen in various applications. All CEN/CENELEC bodies are mirrored at national level. The content is transferred to national standards in these national mirror committees.

Internationally, various ISO Standards for hydrogen aim to establish uniform global standards for hydrogen technologies in order to facilitate smooth integration and cooperation between countries. There are already a large number of bodies for this purpose, which are also mirrored at national level. ISO/TC 197 Hydrogen technologies, led by the Standards Council of Canada (SCC), is currently the only international committee that deals exclusively with hydrogen technologies. This body deals with "standardization in the field of systems and devices for the production, storage, transport, measurement, and use of hydrogen" [12]. In addition, hydrogen is one of many topics dealt with in the various ISO bodies. IEC and ITU are also active internationally in setting technical rules in the hydrogen sector. Their work is mainly mirrored in Germany in the work of DKE and VDE.

A comprehensive analysis of the existing standards and technical rules has been carried out as part of the work on this Roadmap. The result is the Standards Database for Hydrogen Technologies. It lists over 850 documents drawn up in almost 270 bodies at national, European and international level. For example, more than 60 documents are already available in the field of hydrogen production. There are already over 700 documents in the areas of infrastructure, application and quality infrastructure.

2.2 Actors in the hydrogen technologies environment

The importance of standards, specifications, and a uniform set of technical rules for a successful market acceleration of hydrogen technologies is emphasized in various national, European and international strategies and publications. The key activities are highlighted below, although the rapidly evolving environment means that no claim is made to completeness.

The German government's National Hydrogen Strategy [14] and its Update [6] formulate the need for scientifically recognized and standardized measurement methods and evaluation criteria, as well as internationally acknowledged standards and technical rules. The international harmonization of standards and technical rules regarding mobility applications for hydrogen and fuel cell systems, such as refuelling standards, hydrogen quality, calibration and approval of ships, is also named as a concrete measure. Thus, as part of the Hydrogen Innovation and Technology Centre [15], a testing, inspection and development environment is to be explicitly created, which will also contribute to the development of standards and technical rules. The importance of uniform, internationally acknowledged sustainability standards and certification systems is emphasized, without which no sustainable ramp-up of the hydrogen market is possible.

The European Hydrogen Strategy [16] emphasizes that the EU's leading position in international forums for standards and technical rules, regulations and definitions in the hydrogen sector should be strengthened. This requirement is also highlighted in the EU Standardisation Strategy [17] issued in February 2022. The strategy aims to make European standardization once again an element of a resilient, green and digital EU single market and to strengthen the role of the European standardization system throughout the world. Standards that support the development of the clean hydrogen [17] value chain are explicitly highlighted as standardization "urgencies" in the EU Standardisation Strategy. These standards proposals are to be implemented as a matter of priority and quickly by means of standardization requests issued by the Commission.

One result of the EU Standardisation Strategy was the establishment of the High-Level Forum on European Standardisation [18] in January 2023. The Workstream Clean Hydrogen of the Forum recommends accelerating and prioritizing the development of standards for hydrogen technologies and European participation in international standardization projects. On the occasion of the founding of the European Forum, the German Strategy Forum for Standardization [19] was constituted in February 2023 by the Federal Ministry for Economic Affairs and Climate Action, which is responsible for standardization policy within the German government. The National Strategy Forum for Standardization will not only reflect the work of the European Forum, but will also specifically strengthen and expand the role and participation of German experts in European and international standardization. For an overview of activities relating to hydrogen in standardization and technical rule-setting, the Strategy Forum refers to the results of this Roadmap.

The European Clean Hydrogen Alliance Working Group on Standardization (ECH2A WG) was founded as a result of the 2021 report published by the European Clean Hydrogen Alliance [11], [20] which identified the lack of standards as one of the key hurdles to the introduction of hydrogen technologies and applications. Within one year, the members of the Working Group developed the Roadmap on Hydrogen Standardization [17], which was published in March 2023. That roadmap highlights standardization priorities for production, infrastructure, industrial applications, mobility, sector coupling in the energy sector, buildings and cross-cutting issues. These findings have been incorporated into the development of this Standardization Roadmap Hydrogen Technologies.

At international level, a number of initiatives and projects are concerned with supporting pre-normative research projects, promoting the participation of experts in standardization work and closing gaps in standardization. Examples include the International Partnership for a Hydrogen Economy (IPHE) [21], Hydrogen Council [22], International Renewable Energy Agency (IRENA) [23] and United Nations industrial development organization (UNIDO) [24]

At the international political level, the importance of the development and mutual recognition of international standards and certification schemes for a successful scaling-up of the hydrogen market is emphasized. This is highlighted, for example, in the Communiqué of the G7 Ministers for Climate, Energy and the Environment published in spring 2023 [25]. At COP 28 in December 2023, the joint declaration of intent on the mutual recognition of certification schemes for renewable and low-carbon hydrogen and hydrogen derivatives was presented, which has so far been signed by 36 nations [26]. This declaration lays an important foundation for cross-border trade in renewable and low-carbon hydrogen.

In addition to the aforementioned political initiatives and contributors, research projects are another important building block for the development of standards and technical rules. There are a large number of national, European and international initiatives and research projects whose results are significantly advancing the state of the art in hydrogen technologies. One international initiative is the IEA Hydrogen Technology Collaboration Programme (Hydrogen TCP) [27]. Since its foundation in 1977, this research and development programme has carried out around forty tasks on specific hydrogen topics, including pre-normative research and standards development.

The Clean Hydrogen Partnership plays an important role in financing research projects at European level. The Clean Hydrogen Partnership is currently funding several projects for pre-normative research in the areas of safety, filling stations, hydrogen-natural gas blending, hydrogen applications for shipping and hydrogen quality [28]. In addition, the Partnership of Metrology [29] is funding numerous projects that will enable the European Metrology Networks (EMN) to meet future metrology needs in a targeted manner. The EMN Energy Gases under EURAMET e.V. plays a key role with regard to hydrogen [30].

In Germany, the Hydrogen Flagship Projects [31] of the Federal Ministry of Education and Research and the Transfer Research Trans4Real of the living labs of the energy transition [32] of the Federal Ministry for Economic Affairs and Climate Action, as well as the innovation research programme of the DVGW [33] should be mentioned. A publication on standardization in the field of hydrogen from a legal and technical perspective was issued at the beginning of 2023 as part of Trans4Real [34]. The DVGW's innovation programme focuses on the transformation of grid-based energy supply to climate-neutral gases –

with the main focus on hydrogen – and provides findings for the development of the corresponding technical rules. The Hydrogen Research Network, the national network for experts from research and practice, also takes standards and technical rules into account as part of the Cluster Safety, Acceptance and Sustainable Market Launch [35].

This overview provides an insight into the variety of initiatives, strategies and contributors that influence the drawing up of standards and technical rules. Accordingly, taking this stakeholder landscape into account and actively networking with relevant activities is one of the core objectives of this Standardization Roadmap Hydrogen Technologies.

3 Objectives and methodological approach

This Standardization Roadmap takes up the demands for coordinated standards and technical rules and supports those involved in the future hydrogen economy in the creation of a uniform set of technical rules. It identifies the needs in the area of standardization and technical rule-setting and makes recommendations. In addition to national positioning, the Roadmap enables Germany to participate in the development of a hydrogen economy in a coordinated manner at European and international level.

3.1 Standardization Roadmap vs standardization work

A standardization roadmap is an instrument for the upstream, structural, and systematic determination of needs for standardization and technical rule-setting. The aim of this document is to draw up a coordinated roadmap for the necessary recommendations for action in standardization and technical rule-setting as well as for pre-normative research with the involvement of all relevant interest groups. Once the recommendations for action have been drawn up by the experts of a Standardization Roadmap, they will be passed on to the technical standardization bodies to work out the content. Ideally, the technical rule-setting bodies are involved in the drawing up of the Standardization Roadmap with representative groups in order to establish contact as early as possible and to transfer the know-how from the Standardization Roadmap to the technical rule-setting bodies, and vice versa.

Traditional standardization work, on the other hand, is concerned with developing the content of technical rules. The general procedure for this is explained in Section 2.1.1.

3.2 Objectives and content of the Standardization Roadmap Hydrogen Technologies

The aim of this project is to set up the conditions for a complete quality infrastructure. Based on an overview of the status quo of standardization and technical rule-setting in the field of hydrogen technologies, requirements and challenges for the entire value chain are identified and concrete needs for the expansion of existing standards and the development of new standards and technical rules are formulated. In this way, a coordinated national approach is defined. Based on these recommendations, specific standardization projects and technical rule projects are to be initiated, which will be developed in the technical rule-setting bodies. The strategic promotion of standardization and technical rule-setting of hydrogen technologies will close the gaps in the existing standardization landscape and set the course for widespread establishment. Figure 3 illustrates the objectives of the Standardization Roadmap Hydrogen Technologies.

The Roadmap also serves as a platform for networking the most important interest groups in the hydrogen economy and coordinating national standardization and technical rule-setting. Relevant initiatives, projects and technical rule-setting in the hydrogen sector are addressed and linked.

The summary of the status quo includes the standards research described in Section 2.1.2 and can be found on the Internet in the Standards Database for Hydrogen Technologies [13]. The development of a strategic roadmap for standardization and technical rule-setting, and the targeted support of standardization projects and technical rule-setting projects is based on the recommendations for action developed by the various working groups (WG) and presented in Section 4. The recommendations for action are passed on to the relevant technical

Objectives of the Standardization Roadmap Hydrogen Technologies are...

- ... covering the entire value chain of H_2-Technologies
- ... coordination of all national regulators and networking with stakeholders
- ... establishment of a coordinated national approach as a basis for European and international activities
- ... networking with relevant initiatives and projects in the field of H_2 and standardization
- ... targeted initiation and support of urgent standardization projects

Figure 3: Objectives of the Standardization Roadmap Hydrogen Technologies (Source: own illustration)

standardization bodies, where the standard or technical rule on the relevant topic is then developed. Through the representation of German interests at CEN/CENELEC/ETSI and ISO/IEC/ITU, these topics reach European and international level. This enables the co-determination of a uniform national, European and international approach. The freely accessible and free participation in the drawing up of this Standardization Roadmap creates a platform for all stakeholders on which the various companies, organizations or initiatives can exchange ideas and form an overarching network. In order to accelerate the market ramp-up as quickly as possible and close the gaps in standardization and technical rule-setting, this Roadmap also strives to provide financial support for individual, particularly urgent and important implementation projects. An implementation project is one that is based on a recommendation for action and is recommended for funding by the bodies working on this Standardization Roadmap, including the Steering Committee. In addition, such projects are supported by approved funding from the BMWK and initiated and implemented by a responsible technical rule-setting body, see Section 3.3.2.

The networking of the most important interest groups is supported by the cooperation of people with relevant expertise from different areas and companies in the working groups of the Roadmap. Around 600 experts have contributed their in-depth knowledge to this Roadmap. Their diverse backgrounds and experience make it possible to take a holistic approach to the development of standards and technical rules. The needs for hydrogen technologies were developed collaboratively through a lively exchange and constructive cooperation on the respective topics. These needs form the basis for the safe and efficient use of hydrogen technologies. Figure 4 clearly shows the broad spectrum of application areas from which the Roadmap experts come. At just under 60 %, stakeholders from industry make up the largest proportion of the interest groups involved. Experts from research (10 %), universities and colleges, as well as associations, foundations and the public sector are also involved. It is particularly noteworthy that, in addition to the 66 % who already have experience with standardization work, 34 % of experts without standardization experience also took part in this Roadmap (see Figure 5). The participation of new experts enriches standardization and technical rule-setting with additional know-how and new approaches. This reflects the interest in standards and technical rules shown by organizations that have not yet been involved in standardization. It will enable standards and technical rules to be developed with all relevant stakeholders in the future.

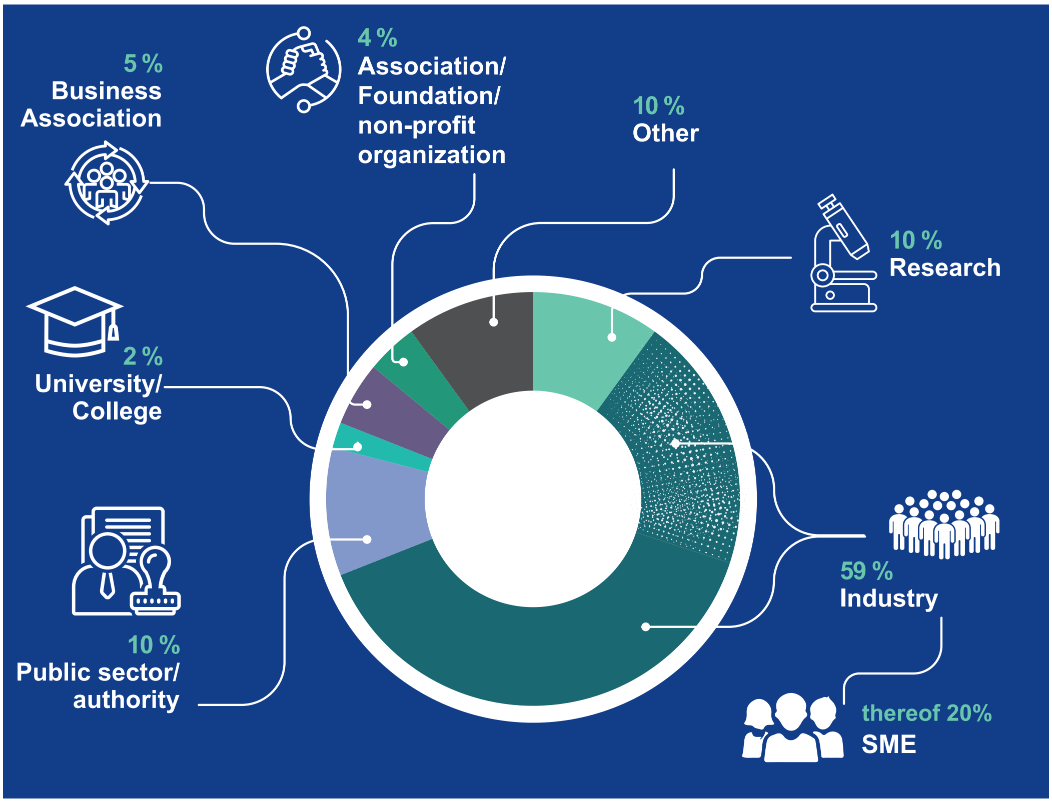

Figure 4: Participation of interest groups[1] (Source: own illustration)

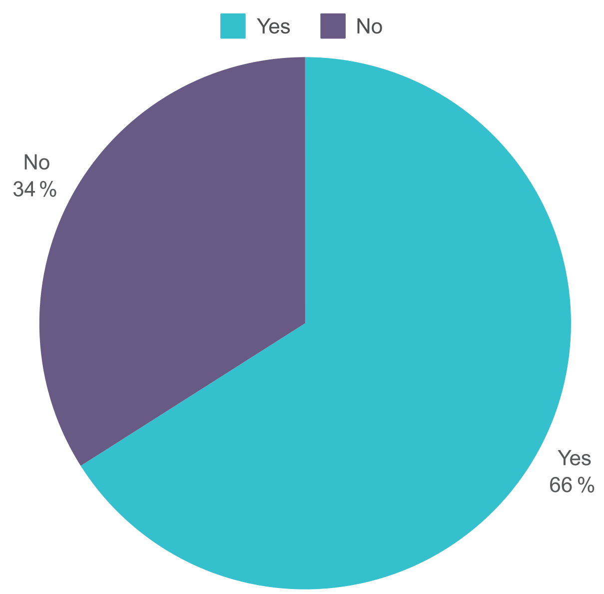

Figure 5: Experience with standardization of participating experts[2] (Source: own illustration)

3.3 Methodical approach

This section describes the methodical approach of this project. The structure of the project and the procedure for determining the inventory of standards and other technical rules are explained. The implementation of the implementation projects and the determination of the need for technical rule-setting are also discussed.

3.3.1 Project structure and project consortium

All project participants have special expertise in technical rule-setting for hydrogen technologies. DIN is the German standardization organization recognized in an agreement with the German government, and also represents German interests in European and international standardization. DIN standards committees develop standards and specifications for hydrogen technologies across the entire value chain, particularly in the areas of measurement technology, storage, mobility, materials and safety aspects. Besides DIN, DKE is

1 Result of survey of 167 persons
2 cf. Footnote 1

the second standards organization recognized by the German government. It is responsible for the field of electrical engineering, electronics and information technology and represents German interests at European and international level. It therefore supplements the project with issues relating to the connection and integration of hydrogen technologies into the electrical energy supply system. The Forum Network Technology/Network Operation in the VDE (VDE FNN) is responsible for the network access rules. DVGW is the leading industry association and competence network for all issues relating to the supply of gas, hydrogen, and drinking water and is designated and recognized in the German Energy Industry Act (EnWG) [36] for setting technical rules in these areas. Climate-neutral gases and in particular hydrogen, the energy carrier of the future, are of particular importance in the work of the DVGW. It is also responsible for the DIN Standards Committee Gas Technology, which, among others, organizes the international activities of ISO/TC 197 Hydrogen Technologies in Germany. NWB is responsible for the DIN Standards Committee Railway (FSF). VDA is responsible for the DIN Standards Committee Road Vehicles and Mobility (NAAutomobil). VDI is the third largest technical rule-setter in Germany and publishes VDI standards and recommendations of the VDI experts. At VDI, the topic of hydrogen is considered in particular in the domain of sector coupling with Power-to-X technologies (PtX). VDMA is the largest network organization of the mechanical engineering industry in Germany and Europe and is responsible for DIN Standards Committee Mechanical Engineering (NAM), which represents Germany with a total of 27 specialist areas in European (CEN) and international standardization (ISO).

The consortium is thus made up of the relevant German national technical rule-setting organizations, which together provide the national platform for standardization and technical rule-setting, in which all experts in the hydrogen economy can coordinate and pool their knowledge synergistically.

As part of the development of this Roadmap by DIN, DKE, DVGW, NWB, VDA, VDI, and VDMA, five topics were defined that cover the entire hydrogen value chain. These topics are oriented towards the six fields of action identified by the National Hydrogen Strategy (NWS). The five topics are Production, Infrastructure, Application, Quality infrastructure and Further training, safety and certification. These topics represent the upper level of this Standardization Roadmap and are implemented in the relevant working committees (WCs). They are made up of representatives from the sub-working committees (SWCs) and ensure networking between the sub-working committees and coordination among the working committees.

The various SWCs ensure a targeted steering of the results and are made up of representatives from and coordinate the subordinate working groups (WGs). They also summarize and evaluate the work results of the WG. The technical development of the Standardization Roadmap Hydrogen Technologies was carried out in these topic-specific WGs with the involvement of experts from all stakeholders. Altogether there are 12 SWCs and 39 WGs on various topics (see Figure 6). WCs, SWCs and WGs are supervised by one person from the project consortium and almost all are led by an expert elected by vote.

The WG CCU/CCS (Carbon Capture Utilization/Carbon Capture Storage) was made dormant during the course of the project. The German National Hydrogen Strategy referred to CCU/CCS processes to support the upscaling of the hydrogen technologies market. The relevance of this topic was taken into account for the initial structuring of this Roadmap. During the development of the Roadmap content, the connection between CCU/CCS processes and hydrogen became increasingly important. Against this background, processes involving hydrogen were transferred from the carbon utilization area to WG PtX and from the carbon capture area to WG Other production methods. The topic of carbon storage is not further dealt with in this Roadmap.

Figure 6 presents the bodies of the Standardization Roadmap Hydrogen Technologies (WCs, SWCs, WGs).

The WCs summarize the individual topics of the associated WGs and SWCs and cluster them along the value chain to produce an overall result.

In addition, a Steering Committee of leading political representatives and stakeholders from industry, science and civil society was set up. The Steering Committee guides the content and strategic direction of this Roadmap, provides impetus for the work of the WCs, SWCs, and WGs, makes

Figure 6: Bodies of the Standardization Roadmap Hydrogen Technologies[3] (Source: own illustration)

recommendations for action and recommends prioritized standardization projects and technical rule-setting projects to the BMWK for funding[4].

Work on the project officially began with the kick-off event in March 2023. Since then, four to five WG meetings have been held, depending on the status of the WG. Each meeting had a different thematic focus. While each first WG meeting dealt with an analysis of the status quo, the second WG meeting already developed the needs for technical rule-setting. These were then further developed into concrete recommendations for action. Thanks to the participation of the experts also outside of the meetings, the results compiled in Section 4 were achieved. The SWCs and WCs each met twice during this time. The steering committee meets twice a year at the end of the meetings.

3.3.2 Project phases

The development of content can be roughly divided into three phases, whereby these phases can run in parallel.

These three phases are:
1. Identification of existing standards and technical rules;
2. Identification of new needs for technical rules and pre-normative research and drawing up of concrete recommendations for action;
3. Implementation of the recommendations for action (initiation of implementation projects).

These steps are presented in Figure 7. The figure illustrates how the transition between the individual phases works.

3 Note to the figure:
*) WG CCU/CCS is dormant.
Topics regarding carbon utilization have been taken up by WG 3.2.2 PtX.
Topics regarding carbon capture have been taken up by WG 1.1.2 Other Production Methods.
Topics regarding carbon storage have been removed from the scope of this Standardization Roadmap.

4 The development of this Standardization Roadmap by DIN, DKE, DVGW, NWB, VDA, VDI and VDMA is funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK) as part of the Standardization Roadmap Hydrogen Technologies funding project (funding reference 03EI3081A-G).

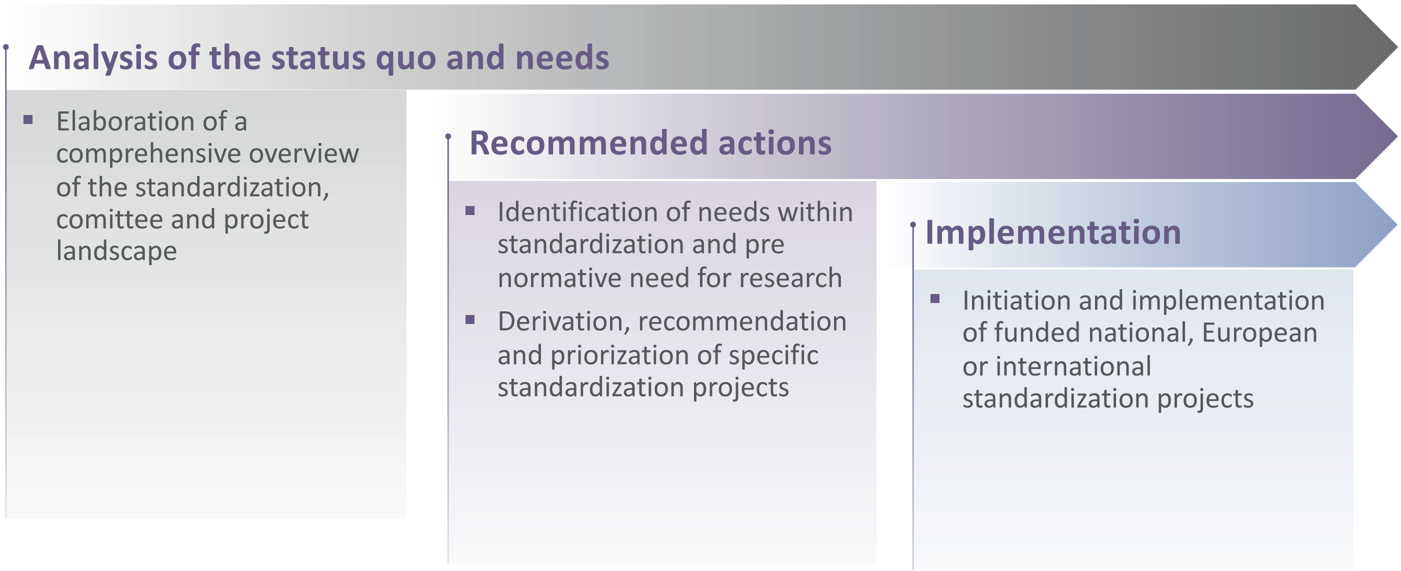

Figure 7: Project phases of the Standardization Roadmap Hydrogen Technologies (Source: own illustration)

3.3.2.1 Analysis of the status quo

To identify the need for standards and technical rules in the field of hydrogen technologies, the first step was to carry out a comprehensive analysis of standards and technical rules that have already been published. For this purpose, the current published relevant standards and technical rules in the databases of the respective technical rule-setting institutions were consolidated. This collection was compiled in collaboration with all of the Roadmap experts to produce an initial interim status and then was further expanded. The assessments and further proposals of experts regarding the listed documents were discussed and adapted at the respective WG meetings. Not only documents relating specifically to the WG topic were discussed and included, but also standards and technical rules from other areas that affect the scope of that WG and can support the formulation of needs. Due to the complexity and thematic links to other WGs, it has not yet been possible to complete the analysis of the status quo for some WGs.

The status quo analysis thus reflects the currently identified status of the standardization landscape with regard to hydrogen technologies. This overview is published in the publicly accessible Standards Database for Hydrogen Technologies [13] and can be viewed via the website or the following QR code. In the course of the project, the status quo will be continuously supplemented and updated.

This status quo analysis forms the basis for the subsequent needs analysis. By identifying current publications, gaps in standardization and technical rule-setting can be specifically identified. These open questions are taken up in the next step in the development of needs proposals.

3.3.2.2 Development of needs and specification of recommendations for action

Based on the inventory and the Standards Database for Hydrogen Technologies [13] advice is given on the needs for standardization and technical rule-setting or necessary pre-normative research within the committee meetings. Different methodological approaches were used for the initial collection of ideas and proposals, depending on the composition of the WGs, e.g. brainwriting, digital whiteboards or lectures. Initially, many kinds of ideas and proposals were collected.

Further WG meetings are being held to formulate specific needs, ideally in close cooperation with the relevant technical rule-setting bodies. They are also being prioritized according to relevance in terms of content and time. The results of the WG meetings are then discussed and evaluated at the SWC and WC meetings. Once a need has been confirmed and recommended by all Roadmap committees, including the steering committee, it is issued as an official recommendation for action for the Standardization Roadmap Hydrogen Technologies. In this way, a concrete recommendation for action for technical rule-setting is developed step-by-step from a diffuse need.

3.3.2.3 Implementation

A key objective of this Roadmap is to submit recommendations for action for implementation as a standardization project or project for the development of a standard or technical rule addressed to the bodies responsible for technical rule-setting. Financial support is available for efficient and rapid implementation.

Projects at national, European or international level are eligible for funding. Both the development of new documents as well as the updating of existing standards, specifications or technical rules are possible. The support also includes an expense allowance for experts for taking over project management or working on the project.

For a standardization project or project for drawing up a technical rule to be financially supported as an implementation project, it must be based on a recommendation for action declared in the Roadmap; it must also be recommended for funding by the Roadmap bodies, including the steering committee, and the funding must be approved by the BMWK.

All non-funded projects are also handed over to the technical rule-setting bodies, which should then include these projects in the body’s development programme after consultation. This process takes place in parallel with the further development of needs in the Roadmap. All implementation projects recommended for funding to date can be found in the corresponding sections dealing with the WGs in Section 4 and in Section 7.

4
Results

The development of this strategic Standardization Roadmap for the technical regulation of hydrogen technologies began with the founding meetings of the 39 working groups in spring 2023. The results of this work are presented in this section and represent the status of the project up to March 2024.

For each working group, the status quo is described giving the status of the work, and the requirements and challenges in the respective subject area are addressed. In addition, the needs for closing the gaps in standardization are explained, and the funded implementation projects are named.

The publicly accessible Standards Database for Hydrogen Technologies [13] has been implemented on the basis of these analyses. The database contains more than 850 entries on national, European and international standards and technical rules.

The degree of maturity of the status quo varies greatly; for example, the collection of technical rules on grid-based infrastructures is already almost complete, whereas a large number of gaps that need to be closed have been identified in the areas of aviation and shipping, alternative types of hydrogen production and in the area of derivatives.

Around 180 needs for technical rules were identified as part of the needs analysis. Concrete recommendations for action were derived for the majority of the subject areas, and in many cases it was possible to specify the implementation, i.e. to define the level of development (national, European or international project) and to identify and involve the responsible body.

To ensure the rapid and targeted implementation of high-priority needs, proposals for implementation projects to be funded were evaluated and recommended for funding as part of two funding rounds. In summer 2023, the proposals for the first implementation projects in the areas of hydrogen transmission, storage, components, and rail transport were evaluated. Nine implementation projects were funded by the BMWK. The focus of this first initiation round was on the important and urgent technical rule-setting projects that are being driven forward at national, European and international level and that have been developed to such an extent that they could be initiated as early as summer 2023. In the second initiation round in fall 2023, 14 implementation projects were supported. These were new projects at national and European level in the areas of hydrogen properties, production, industry, quality infrastructure and heat. An overview of all projects funded to date can be found in Section 7. There will be three further initiation rounds for implementation projects in this project.

4.1 Production

WC Hydrogen production forms a coordinating umbrella for the areas of generating plants and hydrogen properties.

Among the generating plants, electrolysers exhibit a high level of technological progress. One challenge is the international harmonization of the valid standards. When considering other types of production, the first step is to evaluate whether they are already relevant to standardization.

The topic of hydrogen quality is being actively discussed. Here it is important to find a balance between the different requirements of applications, gas infrastructure and the provision of hydrogen. Based on this, the WG Verification and sustainability aspects of hydrogen is working on the need for a uniform criteria catalogue.

A key element for the hydrogen market ramp-up is the grid-friendly interaction of electricity, heat and gas infrastructure, which is being analyzed in the WG Total system integration.

4.1.1 Electrolysis

WG Electrolysis deals with the production of hydrogen by water electrolysis and all associated aspects of it. These include, among others, the following types of electrolysis: alkaline water electrolysis, alkaline membrane electrolysis, polymer electrolyte water electrolysis and high-temperature water electrolysis. The electrolysis process from power conversion to the transportable product, including the auxiliary systems, is considered.

Electrolysis

4.1.1.1 Analysis of the status quo

As part of the analysis of the status quo, research was first carried out to obtain an overview of existing standards and technical rules as well as regulations and projects. A total of 57 existing standards regarding the core process of water electrolysis were identified. Standards and technical rules without specific reference to hydrogen production or those that fall within the scope of other Roadmap WGs (e.g. WG Explosion protection or WG Safety design principles) are not considered. The standards and technical rules included in the analysis are divided into nine national, 19 European Standards and ten International Standards.

In addition to the standards and technical rules, thematically linked regulations, directives, proposed legislation, and projects were also taken into account. A total of eleven entries of this type were identified.

In order to provide a comprehensive source of information, reference is made to the published Standards Database for Hydrogen Technologies [13]. Figure 8 presents the identified bodies that are important for the development of technical rules in the field of electrolysis. An overview of the abbreviations used to describe these bodies is given in Section 9.

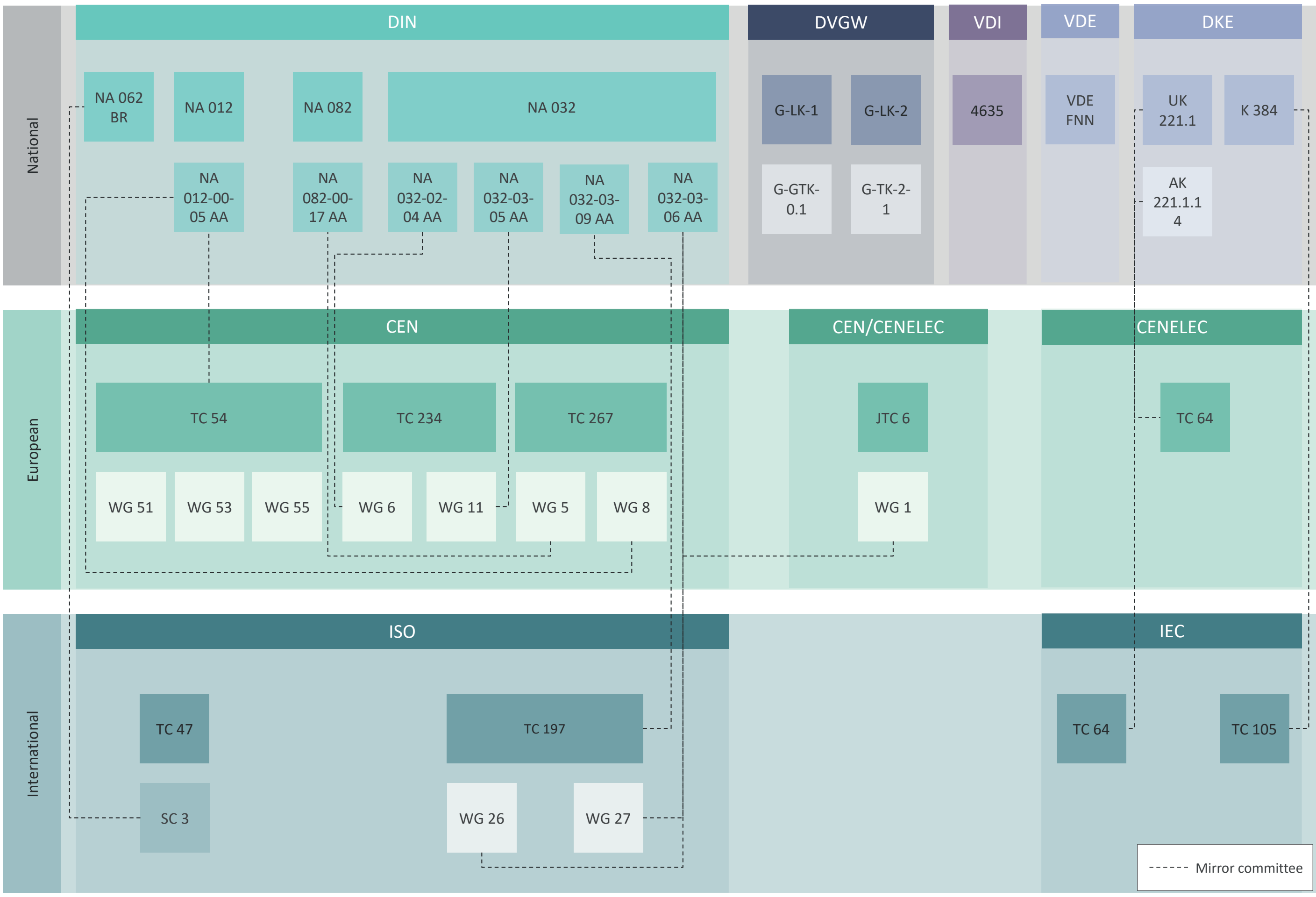

Figure 8: Overview of bodies relevant to technical rule-setting in the area of electrolysis (as of 03-2024)

(Source: own illustration)

4.1.1.2 Requirements and challenges

In addition to the needs that have already been identified as implementation projects, the WG sees the following challenges:

To date, there is no standardized procedure for determining the efficiency of electrolysers. In addition, the specific requirements for electrolysers installed offshore have not yet been standardized. Another current challenge is the lack of harmonization of international markets. This is particularly reflected in the approval relevance of European Standards and technical rules for international projects. Conversely, some of the U.S. standards, for example, are not applicable for Europe. This leads to uncertainties and incompatibilities in the approval and planning process. Specific national, European and international measures are needed here, including within the framework of this Roadmap, in order to establish globally recognized standards and technical rules. International Standard ISO 22734:2019-09 [37] requires rapid national accreditation by the DAkkS.

Water quality poses a further challenge, as there are no standards for water quality with regard to the requirements of electrolysis. Furthermore, there is a lack of standardization regarding the operating modes of electrolysers. This is problematic with regard to uniform acceptance and evaluation criteria, among other things. The identified standardization needs for explosion protection were passed on to WG Explosion protection for further processing. Various challenges are seen with regard to the by-product oxygen. Both safety and economic aspects would have to be considered in the future. There is still a need for research in this area.

The WG was faced with the challenge of assessing which technologies and applications will become established in the coming years and what challenges companies active in these areas will face regarding the application of standards and technical rules.

4.1.1.3 Needs analysis

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.

NEED 4.1.1-02:
Efficiency and stability of surface coatings and solid materials

CONTENT: Stability test; efficiency test; electrolysis stack; degradation

EXPLANATORY NOTES: Description of a standardized test method for stability testing and efficiency testing of electrolysis stacks and the materials used. At present, often only data from the manufacturing companies are provided according to their own test methods, which are not comparable depending on the method. Existing test methods are to be supplemented by material analysis.

IMPLEMENTATION: Ideally at international level, if necessary first at national level and then internationally.

NEED 4.1.1-03:
Guidelines for the design, construction and acceptance of electrolysers for the production of hydrogen

CONTENT: Electrolysers; design; construction; acceptance

EXPLANATORY NOTES: The VDI standard 3985 [40], which describes the project process for combined heat and power plants (CHP) with combustion engines or gas turbines, provides the impetus. With regard to electrolysers, this project would have to be carried out for various use cases (electricity generation and hydrogen acceptance), e.g. grid-connected, grid-independent via wind or solar energy, H_2 generation for refuelling stations, continuous acceptance, gas grid feed-in, etc. Assistance with implementation can simplify and accelerate the process for stakeholders.

IMPLEMENTATION: National project

4.1.1.4 Implementation projects

The need VDE 0100-7XX Electrical protective measures in water electrolysers was introduced to this Roadmap by the technical rule-setting body and financial support was approved. A national document is to be drawn up first, which will then be introduced internationally. A call for experts has been launched and the document will be developed.

4.1.2 Other production methods

WG Other production methods deals with the methods and plants for the production (incl. treatment) of hydrogen with application-related utilization quality that are not obtained via water electrolysis. One of the aims of this WG is to draw up a catalogue of methods and, on this basis, to identify needs for technical rule-setting and to initiate corresponding projects.

4.1.2.1 Analysis of the status quo

During the analysis, it turned out that it would be expedient to first compile a collection of various methods for hydrogen production outside of electrolytic processes (catalogue of methods). These methods were categorized into the following groups according to the energy input for hydrogen production:

1. Radiant energy – Photosynthetic methods;
2. Chemical energy – Fuel/substrate – Gasification, biological fermentation;
3. Thermal energy (elevated temperature, independent of primary energy) – Thermochemical processes.

In view of the high expected potential and innovation pressure in the field of hydrogen technology, the task of WG Other production methods was naturally comprehensive. It turned out that the technical maturity of these proposals varied greatly. With the help of a set of criteria (decision tree, see 4.1.2.2 and Figure 9) developed in WG Other production methods, the next step is to examine the methods with regard to a possible need for standardization.

4.1.2.2 Requirements and challenges

Due to the varying technological maturity of the methods identified, it proved useful to develop a model for assessing standardization capability. Based on the catalogue of methods and this model, a clearly structured needs analysis for technical rule-setting can be carried out along jointly developed criteria in the further development of this Roadmap.

A decision tree was developed as a model for assessing the standardization capability (Figure 9). The decision tree focuses on three central criteria that need to be examined for a further needs analysis:

a. Relevance for the WG;
b. Climate neutrality;
c. Technology Readiness Level (TRL) (see DIN EN 16603-11 [41]).

With regard to the standardization needs, it was agreed in this WG that standardization of technologies from TRL 8 [42] is sensible. TRL 8 means that "there is a qualified system with proof of functionality in the area of application" [...], and further requires that the state of the art (see German Federal Immission Control Act [43]) is complied with. As hydrogen technology is a dynamic, rapidly developing field, innovative processes that do not currently have a TRL 8 should also be taken into account. To this end, the decision tree contains a second branch "future relevance". The criteria listed here serve as a basis to support a need for standardization for technologies for which currently the use of prototypes is known at most (max. TRL 7). In particular, technical feasibility should be identifiable on the basis of independent sources.

The decision tree was tested in relation to the "solid matter pyrolysis" method. A relevance for the WG is seen. The climate neutrality of the process was discussed with the result that solid matter pyrolysis can in principle be made climate neutral. In Germany, no plant is known to have a TRL > 7, so the "future relevance" block was run. Under the point of basic feasibility, it was unanimously determined that the production of hydrogen from pyrolysis can be considered in theory but is not technically feasible. Therefore, no need for standardization was seen for this technology at the current time.

The decision tree, which is continuously being updated and developed, explains the decisions of the WG and clearly shows the ongoing process of review and adjustment.

Figure 9 presents the identified bodies that are important for the development of technical rules in the field other production methods. An overview of the abbreviations used to describe these bodies is given in Section 9.

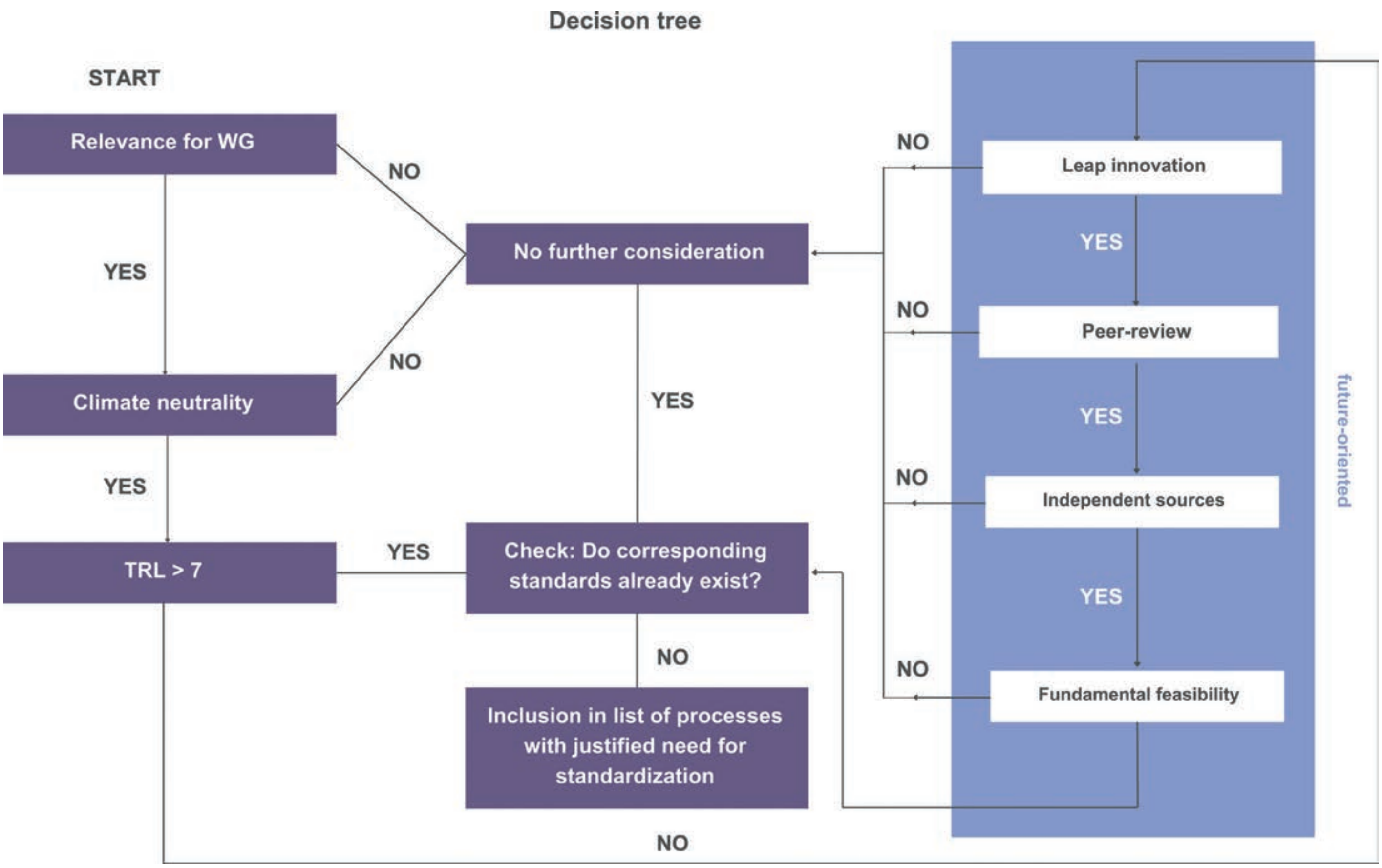

Figure 9: Decision tree for standardization needs

(Source: Standardization Roadmap Hydrogen Technologies WG Other production methods)

Total system integration

4.1.2.3 Needs analysis

The WG is currently still working on specific needs. The requirements and challenges mentioned above make it difficult to identify needs. The specified needs will be published in the second version of this Standardization Roadmap Hydrogen Technologies at the end of 2025.

4.1.2.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.1.3 Total system integration

The economically efficient and grid-friendly interaction of the electricity, heating, and gas infrastructures will be a key element of sector coupling in the future energy system. The ability to store hydrogen produced in a climate-friendly manner in the gas infrastructure and the possibility of feeding this energy back into the electricity system as required using gas turbines or fuel cells forms the basis for a functioning overall energy system. Climate-friendly produced hydrogen makes it possible to significantly reduce CO_2 emissions, especially in the industry, heating and transportation, where energy efficiency and the direct use of electricity from renewable energies are not sufficient. The right combination of all five sectors will generate added value for the economy in the long term.

4.1.3.1 Analysis of the status quo

As larger electrical energy users, electrolysis plants generate additional demand for electrical energy. There are corresponding standards and provisions for the connection of systems (e.g. technical connection rules, grid codes, DIN EN 50549-1 [44], DIN EN 50549-2 [45]), which define the electrical connection, energy measurement and also the controllability or communication of the systems with the grid (e.g. DIN EN IEC 61850 series of standards [46]) and, if applicable, the energy market. With regard to the use of hydrogen, reference can be made to existing requirements in the DVGW technical rules. Reconversion into electricity can be realized via fuel cells or gas-fired power plants that use hydrogen or derivatives as an energy carrier. The existing technical rule collections mainly comprise national and European Standards and technical rules.

Figure 10 presents the identified bodies that are important for the development of technical rules in the field of total system integration. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.1.3.2 Requirements and challenges

Specific technical and regulatory requirements must be met in order to ensure the system stability of the interconnected electrical grid (called “grid codes”). These include minimum requirements for the technical capabilities of the systems, such as the ability of electrolysers to remain connected to the grid within certain voltage limits in the event of grid disruptions. For the German transmission grid, specific requirements for electrolysers [47]have been defined by the transmission grid operators, which will be incorporated into the revision of VDE-AR-N 4130 [48]. Requirements for electrolysers are also defined in the new version of the European network code NC DC (Network Code Demand Connection).

The concept of the Smart Grid Architecture Model (SGAM) aims to identify gaps in the standardization of smart grids and is used to develop smart grid system architectures, as shown in Figure 11. The main focus of the SGAM is on functional interoperability in the smart grid. Due to the increasing interactions between electricity, gas and heating networks, an SGAM extension has become necessary, which is already described in DIN IEC/TS 63200 (VDE V 0160-632-1) [49]. In the context of hydrogen system integration, the interaction models and energy flows between the grid-bound infrastructures of the above-mentioned networks must be described.

Hydrogen production and reconversion to electricity, together with gas storage systems, are seen as a storage system for additional flexibility in the electricity system, as shown in Figure 12. This flexibility is needed in the system in order to balance out the volatility of renewable energies and to utilize renewable surpluses. The electricity grids are a limiting factor, and the transmission of wind energy is already a

Total system integration

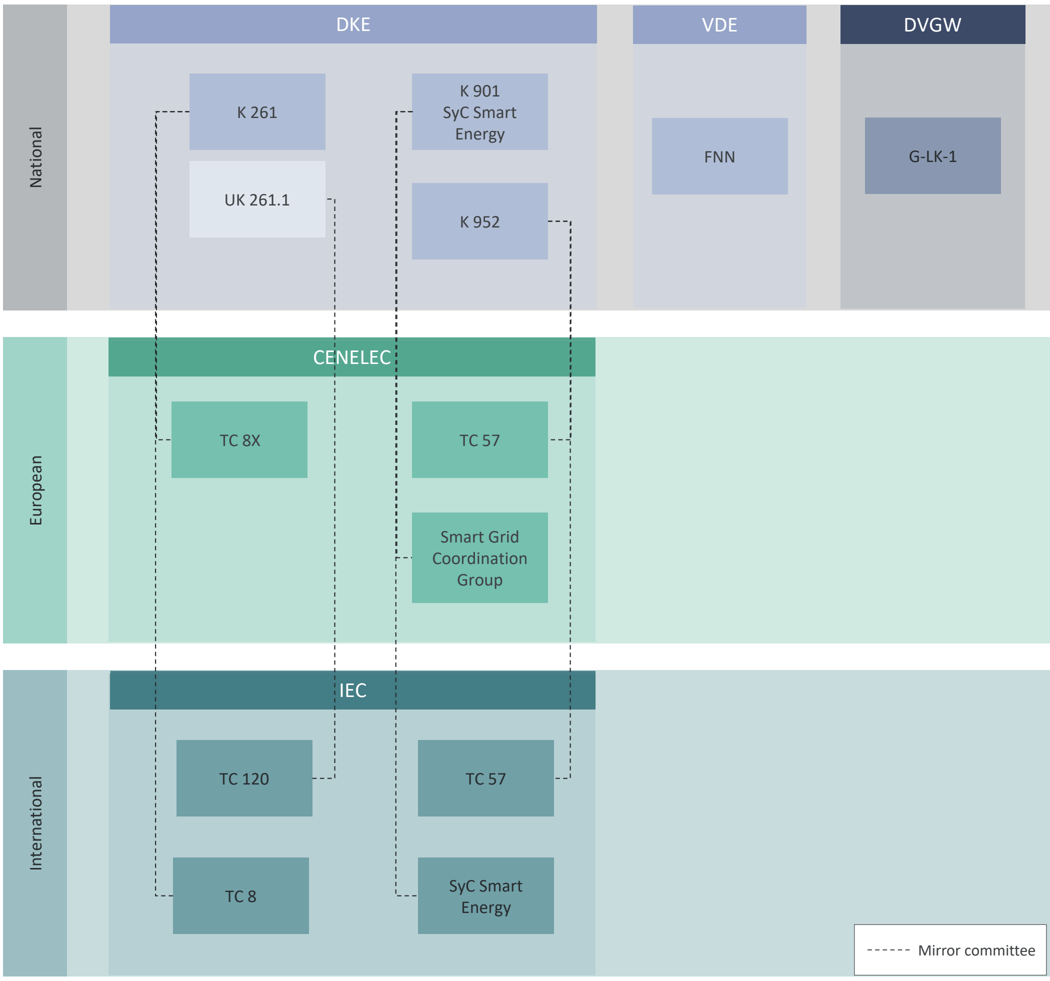

Figure 10: Overview of bodies relevant to technical rule-setting in the area of total system integration (as of 03-2024) (Source: own illustration)

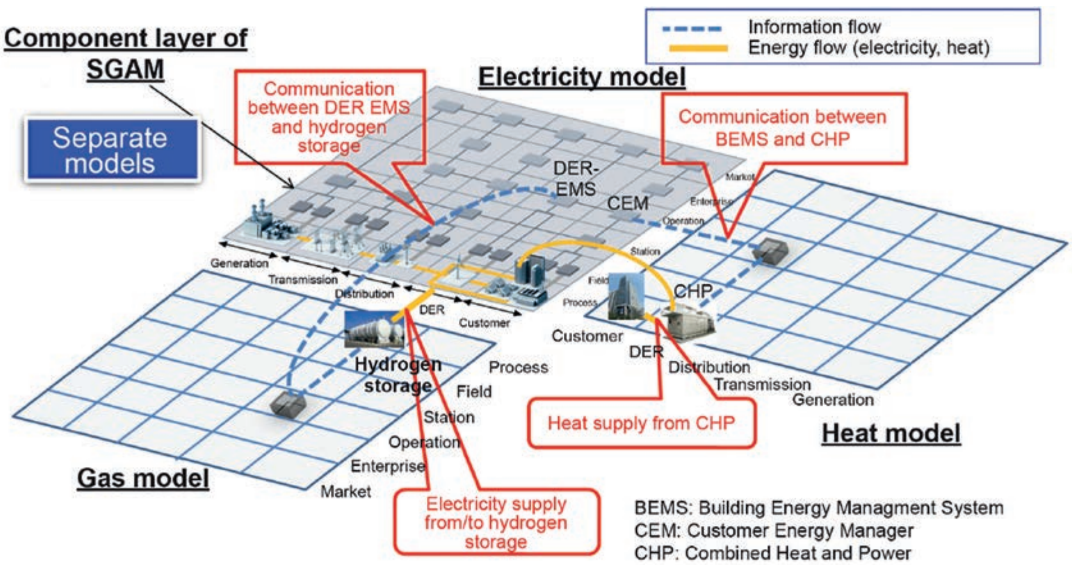

Figure 11: Interaction model of the extended SGAM component layer using the example of hydrogen storage according to IEC/TS 63200 (Source: [49], DKE)

Total system integration

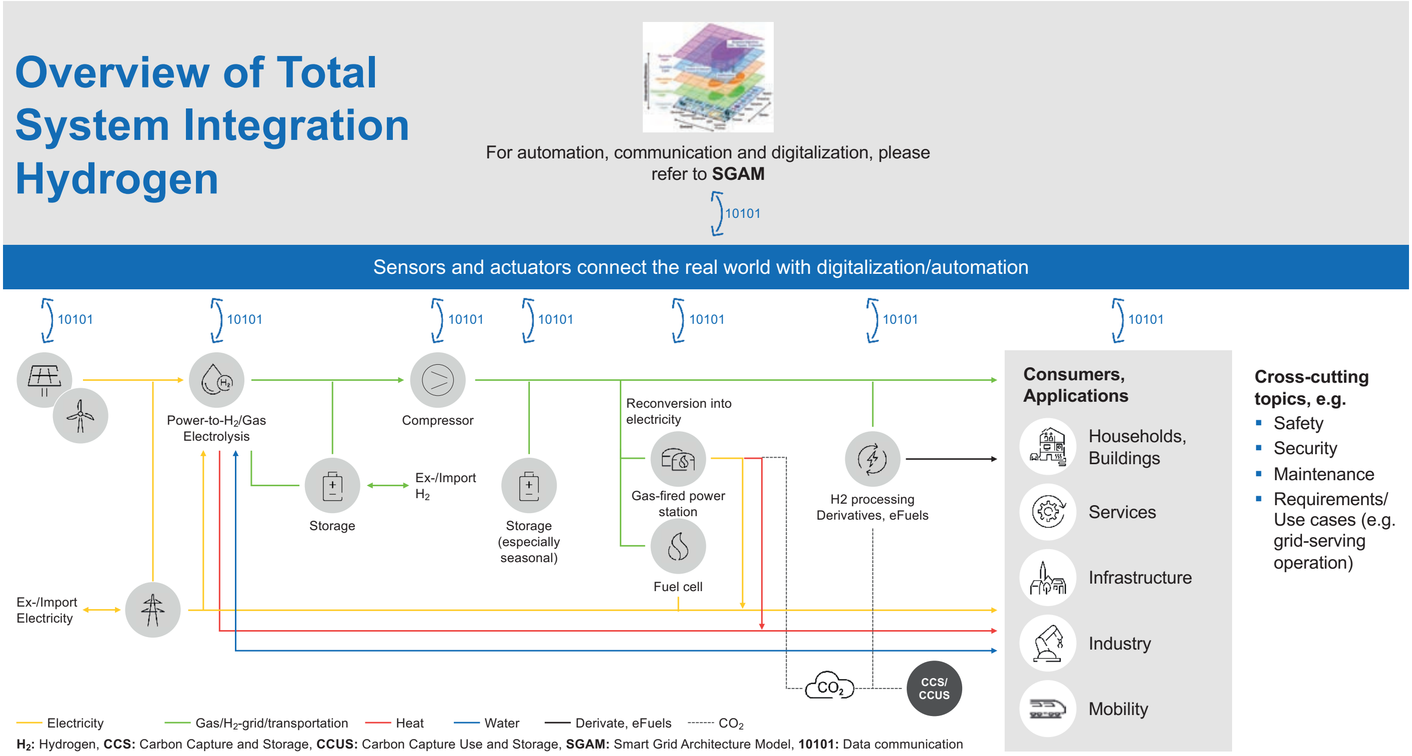

Figure 12: Overview of total system integration H_2 (Source: DKE along the lines of [50])

problem today. It is to be expected that grid expansion will not keep pace with the expansion of renewable energies. This means that geographically advantageous site planning for electrolysis plants must also be included in an overall assessment. In addition, the water supply and waste heat utilization for electrolysis and reconversion must be taken into account as part of optimized design.

4.1.3.3 Needs analysis

The WG is currently still working on concrete needs. The requirements and challenges mentioned above make it difficult to identify needs. The specified needs will be published in the second version of this Standardization Roadmap Hydrogen Technologies at the end of 2025. However, the following facts have already been established:

The optimized coupling of different energy carriers in different applications in central and decentralized systems requires cross-system coordination and communication. Different communication standards and data models are used in different domains. Semantic interoperability facilitates cross-sector data exchange. To this end, newer technologies should be investigated alongside the familiar standards of the energy industry, e.g. cross-sector data spaces such as GAIA-X, a data space for the H_2 value chain, digital twins, digital product passports, asset administration shells, digital calibration certificates or digital conformity assessments. Current projects such as Energy Data-X, QI Digital [51] and Manufacturing-X are interesting starting points.

Energy system models and simulations, taking into account the dependencies, framework conditions and system boundaries of the individual sectors, serve to integrate the sectors. From an electrical perspective, topics such as grid serviceability, energy markets, flexibility, connection conditions, installation, system stability, system services, etc. are essential. Comparable system aspects must be known for all sectors and infrastructures. These holistic energy system models serve as the basis for optimization, design, prioritization, recommendations for action, strategies, etc. for total energy system optimization [52].

4.1.3.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.1.4 Hydrogen composition

WG Hydrogen composition deals with the chemical-physical properties (material or combustion properties) of hydrogen and its gaseous and solid by-products. The purity and associated classification of hydrogen for the various applications (energy-bearing institution, fuel and raw material) is also considered. The various needs of the entire value chain are taken into account for the various applications. In this context, the entire value chain means production, transmission, storage, distribution, end use and quality assurance. The WG focuses on hydrogen as a main component as opposed to hydrogen as an admixture (see [53], [54], [55], [56]).

4.1.4.1 Analysis of the status quo

Hydrogen composition is well included in technical rules at national, European and international level. The technical rules are continuously improved and further developed through active committee work. Many recently completed and ongoing research projects support this.

One current project is the TransHyDE flagship project funded by the Federal Ministry of Education and Research (BMBF) [31]. The aim of the project is to develop technologies for the transmission and storage of hydrogen and, on this basis, to make recommendations for the national hydrogen infrastructure. The quality of hydrogen is examined here in the context of the conversion of natural gas transmission networks to hydrogen. Sampling and analysis methods are being developed to ensure customer-specific gas quality requirements.

A recently completed extensive research project of the DVGW is the Roadmap Gas 2050 [57]. An important finding resulting from this is that hydrogen admixtures are most likely to fall below the relative density limits specified in DVGW technical rule – code of practice G 260 [53]. The knowledge gained is being incorporated into the current revision of DVGW technical rule – code of practice G 260 [53]. Projects not only on analysis and sampling [58], [59], [60], but also application-related projects on hydrogen refuelling stations or fuel cells [61], [62], [63] provide helpful findings for the field of hydrogen composition.

WG hydrogen composition identified a total of 13 published standards and technical rules relating to hydrogen composition. Further technical rules are still being developed and are available as drafts or working documents. In the course of the status quo analysis, a distinction was made between the standards that are directly relevant to the WG and those that are only tangentially relevant. Between five and ten technical rules have emerged that are directly relevant to the WG [13].

Technical rule-setting makes the political framework conditions at national and European level more concrete.

Figure 13 presents the identified bodies that are important for the development of technical rules in the area of hydrogen composition. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.1.4.2 Requirements and challenges

These open questions pose a challenge in the needs analysis:

- → Hydrogen will be available from different sources (on-site production, import, storage) with different compositions. Which sources will provide which compositions and to what extent?
- → Potential applications have very different requirements in terms of composition. What are the minimum requirements for the composition of the hydrogen to be fed in?
- → Cost-intensive treatment processes could be necessary, depending on the composition requirements. What is economically feasible in terms of technology and in compliance with the law?
- → What could a uniform European quality standard look like?

The open questions identified overlap with the knowledge gaps identified in one study [64].

Hydrogen composition

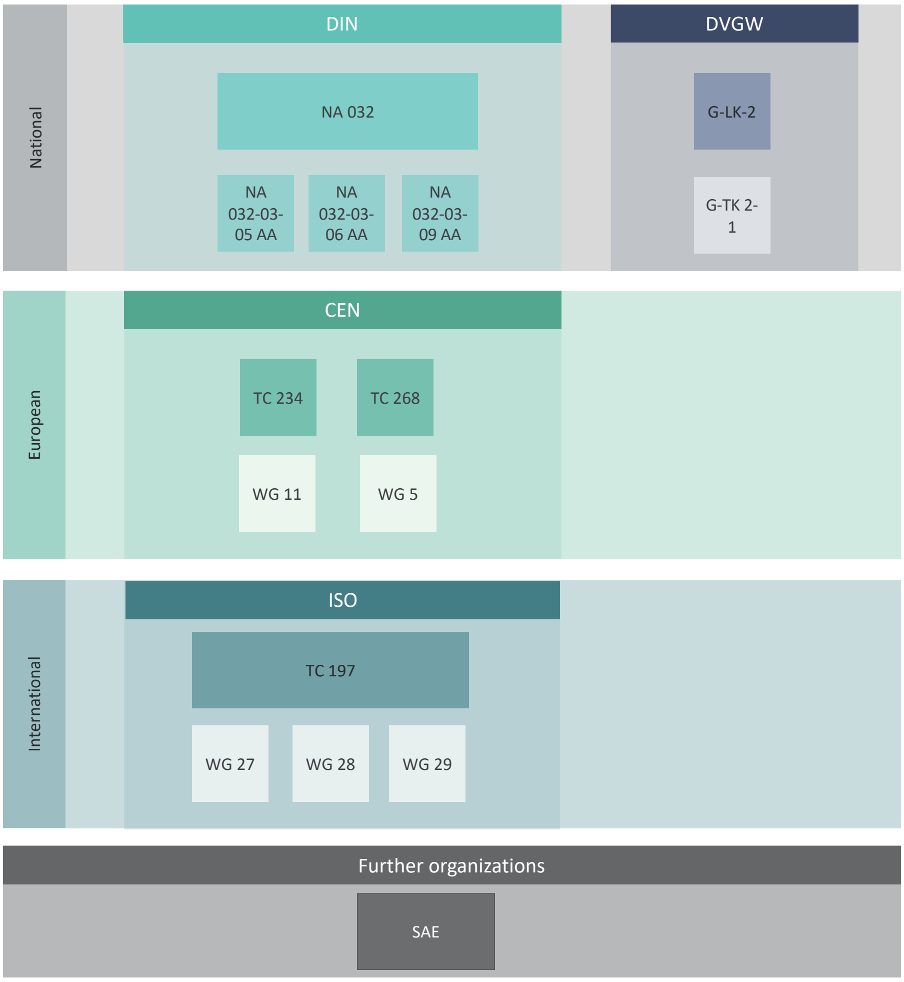

Figure 13: Overview of bodies relevant to technical rule-setting in the area of hydrogen composition (as of 03-2024) (Source: own illustration)

The WG sees the following need for research: There is a lack of rules as to which composition should be made possible when feeding into the grid and which only for the off-take. If hydrogen is considered in accordance with ISO 14687 Grade A (98 mol-% H_2) [54], which is currently being revised, a maximum of 2 mol-% of by-products and gases remain. There is a need for research to evaluate, define and describe the possible by-products with regard to application compatibility and to be able to precisely determine them by means of suitable analytics in the case of a dispute procedure, e.g. according to DIN EN ISO 4259-2 [65], see also Section 4.4.1, in particular Need 4.4.1-01, and ISO 21087 [66]. In addition, the question arises as to the cost-benefit of the respective market participants removing various substances from the gas before input or after off-take of the gas. This concerns both the type of separation and the associated costs, such as gas analysis.

For some applications (e.g. fuel cell technology) a high purity of hydrogen is necessary. On the other hand, there are applications that manage with a lower purity (e.g. combustion engines). Existing assets, such as storage facilities or transmission networks, have limitations as to which purity can be ensured [64], [67]. Safety and immission aspects limit the choice of hydrogen storage technologies and sites. The same applies to the installation and approval of gas separation plants. In addition, high purity limits also influence the development of various hydrogen production methods. The question arises as to which purification costs are to be borne or reimbursed by whom. In addition, there is a need for security in the implementation of purity in accordance with technical rules. Security can be provided, for example, by an implementation plan as a cooperation agreement in accordance with the German Energy Industry Law (EnWG) [36] and the Gas Network Access Ordinance (GasNZV) [68] for a financially viable conversion of the existing gas infrastructure and financial subsidies to replace incompatible existing systems in the existing natural gas infrastructure.

It is therefore a challenge to find a uniform composition. For decarbonization to be successful, cost sharing and the technical perspective and life cycle analysis must be considered together. This will require a political solution, among other things.

4.1.4.3 Needs analysis

NEED 4.1.4-01:
Possible sources of catalyst poisons and other by-products

CONTENT: Informative details; critical by-products

EXPLANATORY NOTES: For future catalytic applications, there are relevant by-products which are currently not considered in DVGW technical rule – code of practice G 260 [53]. Even small traces of catalyst poisons can damage the appliance. In terms of the appliance, appropriate purification methods are used, the technical design of which could be simplified by informative details, in particular which substances are to be expected and the extent to which they are to be expected. It is important to bear in mind that gas grid operation should provide a quality that represents the highest common denominator for all applications.

IMPLEMENTATION: This need is being incorporated into the current revision of DVGW technical rule – code of practice G 260 [53]. This need is partially addressed in DVGW technical rule – code of practice G 260 [53]. The revision of ISO 14687 [54] already takes partial aspects of this need into account. A possible placement is seen in DIN EN 17124 [55].

NEED 4.1.4-02:
Uniform quantities in DVGW technical rule – code of practice G 260 [53]

CONTENT: Standardization; quantities

EXPLANATORY NOTES: DVGW technical rule – code of practice G 260 [53] uses mol-% or mg/m3 for the second gas family when specifying limit values. But for the fifth gas family, group D, limit values are given in µmol/m3 (in accordance with DIN EN 17124 [55]). The use of uniform quantities in DVGW technical rule – code of practice G 260 [53] would increase legibility and enhance comparability with International Standards.

Further quantities used internationally are ppm or ppm by weight. In German technical rules, the calorific value is given in kWh instead of MJ. Currently, there is corresponding information on conversion.

IMPLEMENTATION: This need is being incorporated into the current revision of DVGW technical rule – code of practice G 260 [53].

NEED 4.1.4-03:
Adaptation of DIN EN 17124 [55] in accordance with possible changes to ISO/DIS 14687 [69]

CONTENT: Gas quality category

EXPLANATORY NOTES: At international level, the introduction of a new gas quality category, Grade F, is being discussed in ISO/DIS 14687 [69]. ISO/DIS 14687 [69] describes the quality of hydrogen as a fuel for various applications. Grade F with ≥ 98 mol-% hydrogen defines a fuel quality for use in modern zero-emission road vehicles without central exhaust gas purification, such as in industrial plants. In the future, there is a need to incorporate this change into European Standard DIN EN 17124 [55]. DIN EN 17124 [55] specifies the quality characteristics of hydrogen for use in PEM fuel cell vehicles. It describes the hydrogen quality legally required for road vehicles at public filling stations in accordance with the 10th Federal Immission Control Act (BImSchV) [56].

IMPLEMENTATION: Implementation can only start once the revision of ISO/DIS 14687 [69] has been completed. The discussion about adopting Grade F at European level has already been initiated. It is important that this adoption is incorporated into the 10th Federal Immission Control Act (BImSchV) [56]. If the adoption into DIN EN 17124 [55] is not carried out, it will be implemented in a new project.

4.1.4.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.1.5 Verification and sustainability aspects of hydrogen

WG Verification and sustainability aspects is developing a concept for the clear differentiation of hydrogen and its derivatives for energy and material use depending on the origin of the energy provided. The sustainability aspects (ecological, economic, social) focus on the production, transport and storage of hydrogen and its derivatives. The WG has identified the need for a concept to assess the sustainability criteria of hydrogen and hydrogen derivatives.

4.1.5.1 Analysis of the status quo

Technical rules for the transmission and use of gases, e.g. as an energy carrier, are comprehensive. In addition to the technical requirements for the construction of pipelines, components and systems, safety and environmental requirements for construction, monitoring and maintenance are also described. The majority of the technical rules were developed on the basis of practical knowledge, particularly regarding the use of methane. Based on comparative research results, provisions for the application were expanded to include hydrogen.

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 (RFNBO [70]) are defined by the Renewable Energy Directive, RED II [71] and associated delegated regulations at European level and by the 37th Federal Immission Control Act (BImSchV) [72] at German level. The corresponding certification systems in accordance with the Delegated Regulation for hydrogen for RED II eligibility [71] and a national mass balance system will be completed in the course of 2024.

Regulations that describe an assessment and systematic recording of environmental impacts are considered to be particularly trend-setting. Guidelines, regulations, and EU directives are also already available at international level. However, a concrete reference to classification systems for investment projects for implementation, for example the EU Taxonomy Regulation [73], or for evaluation in accordance with the UN's Sustainable Development Goals [74], is rarely recognizable in the regulations, as their main focus is on a description of the technologies used.

A comprehensive comparative assessment basis for all production methods of hydrogen, its source materials and its derivatives, and the assessment of the relevant environmental impacts that go beyond emissions cannot be found.

4.1.5.2 Requirements and challenges

Processes for the production of hydrogen and its derivatives, as well as the associated certification schemes for sustainability, are diverse. Existing hydrogen production paths cannot be comprehensively compared with the existing systems. Existing sustainability assessments differ in the number, weighting and definition of individual aspects, which are determined by the area of application and the purpose of the respective system. A distinction can be made between regulatory provisions and other labels that lead to different quality requirements. This problem has so far only been partially solved by standardization. Traceable compliance with the criteria along the entire supply chain to ensure trust in the relevant standards and the certification schemes of various markets based on these standards has therefore not yet been achieved. Application is made even more difficult by the regulatory framework, which on the one hand describes certain aspects or technologies in particular detail or sets strict provisions, while on the other hand hardly specifying other aspects or not specifying them at all.

Against this background, it is important to have a minimum of uniformly relevant and concrete sustainability criteria that create transparency, traceability and thus comparability of the various technologies, also internationally. The various political, geographical and socio-economic circumstances of different countries should be taken into account when defining the sustainability criteria against the background of a global market for hydrogen, both for domestic production and for imports from abroad. The dynamic development in this area and the strong market ramp-up require a quick and, above all, targeted solution to this problem.

The goal of a holistic view of sustainability aspects is desirable and should be pursued, but could run counter to the goal of accelerating the hydrogen market ramp-up. Bringing the two objectives together is a challenging task. This is due to the various political, geographical and socio-economic conditions in the hydrogen exporting countries, which generally differ greatly from European Union standards. The approach to standardization of sustainability aspects in relation to hydrogen and its derivatives must therefore ensure that their trade and market development are not hindered, but promoted through comparability and transparency.

4.1.5.3 Needs analysis

NEED 4.1.5-01:
Sustainability criteria for hydrogen and hydrogen derivatives as energy carriers

CONTENT: Sustainability aspects; criteria

EXPLANATORY NOTES: Principles, criteria and indicators for the sustainability of the production, transmission and storage of hydrogen and its derivatives are necessary to facilitate the assessment of the environmental, social and economic aspects of sustainability. The criteria should be applicable to all types of production of hydrogen and its derivatives and apply regardless of the technology used for production, geographical location, storage or final use. No threshold or limit values are to be defined in this project. There will also be no evaluation of the criteria. The sustainability aspects of the end applications are not part of the scope of this project.

IMPLEMENTATION: A concept for sustainability criteria is to be developed as part of a national project.

4.1.5.4 Implementation projects

Need 4.1.5-01 was initiated at DIN as an implementation project with the title Sustainability criteria for hydrogen and its derivatives and is being implemented as a national project in NA 172-00-10-01 GAK Joint working group NAGUS/NAGas: Sustainability criteria for hydrogen and its derivatives.

4.2 Infrastructure

Working committee Infrastructure is responsible for the standards and technical rules in the field of infrastructures required for the supply of hydrogen. In addition to grid-based infrastructures, this also includes the storage facilities connected to the infrastructure (above and below ground) as well as facilities for liquefying hydrogen. WC Infrastructure is divided up into two sub-working committees, Transmission pipelines and distribution grids and Storage.

First, an analysis of existing standards and technical rules for hydrogen rule-setting was carried out. Here it was identified that there are already more than 390 technical rules and standards that contain provisions on hydrogen as a medium [13].

The next step was to look at the needs that arise for the upscaling of the hydrogen economy and which still need to be developed in terms of technical rules in comparison with the analysis of the status quo. A concrete need for 68 technical rules was identified. While almost a complete collection of technical rules for hydrogen ramp-up is already in place in the area of grid-based infrastructure, extensive standardization and technical rule-setting is still required in the area of storage.

4.2.1 Piping

WG Piping is responsible for determining the standardization needs in the field of industrial pipes for plant supply and in the field of flanges and their connections, as well as process pipelines. This includes, among other things, requirements for above-ground or ducted or buried pipelines made of metallic and non-metallic materials for hydrogen and hydrogen blends at different pressures and temperatures. With the aim of achieving safe operating conditions, requirements for industrial piping systems and their supports made of metallic materials, including safety devices, are of particular importance (e.g. DIN EN 13480 series of standards [75]). Industrial piping systems differ from long-distance pipelines. The latter are transmission pipelines (WG Transmission pipelines) outside the industrial plants, e.g. refineries, and are not part of the subject areas of WG Piping. Distribution networks are dealt with in WG Distribution networks.

4.2.1.1 Analysis of the status quo

In the course of the development of the Standardization Roadmap Hydrogen Technologies, existing standards were reviewed for their suitability for use, construction and operation in conjunction with hydrogen technologies. It was found that the standards for pipes and semi-finished products available to date could in principle also be suitable for hydrogen technologies. However, a more detailed review is necessary. Standardization work still needs to be carried out, particularly in the area of testing semi-finished products and their processing into pipes. At the moment, individual reviews are necessary for many projects. Standards and technical rules also need to be revised. Semi-finished product standards are not to be drawn up for use in special media; instead, they are to be reviewed for use in hydrogen technologies. Internationally, some hydrogen-compatible standards or those specifically for hydrogen are already available, but tests and amendments are required for European and national use.

A special focus is placed on maintenance and operation. In some cases, international technical rules can be used, and European and national particularities can be added to them. Here, too, a national need for additional standards and technical rules has been identified [13]. Additional research projects have also been initiated at a political level.

Figure 14 presents the identified bodies that are important for the development of technical rules in the field of pipings. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.2.1.2 Requirements and challenges

The Pressure Equipment Directive [76] applies to the placing on the market and CE marking of all pressure equipment (vessels, pipelines, equipment) and assemblies above 0,5 bar; the exemption for long-distance pipelines ("transmission pipelines") must be observed. The German Energy Industry Act [36] also applies to energy systems. The challenges here are the differentiation of which regulations are used when, and the synergy of a European competitive strategy according to EN regulations. Requirements for pipelines for the transmission of hydrogen result from varying external and internal factors. European Standards offer the advantage of a harmonized European hydrogen strategy. The DIN EN 13480 series of standards [75] provides a set of rules that covers the entire manufacturing process and includes material and production standards.

The following challenges have been identified in addition:

1. Differentiation by application (operating temperature, pressure and possible damage mechanism) or by material type (ASME B31.12 [77]).
2. Qualification methods for pipe steels
   a. Which tests are to be carried out by pipe manufacturers (also applies to all other pressure bearing parts)?
   b. Effects on the technical delivery conditions such as the DIN EN 10216 series of standards [78], the DIN EN 10217 series of standards [79], etc.
3. Methods for the qualification of material-changing or supplementary processes. Additional tests may be required, which must be supplemented in the relevant qualification standards.
4. Toughness requirements
   a. To prevent brittle fracture, based on fracture mechanics and specific limits for imperfections.
   b. Taking into account the influence of hydrogen on the ductile transition temperature.
5. Welding consumables are additional materials that have so far been assessed and used in the same way with regard to their mechanical and corrosive properties. This must be reviewed and modified where necessary.
6. Rededication of existing pipelines: What strategy must be pursued in terms of the above-mentioned points?
7. How can repairs be requalified?

Piping

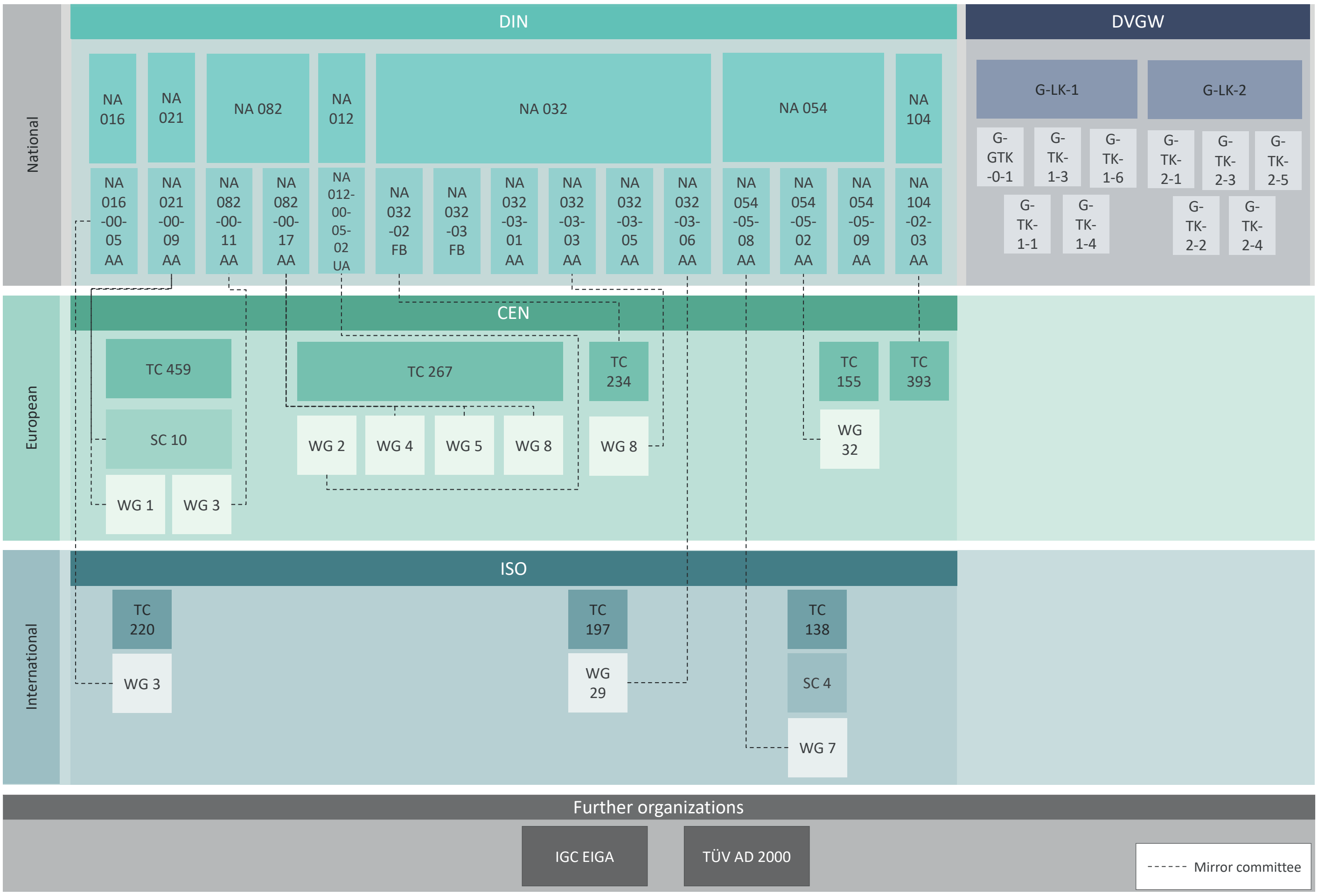

Figure 14: Overview of bodies relevant to technical rule-setting in the area of piping (as of 03-2024) (Source: own illustration)

What requirements must companies meet in order to offer hydrogen-compatible products or services? Building on the experience of the process industry, an initial initiative was launched at European level. It is becoming apparent that points 2, 3, 4 and 5 in particular require additional pre-normative research. The speed of implementation will depend on the financial support.

4.2.1.3 Needs analysis

NEED 4.2.1-01:
DIN EN 13480-11, Metallic industrial piping – Part 11: Additional requirements for hydrogen application piping [80]

CONTENT: Industrial piping; hydrogen embrittlement; modes of operation

EXPLANATORY NOTES: Requirements for new metallic industrial piping for hydrogen applications supplementary to DIN EN 13480-1 [81] to DIN EN 13480-8 [82]. Differentiation between four basic operating modes with specific damage mechanisms caused by hydrogen:

1. operation at cryogenic temperatures;
2. embrittlement/degradation in a hydrogen-containing environment or hydrogen-induced/assisted cracking (HEE);
3. high-temperature hydrogen attack (HTHA);
4. operation with cyclical loading (Fatigue).

IMPLEMENTATION: High priority European project in CEN/TC 267. DIN is responsible for national rule-setting in this case. The responsible body is DIN working group NA 082-00-17-01 AK EN 13480-11.

NEED 4.2.1-02:
DVGW technical rule – code of practice G 614-1, Above ground gas pipework on premises behind point of delivery, Part 1: Planning, installation, testing and commissioning [83] and DVGW technical rule – code of practice G 614-2, Above ground gas pipework on premises behind point of delivery, Part 2: Operation and maintenance [84]

CONTENT: Above-ground pipelines; planning; maintenance

EXPLANATORY NOTES: Planning to commissioning of above-ground gas pipelines on the factory premises behind the point of delivery up to the last shut-off valve before the gas utilization facility, in which gases of the second gas family are transported, as well as their operation and maintenance. Requirements are specified to supplement the applicable technical rules (e.g. DVGW technical rule – code of practice G 462 [85]). The requirements are to be expanded to cover hydrogen. In doing so, it must be ensured that there is a demarcation from the German Ordinance on Industrial Safety and Health (BetrSichV) [86] and the EU Pressure Equipment Directive (PED) [76].

IMPLEMENTATION: Medium priority. Internal revision at DVGW is planned. DVGW is responsible for national rule-setting in this case. The responsible DVGW body is G-TK-2-3 Gas installation.

NEED 4.2.1-03:
Standards series DIN EN 10216, Seamless steel tubes for pressure purposes – Technical delivery conditions [78]

CONTENT: Delivery conditions; non-alloy/alloy steels

EXPLANATORY NOTES: Material selection is made according to the various parts of the DIN EN 10216 series [78]. It is not specified for which media the steel tubes are suitable. Quality requirements such as surface and internal quality and any other necessary quality requirements or additional restrictions are specified. The need for modifications to other series of standards (including DIN EN 13480 [75] and DIN EN 13445 [87]) is currently being examined, after which the adaptations to the DIN EN 10216 [78] series will be assessed.

IMPLEMENTATION: High priority. DIN is responsible for national rule-setting in this case. The responsible body is DIN Subcommittee NA 021-00-09-01 UA Non-alloy structural steel and fine grain steel tubes.

NEED 4.2.1-04:
Standards series DIN EN 10217, Welded steel tubes for pressure purposes – Technical delivery conditions [79]

CONTENT: Steel tubes; quality requirements; discontinuities

EXPLANATORY NOTES: It is not specified for which media the steel tubes are suitable. Quality requirements such as surface and internal quality and any other necessary quality requirements or additional restrictions are specified. The need for modifications to other series of standards (including DIN EN 13480 [75] and DIN EN 13445 [87]) is currently being examined, after which the adaptations to the DIN EN 10217 [79] series will be assessed. The effects on the longitudinal weld also need to be reviewed.

IMPLEMENTATION: High priority. European project. DIN is responsible for national rule-setting in this case. The responsible body is DIN Subcommittee NA 021-00-09-01 UA Non-alloy structural steel and fine grain steel tubes. Should be implemented as part of a regular revision.

NEED 4.2.1-05:
DIN EN 10217-7, Welded steel tubes for pressure purposes – Technical delivery conditions – Part 7: Stainless steel tubes [88]

CONTENT: Steel tubes; low temperatures, filler metals

EXPLANATORY NOTES: The low temperature option should be added so that technical rules for suitable filler metals for this application are available to cover this (liquid hydrogen).

IMPLEMENTATION: High priority. European project. DIN is responsible for national rule-setting in this case. The respon-

Piping

sible body is DIN Subcommittee NA 021-00-09-01 UA Non-alloy structural steel and fine grain steel tubes.

NEED 4.2.1-06:
Cryogenic interfaces / connecting elements

CONTENT: Cryogenic interfaces; Johnston couplings

EXPLANATORY NOTES: Cryogenic interfaces / connecting elements such as the Johnston couplings are not standardized in their external dimensions. This must be standardized in good time before the extensive use of liquid hydrogen, possibly as a new standardization project or as an addition to EN 13371 [89]. This document standardizes the test requirements for Johnston couplings, but not the form.

IMPLEMENTATION: Medium priority. DIN is responsible for national rule-setting in this case.

NEED 4.2.1-07:
DIN EN 10253-2, Butt-welding pipe fittings – Part 2: Non alloy and ferritic alloy steels with specific inspection requirements [90] and DIN EN 10253-4, Wrought austenitic and austenitic-ferritic (duplex) stainless steels with specific inspection requirements [91]

CONTENT: Fittings; additional quality requirements

EXPLANATORY NOTES: It is not specified for which media the steel tubes are suitable. Quality requirements such as surface and internal quality and any other necessary quality requirements or additional restrictions are specified. Currently, the need for amending further standards series (including DIN EN 13480 [75] and DIN EN 13445 [87]) is being reviewed. Internal stresses require special consideration. There is a high risk potential with interactions such as welding.

IMPLEMENTATION: High priority. European project. DIN is responsible for national rule-setting in this case. The responsible body is DIN working committee NA 082-00-11 AA Pipe fittings.

NEED 4.2.1-08:
Scoring in the finished component (flange) due to internal boring / production without overtightening and the production surface (standards series DIN EN 1092 [92])

CONTENT: Flanges; scoring; cracks

EXPLANATORY NOTES: Discontinuities serve as entry points for hydrogen and are regarded as cracks. The assessment, also with regard to service life, can be determined using fracture mechanics methods (e.g. BS 7910 [93]).

As a rule, the depth of the scoring is limited by the surface roughness (peak-to-valley height). The scoring length depends on the diameter of the component, the shoulder length and the feed pitch. There are two problems associated with scoring: firstly, the length of the helix, i.e. the spiral expansion of the scoring, and secondly, an undefined surface that has a scoring depth and scoring length that are greater than the maximum permissible crack dimensions.

IMPLEMENTATION: High priority. European project. DIN is responsible for national rule-setting in this case. The responsible body is DIN working committee NA 082-00-16 AA Flanges and their joints.

4.2.1.4 Implementation projects

DIN EN 13480-11, Metallic industrial piping – Part 11: Additional requirements for hydrogen application piping [80]:

DIN working committee NA 082-00-17 AA Industrial piping and pipelines has contributed to the initiation of a new part to the EN 13480 [75] standards series at European level. The project is currently registered as a PWI (since 2021-08-04). Participation in the project is possible within DIN working group NA 082-00-17-01 AK EN 13480-11. The topic of hydrogen is being addressed in close cooperation with the FNCA.

4.2.2 Transmission pipelines

WG Transmission pipelines is responsible for hydrogen transmission pipelines at pressures between 16 bar and 100 bar for supplying the public with hydrogen and hydrogen blends in accordance with the German Energy Industry Act [36].

Its tasks include the review of existing technical rules for hydrogen transmission and the identification of new requirements for technical rule-setting. This requires the development of the associated framework conditions and product requirements for piping and piping components for hydrogen transmission. Distribution networks (WG Distribution networks) and industrial piping systems (WG Piping) do not fall under the remit of this WG.

4.2.2.1 Analysis of the status quo

Standardization and technical rule-setting for WG Transmission pipelines has been completed for the most part. It is assumed that, with the same mode of operation as for the transmission of natural gas, hydrogen is particularly suitable for the materials. Apart from the research programmes (DVGW hydrogen innovation programme [33]), the entire body of technical rules consists exclusively of standards and technical rules that have already been revised. During the preliminary investigations and technical discussions of the experts from the NAGas bodies at DIN and the Technical Committees (TK) of the DVGW, the relevant technical rules were immediately identified and taken up. Some of the open requirements were already known and being processed by the technical bodies. These will be gradually transferred to the collection in a structured manner over the coming months and years.

At the end of 2023, around 20 technical rules from this working group were included in the already published Standards Database for Hydrogen Technologies [13]. Half of these are already published DVGW technical rules that carry the H_2-ready label, as well as three national DIN Standards. The remaining documents are European or International Standards and technical rules. Relevant political regulations are the German Energy Industry Act (EnWG) [36] and the German High-Pressure Gas Pipeline Ordinance [68].

Figure 15 presents the technical regulation identified bodies that are important for the development of technical rules in the field of transmission pipelines. An overview of the abbreviations used to describe these bodies is given in Section 9.

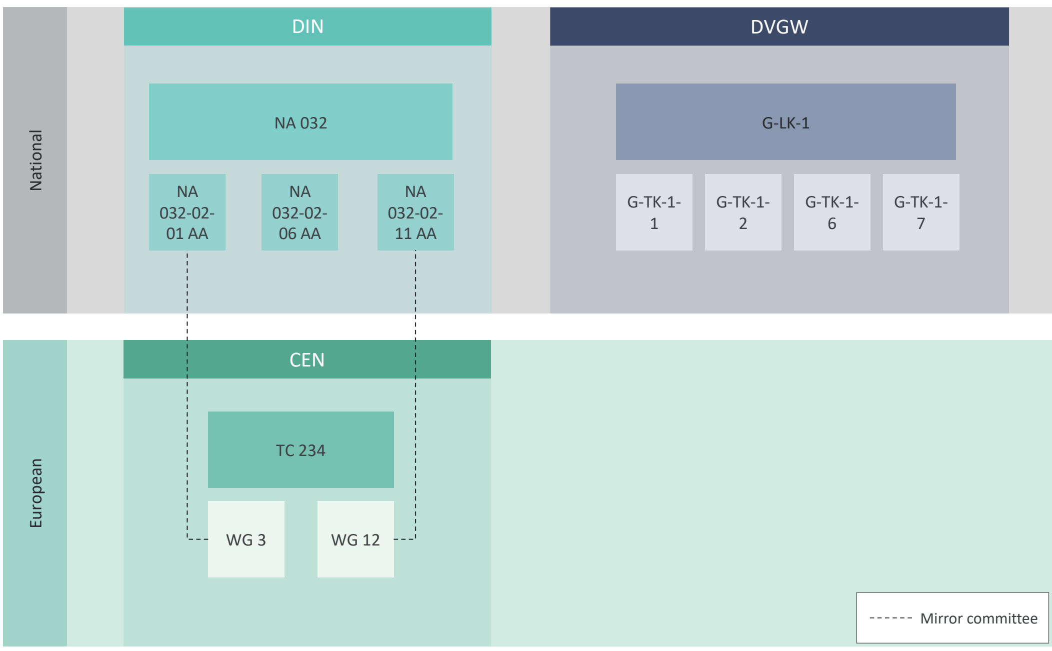

Figure 15: Overview of bodies relevant to technical rule-setting in the area of transmission pipelines (as of 03-2024) (Source: own illustration)

Transmission pipelines

4.2.2.2 Requirements and challenges

In order to continue the integration of hydrogen into the collection of technical rules, the revision of various DVGW technical rule – codes of practice and technical information – guidelines must be continued. Furthermore, additional and new DVGW technical rule – codes of practice and technical information – guidelines must be drawn up. To this end, it will be necessary to carry out research topics that have already been identified. If necessary, further new research topics will have to be identified.

To ensure safe hydrogen transmission, it is essential to close all previous knowledge gaps by means of research projects and to incorporate them into the technical rules in a timely manner.

As of now, the following key challenges have been defined:
→ welding on hydrogen pipes in operation;
→ operation of hydrogen pipelines;
→ training of staff members to handle hydrogen.

The handling of natural gas is known; with hydrogen, operating processes must be adapted (due to the material properties of hydrogen). The following focus points have been identified:
→ traces of gas, measurement;
→ commissioning, de-commissioning;
→ flushing;
→ pigging.

The explosion protection zones in gas regulating stations must also be adapted, as the dispersion of hydrogen is different from that of methane. In addition, the definition of technical leak tightness with regard to hydrogen needs to be reviewed.

4.2.2.3 Needs analysis

NEED 4.2.2-01:
DVGW technical rule – code of practice G 452-1, Tapping and plugging of gas steel pipelines [94]

CONTENT: Planning; preparation; execution; tapping; plugging; gas pipelines; second gas family

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
→ Adopting DVGW technical information – guideline G 221 [95] as a valid technical rule.
→ Expanding the technical rule to include the fifth gas family in accordance with DVGW technical rule – code of practice G 260 [53];
→ Reviewing the technical rule with regard to the special features of the use of hydrogen and hydrogen-natural gas blends;
→ Reviewing the technical rule relating to the use of hydrogen with regard to technical framework conditions and the general suitability of materials for hydrogen (as an additional or replacement gas).

IMPLEMENTATION: This will be implemented starting from 2025 in the DVGW body G-TK-1-1 Gas transmission pipelines

NEED 4.2.2-02:
DVGW VP 642, Fibre-reinforced PE pipes (RTP) and associated connectors for gas pipelines with operating pressures above 16 bar [96] and DVGW VP 643, Flexible, fabric-reinforced plastic inliners and associated connectors for gas pipelines with operating pressures above 16 bar [97]

CONTENT: Testing principles; fibre-reinforced pipes; pipe system; inliner system; flexible and fabric-reinforced plastic inliners

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
→ Expanding the testing principles to include the fifth gas family in accordance with DVGW technical rule – code of practice G 260 [53];
→ Reviewing the testing principles with regard to the special features of the use of hydrogen and hydrogen-natural gas blends;
→ Reviewing the testing principles relating to the use of hydrogen with regard to technical framework conditions and the general suitability of materials for hydrogen (as an additional or replacement gas).

Transmission pipelines

IMPLEMENTATION: This will be implemented starting from 2025 in the DVGW body G-TK-1-1 Gas transmission pipelines

NEED 4.2.2-03:
DIN EN 1594, Gas infrastructure — Pipelines for maximum operating pressure over 16 bar — Functional requirements [98]

CONTENT: Pipeline systems; gas piping grid; construction and operation; environmental protection

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
- → Expanding the standard to include the fifth gas family in accordance with DVGW technical rule – code of practice G 260 [53];
- → Amendments with regard to available technologies for the use of hydrogen;
- → Adding precautions during operating procedures (discharging, flaring, etc.);
- → Consideration of crack propagation in pipelines in relation to the transfer of hydrogen.

IMPLEMENTATION: Implementation will start in 2024 in CEN/TC 234/WG 3.

NEED 4.2.2-04:
DIN EN 12327, Gas infrastructure – Pressure testing, commissioning and decommissioning procedures – Functional requirements [99]

CONTENT: Pressure testing; commissioning and decommissioning; gas infrastructure

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
- → Expanding the standard to include the fifth gas family in accordance with DVGW technical rule – code of practice G 260 [53];
- → Amendments with regard to available technologies for the use of hydrogen;
- → Adding precautions during operating procedures (discharging, flaring, flushing, commissioning etc.);
- → Review with regard to the admissibility of pressure testing methods and their application for the hydrogen-powered infrastructure.

IMPLEMENTATION: This will be implemented starting from 2025 in CEN/TC 234/WG 2.

NEED 4.2.2-05:
DVGW technical rule – code of practice G 463, High Pressure Gas Steel Pipelines for a Design Pressure of more than 16 bar; Design and Construction [100]

CONTENT: High pressure gas pipelines; energy plants; industrial use of gas

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
- → Revision to include new research results from the projects of the DVGW Hydrogen Innovation Program [33];
- → Comparison with DIN 30690-1 [101], which is currently being revised, with regard to components under the influence of hydrogen.

IMPLEMENTATION: This will be implemented starting from 2024 in the DVGW body G-TK-1-1 Gas transmission pipelines.

NEED 4.2.2-06:
DVGW technical information – guideline G 409, Conversion of High Pressure Gas Steel Pipelines for a Design Pressure of more than 16 bar for Transportation of Hydrogen [102]

CONTENT: Design pressure; gas transmission

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
- → Comparison and adaptation to the contents of the current DVGW technical information – guidelines: DVGW technical information – guideline G 464 [103], DVGW technical rule – code of practice G 463 [100], DVGW technical information –

guideline G 405 [104] and DVGW technical rule – code of practice G 260 [53];
- → Determination of the hydrogen partial pressure from which DVGW technical information – guideline G 409 [102] is to be applied;
- → Revision to include new research results from the projects of the DVGW Hydrogen Innovation Program [33].

IMPLEMENTATION: This will be implemented starting from 2024 in the DVGW body G-TK-1-1 Gas transmission pipelines.

4.2.2.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.2.3 Plant engineering

The remit of WG Plant engineering covers all plants that are necessary for the operation of gas networks. The main subject matter is:
- → Functional requirements for the design, construction, operation and maintenance of these plants;
- → Requirements for components in hydrogen plants.

In addition, where the subject can be standardized:
- → Qualification requirements for companies designing, manufacturing and operating hydrogen plants;
- → Qualification requirements for persons for the testing and operation of hydrogen plants – experts and specialists.

4.2.3.1 Analysis of the status quo

Standardization and technical rule-setting for WG Plant engineering has been completed for the most part. The assumption here is that hydrogen suitability is given with the same operating mode of the natural gas regulating station technology and a prior inventory of the plants. Apart from the research programmes (DVGW hydrogen innovation program [33]), the entire body of technical rules consists exclusively of technical rules that have already been revised. During the preliminary investigations and technical discussions of the experts from the NAGas bodies at DIN and the Technical Committees (TK) of the DVGW, the relevant technical rules were immediately identified and taken up. Some of the open requirements were already known and were being processed by the technical bodies. These will be gradually transferred to the collection in a structured manner over the coming months and years.

At the end of 2023, around 53 standards and technical rules as well as DVGW information from this working group were included in the Standards Database for Hydrogen Technologies [13]. Half of these are already published DVGW technical rules that carry the H_2-ready label, as well as one DIN EN Standard. The remaining technical rules are being or will be revised. The Database published in September 2023 gives a detailed listing of the standards and technical rules [13]. Relevant regulations for Germany are the German Energy Industry Act (EnWG) [36] and the German High-Pressure Gas Pipeline Ordinance (GasHDrLtgV) [68].

Figure 16 presents the identified bodies that are important for the development of technical rules in the field of plant engineering. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.2.3.2 Requirements and challenges

The current technical rules for the construction and operation of gas regulating stations are generally applicable to the use of hydrogen. The status of adaptation and revision in the DVGW and DIN bodies corresponds to the needs of the industry. Identified research needs have been addressed to date and are currently being dealt with. The requirements for leaktightness testing of components for hydrogen plants and flow velocities in devices and systems are not sufficiently covered in technical rules. With regard to the leaktightness test, there is a need for clarification regarding the choice of test medium and the permissible leakage rates.

With regard to the flow velocities, further details are required for applications in the higher pressure ranges. Current research projects are mainly looking at theoretical approaches. Theoretical consideration and practical applicability must

Plant engineering

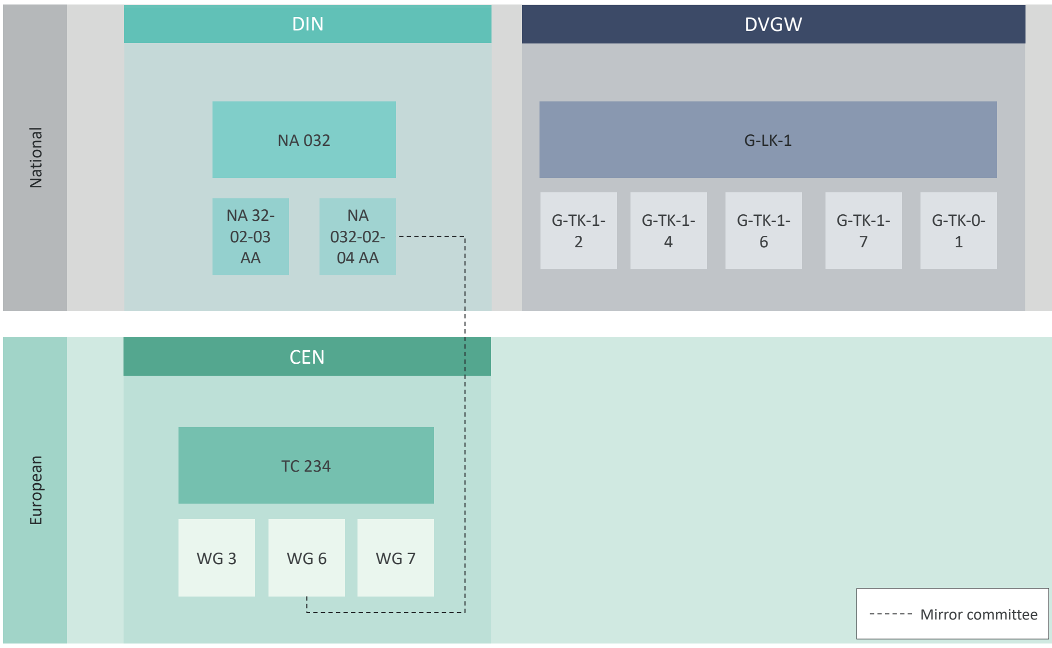

Figure 16: Overview of bodies relevant to technical rule-setting in the area of plant engineering (as of 03-2024) (Source: own illustration)

now be reconciled. Furthermore, there are currently no uniform provisions regarding the criteria for testing and certifying the suitability of components for use under hydrogen conditions. There is a need for action here insofar as the current practice is not comparable. On the other hand, it is sometimes impossible to obtain a comparable confirmation of suitability and use in hydrogen systems from the manufacturing company due to the lack of framework conditions for testing components. These issues often lead to uncertainties among companies and experts regarding the application of the state of the art and the guarantee of comprehensive safety. Economic aspects should also be mentioned in this context, which can result from unnecessary oversizing, for example.

4.2.3.3 Needs analysis

NEED 4.2.3-01:
DVGW technical rule – code of practice G 213, Plants for the production of combustible gas mixtures [105]

CONTENT: Design, long-distance pipeline networks; distribution networks

EXPLANATORY NOTES: With the imminent integration of hydrogen as an essential component of hydrogen-containing gases in the public gas supply, a fundamental revision of this Code of Practice is necessary.

IMPLEMENTATION: This will be implemented starting from 2025 in the DVGW body G-TK-1-4 Plant engineering

NEED 4.2.3-02:
DVGW technical information – guideline G 442, Potentially explosive atmosphere at exhaust openings of venting lines at gas regulating stations or systems [106]

CONTENT: Pipelines; atmospheres

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:

→ The currently valid DVGW technical information – guideline presents a method for determining the extent of the potentially explosive zones;
→ The method is currently being reassessed and updated as part of a research project;
→ The resulting findings will be incorporated in the technical rule as instructions for action.

Plant engineering

IMPLEMENTATION: This will be implemented starting from 2024 in the DVGW body G-LK-1 Gas supply.

NEED 4.2.3-03:
DVGW technical rule – code of practice G 492, Gas Measuring Systems for an Operating Pressure up to and including 100 bar [107]

CONTENT: Decommissioning; disposal; gas measuring systems; gas transmission systems; distribution systems

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
→ A reference to DVGW technical information – guideline G 221 [95];
→ The safety concept of the measuring systems must be coordinated with the safety concepts of the connected pipelines and plants;
→ When drawing up the measurement concept, the gas components and by-products must be taken into account for the entire period of validity of the measurement concept;
→ Consideration of possible biogas or hydrogen feed-ins.

IMPLEMENTATION: Implementation began in 2023 in DVGW body G-TK-1-5 Gas measurement and accounting.

NEED 4.2.3-04:
DVGW technical rule – code of practice G 493-2, Qualification criteria for companies for the maintenance of gas regulating stations and systems [108]

CONTENT: Personnel/technical requirements; hydrogen feed-in plants/systems; biogas feed-in/feedback plants/systems

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
→ Inclusion of the qualification requirements for specialists for testing electrical systems;
→ Inclusion of the qualification requirements for specialists for testing the suitability of devices and protective systems in potentially explosive zones;
→ Inclusion of the qualification requirements for specialists for lightning protection systems in potentially explosive zones.

IMPLEMENTATION: This will be implemented starting from 2026 in the DVGW body G-TK-1-4 Plant engineering

NEED 4.2.3-05:
DVGW technical information – guideline G 494, Measures of sound protection of devices and appliances for gas pressure control and gas measurement [109]

CONTENT: Primary/secondary noise protection measures; gas measuring systems; gas pressure regulating systems

EXPLANATORY NOTES: With the imminent integration of hydrogen as an essential component of hydrogen-containing gases in the public gas supply, a fundamental revision of this Code of Practice is necessary.

IMPLEMENTATION: This will be implemented starting from 2025 in the DVGW body G-TK-1-4 Plant engineering

NEED 4.2.3-06:
DVGW technical rule – code of practice G 497, Compressor stations [110]

CONTENT: Compressor stations; operating pressure; gas supply

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
→ The Scope is to be clearly defined (to differentiate DVGW technical rule – code of practice G 497 [110] from DVGW technical rule – code of practice G 265-1 [111]);
→ Adopt DVGW technical information – guideline G 404 [112] and DVGW technical information – guideline G 442 [106] on avoiding hydrogen emissions;
→ Adopt DVGW Information Gas No. 29 [113] regarding terminology relating to hydrogen applications.

Plant engineering

IMPLEMENTATION: This will be implemented starting from 2024 in the DVGW body G-TK-1-2 Compressor stations.

NEED 4.2.3-07:
DVGW Information Gas No. 17, Lightning protection for gas pressure regulating and metering systems – Guideline for implementing the requirements of DIN EN 62305 [114]

CONTENT: Information; lighting protection

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
→ the testing principles as in DIN 30691 are to be integrated into DVGW Information Gas No. 17 [114];
→ the requirements regarding the explosion group in relation to hydrogen are to be included;
→ the scope is to be extended to include hydrogen supply systems;
→ the lightning protection concepts are to be revised.

IMPLEMENTATION: This has been implemented starting from 2023 in the DVGW body G-TK-1-4 Plant engineering.

NEED 4.2.3-08:
DIN 33822, Gas pressure regulators and safety devices for gas installations for inlet pressure up to 5 bar [115]

CONTENT: Gas pressure regulators; safety shut-off devices; thermal protection; gas shortage protection; gas flow monitors

EXPLANATORY NOTES: This standard applies to gas pressure regulators operated with gases as in DVGW technical rule – code of practice G 260 [53]. Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes adapting the standard with regard to the use of devices under hydrogen conditions, in particular materials and leak testing.

IMPLEMENTATION: This will be implemented starting from 2025 in the DVGW body G-TK-1-4 Plant engineering and DIN working committee NA 032-02-04 AA Gas systems engineering.

NEED 4.2.3-09:
DIN EN 12279, Gas supply systems – Gas pressure regulating installations on service lines – Functional requirements [116]

CONTENT: Gas pressure regulating installations; service lines in gas supply systems

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes adapting the standard with regard to the use and installation of devices under hydrogen conditions.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 032-02-04 AA Gas systems engineering and in CEN/TC 234.

NEED 4.2.3-10:
DIN EN 334, Gas pressure regulators for inlet pressures up to 10 MPa (100 bar) [117]

CONTENT: Gas pressure regulators; inlet pressures; operating temperature range

EXPLANATORY NOTES: Various adjustments must be made regarding the possible use of hydrogen or hydrogen-natural gas blends. This includes adapting the standard regarding the use of devices under hydrogen conditions, in particular materials and leak testing.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 032-02-04 AA Gas systems engineering and in CEN/TC 235 Gas pressure regulators and associated safety devices for use in gas transmission and distribution.

NEED 4.2.3-11:
DIN 30691, Lightning current tests – Flanges with electrically conductive gaskets

CONTENT: Testing standard; electrically conductive gaskets

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
- → specification of test conditions for gaskets covered by DIN 30690-1 [101];
- → specification of the test set-up in relation to DVGW Information Gas No. 19 [118];
- → test schedules including leak testing in accordance with DIN EN 12327 [99].

IMPLEMENTATION: This will be implemented starting from 2024 in the DVGW body G-TK-1-4 Plant engineering and DIN working committee NA 032-02-04 AA Gas systems engineering.

The needs identified in relation to hydrogen in systems engineering were prioritized and standardization projects and technical rule projects for the following were initiated:
- → DVGW technical rule – code of practice G 497, Compressor stations (in gas transmission) [110]
- → DVGW technical information – guideline G 442, Potentially explosive atmosphere at exhaust openings of venting lines at gas regulating stations or systems [106]
- → DVGW technical rule – code of practice G 454, Measures regarding completion of the technical documentation for gas pressure regulating and gas measuring stations [119]

4.2.3.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.2.4 Distribution networks

WG Distribution networks is actively involved in the topic of hydrogen in gas distribution (MOP $\leq$ 16 bar). Open questions about the suitability of materials, components, and parts for hydrogen, as well as questions about subsequent operation (commissioning, pipe network inspection, maintenance, etc.) with gases of the second gas family (hydrogen blending) or fifth gas family in accordance with DVGW technical rule – code of practice G 260 [53] are being clarified. A key aspect here is to ensure the applicability of the relevant technical rules and standards. As far as possible, pilot project results are already taken into account. Consequently, the focus of the work is on identifying requirements for the technical rules in order to provide recommendations for integrated network development planning for gas and hydrogen, network construction or conversion and extended documentation obligations based on these findings.

4.2.4.1 Analysis of the status quo

In accordance with Section 49 (1) of the German Energy Industry Act [36], assets used to produce, transport and distribute natural gas and hydrogen are presumed to comply with the general rules of technology if the DVGW technical rules are observed. Overall, there are already many technical rules for distribution networks and many of the associated activities (e.g. design and construction, operation, pipe network inspection, documentation, maintenance) that can be adapted to the use of hydrogen. In addition, supplementary documents have been published to deal with open issues such as the conversion of natural gas networks to hydrogen-rich gases or pure hydrogen. As of December 2023, the WG Distribution networks has identified 25 published relevant standards and technical rules. These include three European Standards, two DIN Standards and 20 different DVGW documents such as codes of practice, guidelines and gas information documents. However, since the level of knowledge and understanding regarding the use of hydrogen in the gas distribution network infrastructure has developed significantly in the recent past, standardization and needs for action were analyzed not only for documents still to be revised, but also for documents already declared as H_2-ready, which are described in more detail in the following sections. An overview of the relevant documents identified by the WG is given in the Standards Database for Hydrogen Technologies [13].

Figure 17 presents the identified bodies that are important for the development of technical rules in the field of distribution networks. An overview of the abbreviations used to describe these bodies is given in Section 9.

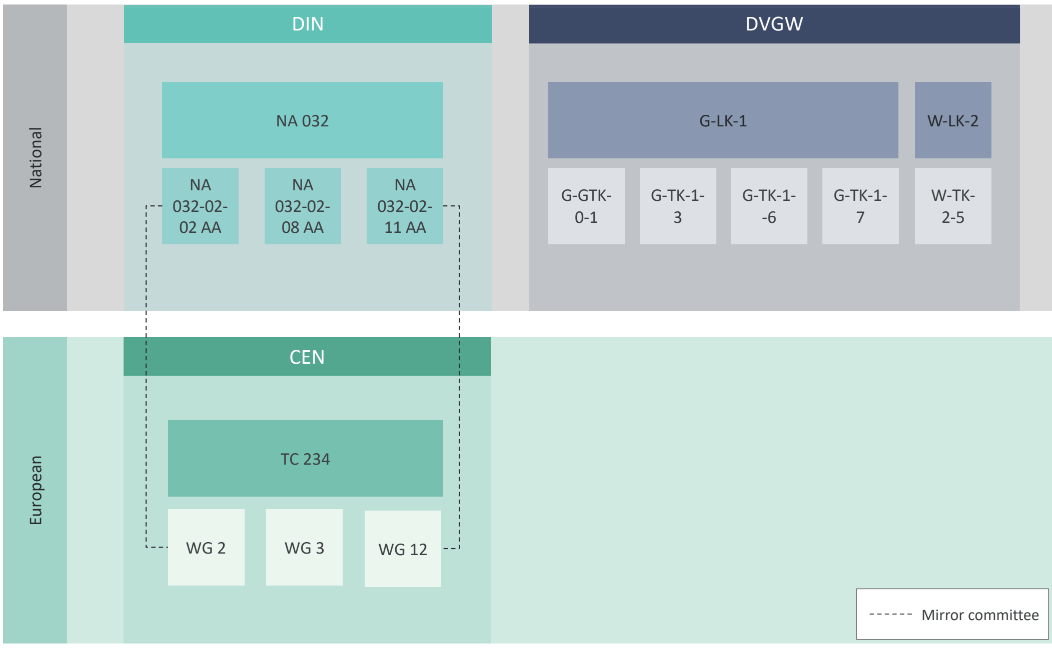

Figure 17: Overview of bodies relevant to technical rule-setting in the area of distribution networks (as of 03-2024) (Source: own illustration)

4.2.4.2 Requirements and challenges

In order to make hydrogen usable in gas distribution, WG Distribution networks identified the following key gaps between the current situation and the desired standards:

1. **Network documentation:** There are no uniform provisions on the documentation of hydrogen pipelines and plants in the plans of the utility companies. This covers various areas such as surveying, GIS and ERP systems, network information, etc. and is crucial for the safe operation of a hydrogen infrastructure (e.g. DVGW technical rule – code of practice GW 120 [120]). Especially in low-pressure networks (up to 1 bar), the documentation often does not meet the requirements for hydrogen conversion, mainly due to the advanced age of the networks and limited data collection in the past. Gathering crucial information requires extensive civil engineering work and laboratory investigations. To make this economical, network operators need a clear framework for a data collection concept that reduces the effort involved (DVGW technical information – guideline G 407 [121], DVGW technical information – guideline G 408 [122]).
2. **Pipe network inspection:** The regular inspection of gas pipe networks is a central operational task and ensures the safety of connected customers and the general public. DVGW technical rule – code of practice G 465-1 [123], which is essential for distribution networks up to 16 bar, currently only considers methane-rich gases of the second and third gas families and must be quickly expanded to include the requirements for hydrogen-rich gases of the fifth gas family. DVGW technical information – guideline G 221 [95] must also be taken into account, and pending codes of practice and guidelines (DVGW technical rule – code of practice G 465-2 [124], G 465-3 [125] and G 465-4 [126]), which contain, for example, hazard potential and equipment technology, must also be adapted to the requirements of hydrogen.
3. **Employment of experts:** Clear areas of application and (additional) qualification requirements for experts and specialists are necessary in order to be able deal with hydrogen technologies. In view of the shortage of specialists, a major expansion of the use of experts or a strict separation between experts for natural gas and those for hydrogen is not realistic.

The specific needs identified by the WG show that suitable documentation and data collection procedures in particular, as well as the adaptation of verification guidelines, are necessary in order to integrate hydrogen safely and economically into gas distribution. The qualifications of specialists must keep pace with these challenges.

Distribution networks

4.2.4.3 Needs analysis

NEED 4.2.4-01:
DVGW technical rule – code of practice GW 303-1, Calculation of gas and water pipeline networks – Part 1: Hydraulic principles, network modelling and calculation [127]

CONTENT: Pipeline network calculation; pressure / flow relationships

EXPLANATORY NOTES: Various adjustments must be made regarding the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:

- → including DVGW technical information – guideline G 221 [95] as a valid technical rule;
- → review of the technical rule collection with regard to the special features of the use of hydrogen and hydrogen/natural gas blends, e.g. flow-dependent pressure drop (reduction in density = f (hydrogen content));
- → significantly higher flow velocity when operating with hydrogen – with the same energy transport (c = f (H_2 content, pressure);
- → operational case and design calculations must be extended to include the addition of hydrogen (as an additional gas or as a replacement gas).

IMPLEMENTATION: This will be implemented starting in 2025 by the DVGW body W-TK-2-4 Water transfer and distribution.

NEED 4.2.4-02:
DVGW technical rule – code of practice GW 368, Restrained Socket Joints for ductile Iron and Steel Pipes, Fittings and Valves [128]

CONTENT: Manufacturing; installation; socket joints; ductile iron/steel piping systems

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:

- → including DVGW technical information – guideline G 221 [95] as a valid technical rule;
- → examing the possible use/suitability of socket joints for hydrogen or H_2 mixtures;
- → examining the permissibility of converting the gas networks from natural gas to pure hydrogen or H_2 as additional gases.

IMPLEMENTATION: This will be implemented starting in 2025 by the DVGW body W-TK-2-3 Components for water supply systems.

NEED 4.2.4-03:
DVGW technical rule – codes of practiceDVGW technical rule – codes of practice: G 452-1 [94], G 452-2 [129] and G 452-3 [130], Tapping and shutting-off

CONTENT: Tapping; shutting-off; gas pipelines

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:

- → including DVGW technical information – guideline G 221 [95] as a valid technical rule;
- → expanding the technical rules to include the fifth gas family in accordance with DVGW technical rule – code of practice G 260 [53];
- → reviewing the technical rules with regard to the special features of the use of hydrogen and hydrogen-natural gas blends;
- → reviewing the technical rules relating to the use of hydrogen with regard to technical framework conditions and the general suitability of materials for hydrogen (as an additional or replacement gas).

IMPLEMENTATION: This will be implemented starting in 2025 for DVGW technical rule – code of practice G 452-1 [94] in G-TK 1-1 Gas transmission pipelines and for DVGW technical rule – code of practice G 452-2 [129] and DVGW technical rule – code of practice G 452-3 [130] in DVGW G-TK-1-3 Gas distribution.

NEED 4.2.4-04:
DVGW technical rule – code of practice G 459-1, Service lines for maximum operating pressures up to and including 5 bar [131]

CONTENT: Erection; service lines; supply; end consumer

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:

→ including DVGW technical information – guideline G 221 [95] as a valid technical rule;
→ checking the suitability of components (e.g. pipes, shut-off valves, isolating joints) for H_2;
→ gas flow detectors; check and assess their suitability and that of DIN 30652-2 [132] for hydrogen;
→ reassess the suitability of threaded joints for use with H_2 (as an additional gas or replacement gas);
→ flanged joints – check the suitability of the DIN Standards given.

IMPLEMENTATION: This will be implemented starting from 2025 in the DVGW body G-TK-1-3 Gas distribution

NEED 4.2.4-05:
DVGW technical rule – codes of practice G 465-1 [123], G 465-3 [125] and DVGW technical information – guideline G 465-4 [126]

CONTENT: Inspection; leaks; device technology

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:

→ including DVGW technical information – guideline G 221 [95] as a valid technical rule;
→ adapt DVGW technical rule – code of practice G 465-1 [123] in relation to hydrogen, e.g. expand Chapter 1 to include the fifth gas family (at present it only covers the second and third gas families);
→ adapt DVGW technical information – guideline G 465-3 [125] in relation to hydrogen, e.g. soil testing; bacterial activity in soil – where applicable! – as well as review Annexes A, B;
→ adapt the scope of DVGW technical information – guideline G 465-4 [126], e.g. without DVGW technical rule – code of practice G 262[5] [133]; Chapter 4 – review of requirements, e.g. in relation to explosion protection and measuring instrument technology.

IMPLEMENTATION: This will be implemented starting from 2025 in the DVGW body G-TK-1-3 Gas distribution

NEED 4.2.4-06:
DVGW technical rule – code of practice G 466-2, Gas Pipework made of Ductile Cast Iron Pipes for an Operating Pressure of more than 4 bar up to and including 16 bar – Maintenance [134] and G 466-3, Gaspipe Work made of PVC – Rehabilitation and Extensions [135]

CONTENT: Maintenance; gas pipework; cast iron pipes; PVC pipes

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:

→ including DVGW technical information – guideline G 221 [95] as a valid technical rule;
→ adapting DVGW technical rule – code of practice G 466-2 [134] with regard to hydrogen, e.g. expand Chapter 1 to include the fifth gas family and a general review of suitability for H_2 (as an additional gas or replacement gas), particularly regarding the use of socket joints – see DVGW technical rule – code of practice GW 368 [128];
→ in DVGW technical rule – code of practice G 466-3 [135] check the suitability of sockets for adhesive jointing for H_2 (as an additional gas or replacement gas).

IMPLEMENTATION: This will be implemented starting from 2026 in the DVGW body G-TK-1-3 Gas distribution.

5 In 2021 replaced by DVGW technical rule – code of practice G 260 [53]

Distribution networks

NEED 4.2.4-07:
DVGW G 472, Gas Pipework made of Plastic Pipes for an Operating Pressure up to and including 16 bar; Installation [136]

CONTENT: Installation; pipework; plastic pipes

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
→ including DVGW technical information – guideline G 221 [95] as a valid technical rule;
→ checking the suitability of pipework components as regards hydrogen (H_2-readiness) should be included;
→ the suitability of the mechanical fasteners should be checked;
→ pressure testing is covered by DVGW technical rule – code of practice G 469 [137]. any amendments must be taken into account.

IMPLEMENTATION: This will be implemented starting from 2025 in the DVGW body G-TK-1-3 Gas distribution.

NEED 4.2.4-08:
DVGW technical rule – code of practice G 469, Pressure Testing Procedures Gastransmission / Gasdistribution [137]

CONTENT: Pressure testing; pipelines; plants

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following points:
→ including DVGW technical information – guideline G 221 [95] as a valid technical rule;
→ checking the admissibility of the pressure test methods in relation to (a) pressure tests with air (possible with H_2 networks) and (b) pure hydrogen and H_2 mixtures (additional gas), e.g. pressure tests with service gas.

IMPLEMENTATION: This will be implemented starting from 2025 in the DVGW body G-TK-1-3 Gas distribution.

NEED 4.2.4-09:
DVGW technical rule – code of practice GW 120, Network documentation in supply companies [120]

CONTENT: Measurement; pipelines; components; gas/water distributions; long-distance pipelines; network documentation

EXPLANATORY NOTES: It must be specified how H_2 pipelines are depicted in plans. In particular, a comparison must be made among the technical rules on the documentation of pipelines in which H_2 has not yet been taken into account (DVGW technical information – guideline GW 115 [138]; DVGW technical information – guideline GW 116 [139]; DVGW technical information – guideline GW 117 [140]; DVGW technical rule – code of practice GW 118 [141]; DVGW technical rule – code of practice GW 120 [120]; DVGW technical information – guideline GW 121 [142]; DVGW technical information – guideline GW 122 [143]; DVGW technical information – guideline GW 126 [144]; DVGW technical information – guideline GW 128 [145]; DVGW technical information – guideline GW 130 [146]).

IMPLEMENTATION: This will be implemented starting in 2025 by the DVGW body W-TK-2-5 Network documentation.

The needs identified with regard to hydrogen in distribution grids were prioritized, and standardization projects and technical rule projects for subsequent technical rules were initiated or applied for.

With regard to the conversion of existing natural gas networks to hydrogen operation in accordance with DVGW technical rule – code of practice G 407 [121] / DVGW technical rule – code of practice G 408 [122] / DVGW technical rule – code of practice G 453 [147] / DVGW technical rule – code of practice G 454 [119], distribution network operators require a clear framework for dealing with incomplete documentation. In addition to generally applicable, economically viable data collection concepts, which are being developed in the H_2-Switch100 project funded by Gasnetz Hamburg [148], other options such as risk assessments or operational trials must also be examined.

Further standardization projects and technical rule projects were initiated in the responsible committees for the DVGW technical rules DVGW technical rule – code of practice G 459-1

[131] / DVGW technical rule – code of practice G 465-1 [123] / DVGW technical information – guideline G 465-4 [126] / DVGW technical rule – code of practice G 466-2 [134] / DVGW technical rule – code of practice G 466-3 [135] / DVGW technical rule – code of practice G 469 [137] / DVGW technical rule – code of practice GW 120 [120].

The need for a standardization project to revise DVGW technical rule – code of practice G 441 [149] was submitted to the responsible WG Components for infrastructure.

4.2.4.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.2.5 Stationary and mobile pressure vessels

WG Stationary and mobile pressure vessels determines the standardization need for stationary and mobile pressure vessels with or without solids storage and their equipment with regard to design, construction, testing and operation/use for the storage and transmission of hydrogen. This covers the entire pressure range from high pressure to the storage of hydrogen close to atmospheric pressure.

4.2.5.1 Analysis of the status quo

A large number of technical rules are already known in the field of stationary and mobile pressure vessels. Around 80 technical rules were identified, most of which were developed at European (CEN) and international (ISO) level and adopted as national standards (DIN EN, DIN EN ISO or DIN ISO). The published technical rules also include technical reports (TR), specifications (TS), codes of practice and guidelines. For detailed information on these technical rules go to the Standards Database for Hydrogen Technologies [13]. The compilation of current documents tends to be viewed with little uncertainty, as many of the standards and technical rules are required by legislation such as the Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) [150] and the Regulation concerning the International Carriage of Dangerous Goods by Rail (RID) [151].

Figure 18 presents the identified bodies that are important for the development of technical rules in the field of stationary and mobile pressure vessels. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.2.5.2 Requirements and challenges

The gaps in standardization identified in the field of pressure vessels are characterized on the one hand by the fact that 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. 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. With a view to the hydrogen economy, new safety approaches are also being added that are better suited to a mass market than previous considerations. There are therefore three main reasons why it is necessary to address the identified needs and close the associated gaps: safety, economic feasibility and openness to new technologies. Ignoring the needs that have already been identified and those that may arise in the future would make hydrogen less attractive for the energy transition and could lead to considerable losses in the acceptance of hydrogen, especially in the area of pressure vessels.

In research and research funding, the focus is often on product development and enabling functionality. However, standardization in the field of storage is usually inextricably linked to safety issues and questions of approval. These aspects and the modernization of associated test methods are not always seen as a supportive instrument, but often as a hurdle. As a result, safety tools such as test methods are now threatening to become a bottleneck during the market ramp-up. To counter the effects of limited resources and unnecessarily complex methods, the innovation of these tools must be seen as a trailblazer. Despite its only indirect, but nevertheless enormous economic importance, safety research must be valued, accelerated and promoted accordingly.

Stationary and mobile pressure vessels

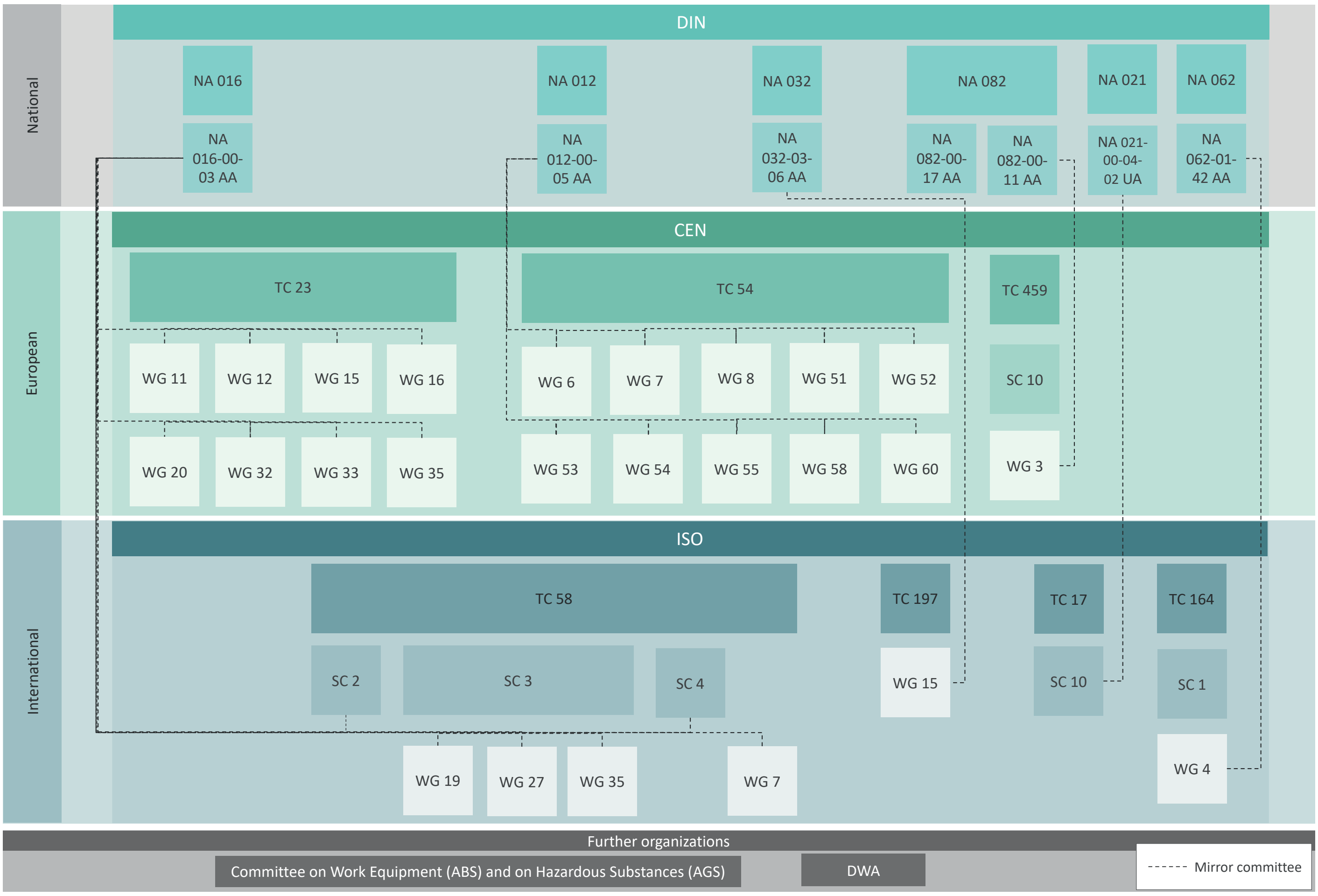

Figure 18: Overview of bodies relevant to technical rule-setting in the area of stationary and mobile pressure vessels (as of 03-2024) (Source: own illustration)

4.2.5.3 Needs analysis

NEED 4.2.5-01:
EN 13385:2002, Transportable gas cylinders – Battery vehicles for permanent and liquefied gases (excluding acetylene) – Inspection at the time of filling [152]

CONTENT: Testing; solid metal containers (type 1); composite containers (types 2, 3 & 4)

EXPLANATORY NOTES: The safe handling of battery vehicles or gas containers with multiple elements (MEGCs) when operating the units must be ensured. As part of the revision of this standard, new transportation concepts and container types as well as the special requirements for testing MEGCs and composite containers of the various types with and without metallic liners must be taken into account. In addition, there are some new references, and the existing tests before and during filling are to be checked.

IMPLEMENTATION: The standard is being revised at European level within CEN/TC 23/WG 35. This work is mirrored at national level in DIN Standards Committee Pressurized gas installations (NDG), NA 016-00-03 AA Transportable gas cylinders and equipment.

Stationary and mobile pressure vessels

NEED 4.2.5-02:
EN 13807:2017, Transportable gas cylinders – Battery vehicles and multiple-element gas containers (MEGCs) – Design, manufacture, identification and testing [153]

CONTENT: Design; manufacturing; identification; testing; battery vehicles; MEGCs

EXPLANATORY NOTES: As part of the revision of this standard, a number of additional requirements, such as the stability of the piping due to vibration during transportation or the fastening requirements of composite containers, must be described in more detail. Another important point is the inclusion of ball valves in accordance with EN ISO 23826 [154] in the scope of the standard. Furthermore, all references will be checked to make sure they are current.

IMPLEMENTATION: The standard is being revised at European level within CEN/TC 23/WG 35. This work is mirrored at national level in DIN Standards Committee Pressurized gas installations (NDG), NA 016-00-03 AA Transportable gas cylinders and equipment.

NEED 4.2.5-03:
EN 13445-15, Unfired pressure vessels – Part 15: Specific requirements for hydrogen applications

CONTENT: Requirements for materials; construction/load cases

EXPLANATORY NOTES: Transparent provisions specifically for hydrogen appliances can facilitate the development and operation of a safe and efficient infrastructure. EN 13445 [87] already provides the normative basis for this, as this series of standards is widely used in industry. Therefore, a new part of EN 13445 which specifies the concrete requirements for hydrogen applications is to be developed.

IMPLEMENTATION: The standard is being developed at European level within CEN/TC 54 and at national level in Germany within DIN Standards Committee Chemical Apparatus Engineering, working committee NA 012-00-05 AA Unfired pressure vessels.

NEED 4.2.5-04:
Probabilistic evaluation of the effect of deterministic minimum requirements in standards

CONTENT: Probabilistic evaluation; minimum requirements in standards

EXPLANATORY NOTES: Development of a tool for the probabilistic assessment of minimum requirements (e.g. minimum bursting strength of pressure vessels). This technical rule should be available to standardization bodies for the analysis of minimum requirements, which can replace a lack of experience with new products and enable safer type approval. The method is to be described in a generally valid and easily applicable manner and checked for practicability and optimized through exemplary application.

IMPLEMENTATION: This standard is being developed at national level in DIN Standards Committee Pressurized gas installations (NDG), working committee NA 016-00-03 AA Transportable gas cylinders and equipment.

NEED 4.2.5-05:
Standardization of constant pressure membrane accumulators

CONTENT: Constant pressure membrane accumulators

EXPLANATORY NOTES: Constant pressure membrane accumulators for hydrogen production plants are membrane gas storage tanks with variable volume and constant pressure, which are not primarily used for gas storage, but as control and regulating elements. This application is essentially characterized by very high level change rates in the range of seconds. The constant pressure is between 5 hPa and 500 hPa above atmospheric pressure.

IMPLEMENTATION: This standard is being developed at national level in DIN Standards Committee Tank installations (NATank), working committee NA 104-01-05 AA Above-ground flat-bottomed tanks.

NEED 4.2.5-06:
Standardization of stationary and mobile hydrogen sorption storage systems (absorption, adsorption)

CONTENT: Stationary and mobile hydrogen sorption storage systems; absorption; adsorption

EXPLANATORY NOTES: Hydrogen sorption storage systems are pressure vessels with fillings made of sorption materials and other components, such as heat exchangers or filter elements, which can be operated at temperatures between -196 °C and +350 °C and pressures between 1 bar and 200 bar, depending on the type of H_2 sorption process. The design, production method, mode of operation, monitoring, safety equipment and approval tests of such sorption storage systems are to be standardized for both stationary and mobile applications (minimum requirements).

IMPLEMENTATION: This standard is being developed at national level in DIN Standards Committee Tank installations (NATank), working committee NA 104-01-05 AA Above-ground flat-bottomed tanks.

NEED 4.2.5-07:
Methodology for the safety assessment of stationary above-ground and near-surface unfired pressure vessels with or without solid support materials for the storage of hydrogen and hydrogen derivatives

CONTENT: Safety assessment and evaluation; test methods

EXPLANATORY NOTES: The technical rules for hydrogen storage systems do not consider the consequences of the failure of different storage technologies in the necessary depth, which leads to a distortion of competition between systems. The aim is therefore to develop a standard that methodically determines and evaluates the consequences in the event of failure, e.g. for carrier materials such as metal hydrides, LOHC and H_2 derivatives, and identifies test methods for demonstrating safe operation.

IMPLEMENTATION: This standard is being developed at national level in DIN Standards Committee Chemical apparatus engineering (FNCA), working committee NA 012-00-05 AA Unfired pressure vessels. Furthermore, standardization at CEN and/or ISO level is desired.

4.2.5.4 Implementation projects

Financial support has been approved for the following three projects and their revision has been initiated:

→ EN 13385:2002, Transportable gas cylinders – Battery vehicles for permanent and liquefied gases (excluding acetylene) – Inspection at the time of filling
→ EN 13807:2017, Transportable gas cylinders – Battery vehicles and multiple-element gas containers (MEGCs) – Design, manufacture, identification and testing
→ EN 13445-15, Unfired pressure vessels – Part 15: Specific requirements for hydrogen applications

4.2.6 Underground gas storage

WG Underground gas storage is responsible for determining the standardization needs for underground gas storage (UGS) with regard to design, construction, testing and commissioning, as well as operation for the storage of hydrogen (salt cavern and pore storage facilities). The WG's remit includes underground and above-ground facilities of UGS. The storage-specific aspects of above-ground facilities must be incorporated into the other WGs where they overlap with their respective topics. UGS is a system-relevant part of the infrastructure for implementing the hydrogen strategy. It is necessary to ensure a continuous service.

4.2.6.1 Analysis of the status quo

In the scope of UGS, 102 technical rules were identified that were classified as being directly or indirectly relevant. 31 of these documents were classified as being directly relevant to UGS in relation to hydrogen service. At present there are no standards specifically on UGS for hydrogen technologies. The fact that, for the most part, there are already technical rules for the natural gas sector, and that these can be built upon, is beneficial for setting technical rules on UGS for hydrogen service. The status of these technical rules is varied. There are

European (EN) and International (ISO) Standards which have been adopted as national standards (DIN EN or DIN ISO). In addition, there are also technical reports (TR), specifications (SPEC), Recommended Practices (RP) of the American Petroleum Institute (API), and guidelines issued by the German Bundesverband Erdgas, Erdöl und Geoenergie e. V. (BVEG) (German Federal Association for Natural Gas, Oil and Geoenergy). Taking the DVGW technical rules into account is only permissible in the pressure ranges defined by these rules, as the effect of hydrogen on the material is pressure-dependent. For detailed information on these technical rules go to the Standards Database for Hydrogen Technologies [13]. The compilation of the current documents can be considered to be almost complete [13].

Figure 19 presents the identified bodies that are important for the development of technical rules in the field of underground gas storage. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.2.6.2 Requirements and challenges

In the field of underground gas storage, there are many standards on the storage of natural gas. The extensive collection of documents in this area, which consists of the historically large body of standards and technical rules (guidelines, leaflets, regulations, etc.), must be expanded to include the new requirements of hydrogen applications. In particular, the

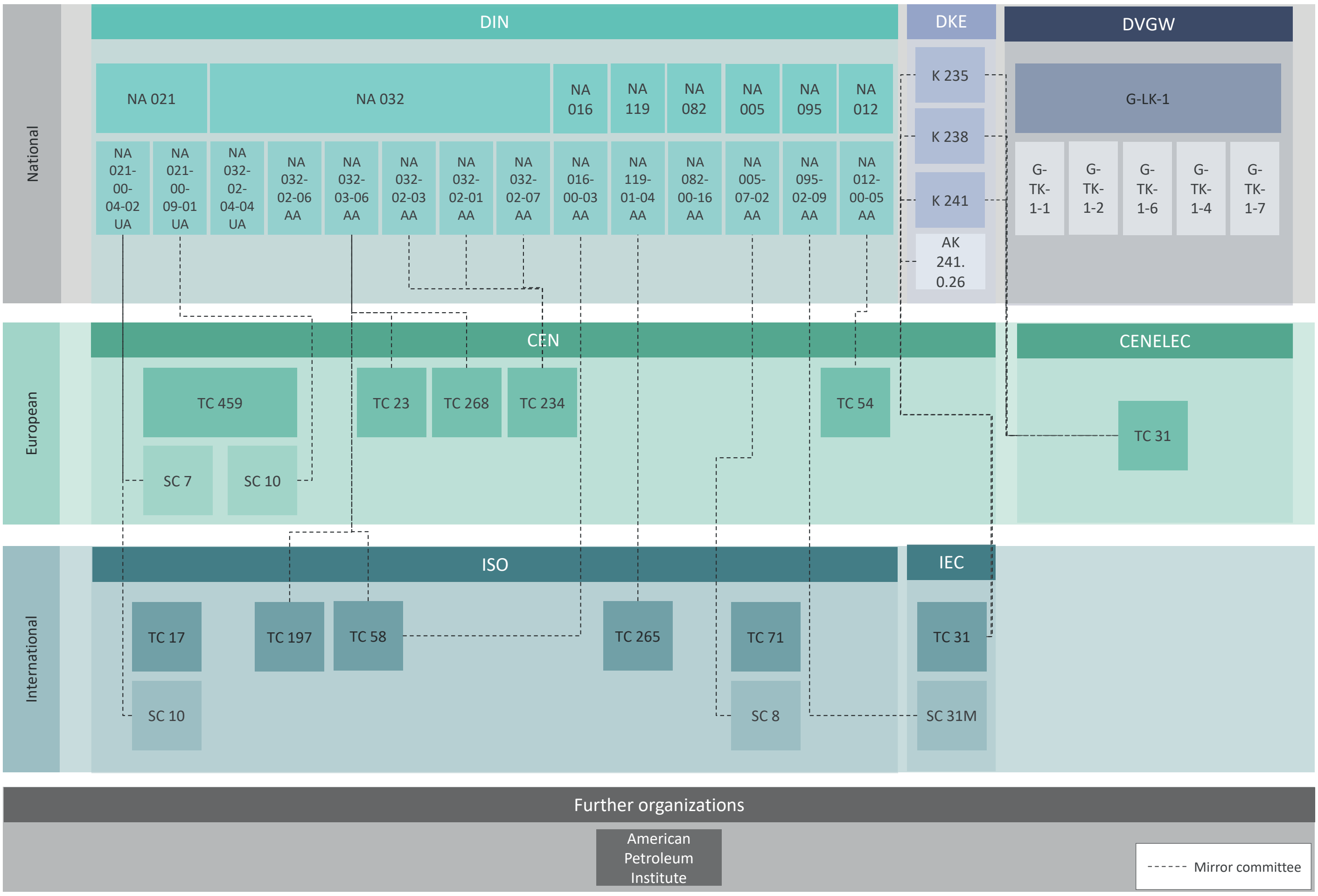

Figure 19: Overview of bodies relevant to technical rule-setting in the area of underground gas storage (as of 03-2024) (Source: own illustration)

Underground gas storage

DIN EN 1918 [155] series of standards, die API technical rules [156], the ASME Standards [157] and the BVEG Guidelines [158] serve as the basis for the design and execution of UGS. At national and European level, there are opportunities to help shape new standards and revise existing technical rules. Currently, API technical rules and ASME Standards, which are frequently used in underground mining, cover technical aspects that do not yet take into account the specifics of hydrogen and are not legally valid in Europe. Closing this gap with the help of legally binding technical rules in Europe is necessary in the medium term.

In addition, European standards and technical rules offer the advantage of involving all Member States in the H_2 Strategy and at the same time ensure better awareness and acceptance across continents, ultimately keeping an eye on competition and safety at the same time. The commercial operation of hydrogen storage in UGS in Germany is already planned starting from 2026. The main reasons that make it necessary to revise the identified needs and close the associated gaps are primarily safety, operating licences and interoperability of the systems, as well as a fast upscaling.

First, an overview was drawn up of the areas in which there are still open needs in the field of underground gas storage facilities and of which specific requirements can apply in underground gas storage facilities and must be taken into account in other areas. The following particularities were identified:

1. In the wet gas areas of the storage facilities, "untreated" hydrogen is present that does not meet the purity requirements of DVGW technical rule – code of practice G 260 [53]. Among other things, free water and moisture can occur. The former can be highly saline. Increased levels of CO_2 and H_2S are also possible.
2. Cyclical thermal and mechanical loads with high amplitudes are to be expected several times a year on hydrogen-carrying components due to storage and withdrawal.
3. The pressure range is up to 300 bar, which is higher than the usual limit of 100 bar.
4. The temperatures of the gas that is injected and withdrawn can fluctuate, up to approx. 180 °C in compressor systems.

In standardization, the framework conditions for the various life phases of an H_2-UGS must be further specified and defined. These special features were forwarded to the other relevant Roadmap working groups in order to point out the corresponding gaps and ensure interoperability of the relevant components.

Above all, there is a need for pre-normative research regarding qualification methods for components and materials; this research should be transferred into a set of technical rules on which delivery condition standards for the components to be used must be based in the future. A further challenge is that certain topics, such as gas pressure control measurement systems, are not purely storage topics and must be solved collaboratively (for different applications and their boundary conditions).

The qualification methods for the rededication of existing UGS and other cavern storage facilities must also be taken into account in the adapted technical rules.

4.2.6.3 Needs analysis

NEED 4.2.6-01:
Leak tests and integrity tests of the underground gas storage facility

CONTENT: Standardized test procedures; test criteria; verification; tightness; integrity; underground systems

EXPLANATORY NOTES: Underground boreholes are tested for leaks and integrity using a suitable fluid. To date, various methods and media (nitrogen/hydrogen or combined) have been used for leak tests of underground hydrogen storage boreholes. These methods and media need to be standardized.

IMPLEMENTATION: First, the BVEG guideline on borehole integrity must be adapted, then a new EN (in CEN/TC 234/WG 4) is to be developed.

Underground gas storage

NEED 4.2.6-02:
Standards series DIN EN 1918, Gas infrastructure – Underground gas storage – Functional recommendations for storage [155]

CONTENT: UGS; pore storage; caverns, above-ground storage; expansion to include hydrogen

EXPLANATORY NOTES: The standards series DIN EN 1918 [155] published in 2016 describes functional recommendations for above-ground storage facilities and four categories of underground storage facilities:
→ Part 1: Storage in aquifers;
→ Part 2: Storage in oil and gas fields;
→ Part 3: Storage in solution-mined salt caverns;
→ Part 4: Storage in rock caverns;
→ Part 5: Surface facilities.

The five similarly structured documents include functional recommendations for design, construction, testing, commissioning, operation, maintenance and decommissioning.

IMPLEMENTATION: The revision of these standards and their expansion to include hydrogen has already been initiated in CEN/TC 234/WG 4 with the cooperation of DIN working committee NA 032-02-07 AA Gas underground storage.

NEED 4.2.6-03:
Cements and materials for cementation of deep wells under the influence of hydrogen

CONTENT: Cements; materials; test methods for qualification

EXPLANATORY NOTES: The aim is to provide an overview of the state of the art in cements and materials for use in wells exposed to hydrogen. This description of preferred materials and applicable test methods for the qualification of cements and suitable alternative materials as part of a technical report is intended to support the updating of relevant standards.

IMPLEMENTATION: Implementation as a pre-normative research requirement and Project Initiation Proposal (PIP) within the framework of the IOGP Standards Solution [159] with the aim of developing an ISO TR in order to achieve general validity. In addition, a DGMK research project is to be initiated in this regard (as well as a new BVEG guideline).

NEED 4.2.6-04:
Downhole equipment – Subsurface safety valve equipment – Delivery conditions

CONTENT: Hydrogen applications; manufacturer standards; qualification methodology

EXPLANATORY NOTES: The standards and test certificates must be revised to reflect the special features of hydrogen. This essentially concerns aspects that could influence safe functioning, such as leakage behavior, thermodynamic behavior, diffusion, solubility, corrosion behavior and embrittlement. In addition to hydrogen (in accordance with DVGW technical rule – code of practice G 260 [53]), the by-products in the high-pressure range of underground storage must also be taken into account.

IMPLEMENTATION: Verification by manufacturing companies; expansion of the relevant standards to include materials and suitability for hydrogen. This can include a Project Initiation Proposal (PIP) as part of the IOGP Standards Solution [159] or a revision of ISO 10417:2004 [160] or ISO 10432:2004 [161].

NEED 4.2.6-05:
Downhole equipment – Packers and bridge plugs

CONTENT: Packers and bridge plugs; manufacturer standards; hydrogen applications; qualification methodology

EXPLANATORY NOTES: The standards and test certificates must be revised to reflect the special features of hydrogen. This essentially concerns aspects that could influence safe functioning, such as leakage behavior, thermodynamic behavior, diffusion, solubility, corrosion behavior and embrittlement. In addition to hydrogen (in accordance with DVGW technical rule – code of practice G 260 [53]), the by-products in the high-pressure range of underground storage must also be taken into account. This requires a qualification methodology or, in future, a qualification standard for packers and bridge plugs (possibly elastomers).

IMPLEMENTATION: Verification by manufacturing companies; expansion of the relevant standards to include materials and suitability for hydrogen. This can include a Project Initiation Proposal (PIP) as part of the IOGP Standards Solution [159] or a revision of ISO 14310:2008 [162].

NEED 4.2.6-06:
Downhole equipment – Lock mandrels and landing nipples

CONTENT: Lock mandrels; landing nipples; manufacturer standards; hydrogen applications; qualification methodology

EXPLANATORY NOTES: The standards and test certificates must be revised to reflect the special features of hydrogen. This essentially concerns aspects that could influence safe functioning, such as leakage behavior, thermodynamic behavior, diffusion, solubility, corrosion behavior and embrittlement. In addition to hydrogen (in accordance with DVGW technical rule – code of practice G 260 [53]), the by-products in the high-pressure range of underground storage must also be taken into account. This requires a qualification methodology or, in future, a qualification standard for lock mandrels and landing nipples (possibly elastomers).

IMPLEMENTATION: Verification by manufacturing companies; expansion of the relevant standards to include materials and suitability for hydrogen. This can include a Project Initiation Proposal (PIP) as part of the IOGP Standards Solution [159] or a revision of ISO 16070:2005 [163].

4.2.6.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.2.7 Liquefaction

WG Liquefaction deals with technical rules that cover liquid hydrogen in the form of cryogenic H_2 (LH_2) and hydrogen carriers (e.g. ammonia, methanol, LOHC). Topics such as definitions, processes for liquefaction, material compositions, material properties and personnel qualifications for handling liquid hydrogen in the aforementioned forms are considered. In addition, requirements for the respective transmission and storage media are dealt with. The circle of experts is manageable due to their specialization in topics such as LH_2 or LOHC, which is reflected in the development of the analysis of the status quo and the needs analysis.

4.2.7.1 Analysis of the status quo

There are a large number of standards, technical rules and product standards applicable to cryogenic hydrogen (LH_2), hydrogen derivatives (NH_3, methanol) and hydrogen carriers (LOHC). Many of the standards and technical rules are exclusively of international origin and therefore outside the direct sphere of influence of German and European technical rule-setting bodies. As of 12/2023 there are about 113 documents. Of these, 64 documents are purely international standards, technical rules and product standards, 21 documents are European/International Standards and technical rules, and 23 are national/European Standards and technical rules. Five specifications (TRGS/TRB) were also identified. A detailed list can be found in the already published Standards Database for Hydrogen Technologies [13]. Relevant regulations are the Pressure Equipment Directives 2014/68/EU (PED) [76], the German Water Management Act (WHG § 62) [164] and the German Ordinance on Facilities for Handling Substances Hazardous to Water (AwSV) [165].

4.2.7.2 Requirements and challenges

As already mentioned above, only a very limited number of experts are active in this WG. For this reason there is currently no head of the WG. The number of experts involved in this WG varies between three and four persons. Of these, three experts are exclusively responsible for the topic of cryogenic hydrogen (LH_2) and one expert for the topic of LOHC. Ammonia and methanol are not covered by this working group.

Nevertheless, it is becoming apparent in the hydrogen economy that ammonia, as a hydrogen derivative, will play a major role in hydrogen imports in both the German [14] and European [166] hydrogen strategies. LOHC is also seen as an important storage and transmission technology in both the German [14] and European [166] hydrogen strategies. The WG therefore believes that it is urgently necessary to step up standardization and technical rule-setting in the field of derivatives (ammonia) and hydrogen carriers (LOHC). Both in the field of cryogenic liquefaction (LH_2) and in the field of reconversion of ammonia into H_2 (cracking) and storage/withdrawal of H_2 in/from LOHC (hydrogenation/dehydrogenation), the corresponding facilities are designed, constructed and operated almost exclusively on the basis of product standards of individual manufacturers. Due to the increasing relevance of hydrogen derivatives and hydrogen carriers in particular, a uniform and publicly accessible standardization should be sought.

4.2.7.3 Needs analysis

NEED 4.2.7-01:
Standard on the uniform definition of "cold interface"

CONTENT: Cryogenic interfaces; liquid hydrogen

EXPLANATORY NOTES: Cryogenic interfaces (e.g. the "Johnston coupling") for liquid hydrogen are not uniquely defined in terms of geometry. To accelerate the technology, it is essential to clearly define the pipe interfaces so that they are compatible with each other. This must be standardized in good time before the extensive use of liquid hydrogen, also with regard to the proof of strength. The following existing standards and technical rules can serve as a basis.

- → Industrial standard CGA V-6 Standard Cryogenic Liquid Transfer Connections [167]
- → DIN EN 13371, Cryogenic vessels – Couplings for cryogenic service (standard on the Johnston coupling) [89]
- → ISO 13984, Liquid hydrogen – Land vehicle fuelling system interface [168]

IMPLEMENTATION: Implementation will begin in 2025. A rule-setting body has yet to be found or set up.

NEED 4.2.7-02:
Standard on the quality assessment of cryogenic liquid hydrogen

CONTENT: Para content; liquefied hydrogens

EXPLANATORY NOTES: A quality feature for the long-term storage of cryogenically liquefied hydrogen (LH_2) is the para content, whereby the higher the para-hydrogen content, the higher the quality of the LH_2. The ortho/para equilibrium of hydrogen is temperature-dependent. At room temperature (293 K) the equilibrium composition (ortho/para) is 75/25 %. At 20 K (liquefied hydrogen), the para content is 99,8 % para-H_2. Ortho-hydrogen and para-hydrogen are energetically different states. During the conversion of ortho-hydrogen to para-hydrogen, energy is released in the form of heat. If the para-hydrogen content in the liquid state (e.g. storage in a tank) is too low, this would lead to additional vapourization of hydrogen due to the heat generated during the ortho/para conversion. Therefore, the para content of liquid hydrogen is a quality characteristic that must be defined in a standard.

IMPLEMENTATION: Implementation is due to begin in 2026. A rule-setting body has yet to be found or set up.

NEED 4.2.7-03:
Requirements for sealing materials in cryogenic applications

CONTENT: Sealants; sealing materials; cryogenic applications

EXPLANATORY NOTES: The requirements for sealing materials and sealants are to be described by determining the scientific basis for hydrogen applications of elastomers, polymers, plastics and other sealing materials. The research necessary for this still needs to be initiated.

IMPLEMENTATION: Implementation is due to begin in 2024. A rule-setting body has yet to be found or set up.

Liquefaction

NEED 4.2.7-04:
Document for defining boundary conditions for filters and absorbers for hydrogen liquefaction

CONTENT: Filters; absorbers; regeneration; hydrogen liquefaction; purity

EXPLANATORY NOTES: Depending on the purity of the H_2, filters and absorbers must be provided during liquefaction, e.g. to remove air components that would freeze out during liquefaction and block pipes. When dimensioning the filters and absorbers, care must be taken to ensure that no ignitable blend (oxygen enrichment) is created. The minimum requirements necessary for this are to be defined.

IMPLEMENTATION: Implementation is due to begin in 2026. A rule-setting body has yet to be found or set up.

NEED 4.2.7-05:
Measuring the para content of cryogenic liquefied hydrogen

CONTENT: Measurement process; LH_2

EXPLANATORY NOTES: Selection of a suitable measurement process that fulfills the following requirements in order to enable comparable measurement results:

→ sampling out of liquid phase;
→ timely on-site measurement;
→ ensuring that no ortho/para conversion takes place between sampling and measurement;
→ ensuring a sufficient measuring accuracy.

IMPLEMENTATION: Implementation is due to begin in 2026. A rule-setting body has yet to be found or set up.

4.2.7.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.3 Application

Working committee Application deals with the industrial and domestic use of hydrogen. This includes facilities for converting molecular energy, possibly via the detour of kinetic energy, into primarily electrical energy and possibly secondarily into thermal energy via combined heat and power – this includes (reversible) fuel cells and heat engines such as turbines and internal combustion engines. This use includes mobility applications on road, rail, water and in the air, as well as special vehicles, including the respective refuelling systems. It also includes the use and processing of hydrogen in process engineering production, including the (petro)chemical industry, power-to-X plants, thermal processing plants and use for reduction processes such as in the steel industry. Energy/heat supply in the domestic and commercial sectors and the necessary control technology are also considered.

4.3.1 Fuel cells

The scope of WG Fuel cells covers all types of fuel cell technologies and their possible applications, i.e. fuel cell energy systems for the provision of electrical and additional thermal power (combined heat and power), such as stationary fuel cell heating devices, fuel cell-based emergency power systems, portable fuel cell energy systems as auxiliary power units and reversible fuel cell energy systems for electrical load shifting. The focus of the activities of WG Fuel cells is on the existing portfolio of fuel cell standards, in particular to determine the extent to which these need to be further developed in order to improve the integration of this technology into the existing infrastructure or to align it with the overall system – see also Figure 20 for the typical system boundaries of fuel cell energy systems.

Fuel cells

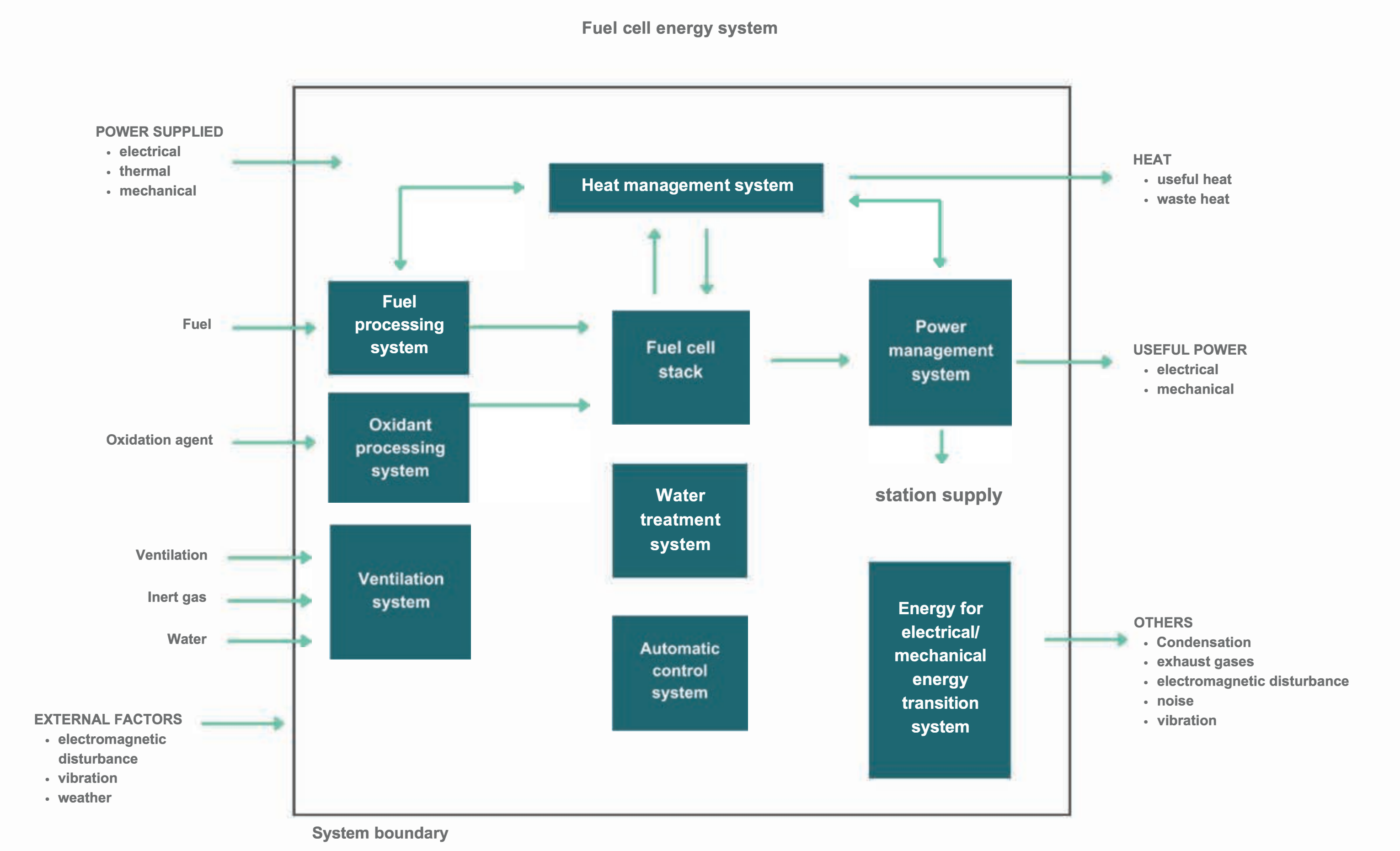

Figure 20: Fuel cell system boundaries (Source: DKE)

Note: Fuel cell applications in the mobility sector are dealt with by the WGs in the sub-working committee "Mobility", i.e. WG Filling systems, WG Road vehicles, WG Railway vehicles, WG Shipping, WG Aviation and WG Special vehicles.

4.3.1.1 Analysis of the status quo

With around 30 published standards, the topic of fuel cell energy systems is already well covered [13]. In addition to fuel cell modules, the main topics covered are stationary fuel cells, fuel cells for propulsion and auxiliary power supply, portable fuel cells, micro fuel cells and reversible fuel cells, as well as test methods and terminology. The portfolio includes standards for general and application-specific safety, as well as installation and supplementary performance test methods.

The collection is regularly reviewed and revised, so that many standards are already available in a revised second edition and in some cases even a third edition is already in progress. The collection of standards is largely available. With a few exceptions, all publications are available as German language versions or DIN Standards and are identical in content to the respective international EN or IEC Standard. Individual standards directly support legislation as harmonized standards or are being developed to support legislation, including, for example, the Low Voltage Directive and the Gas Appliances Directive.

Figure 21 presents the identified bodies that are important for the development of technical rules in the field of fuel cells. An overview of the abbreviations used to describe these bodies is given in Section 9.

Fuel cells

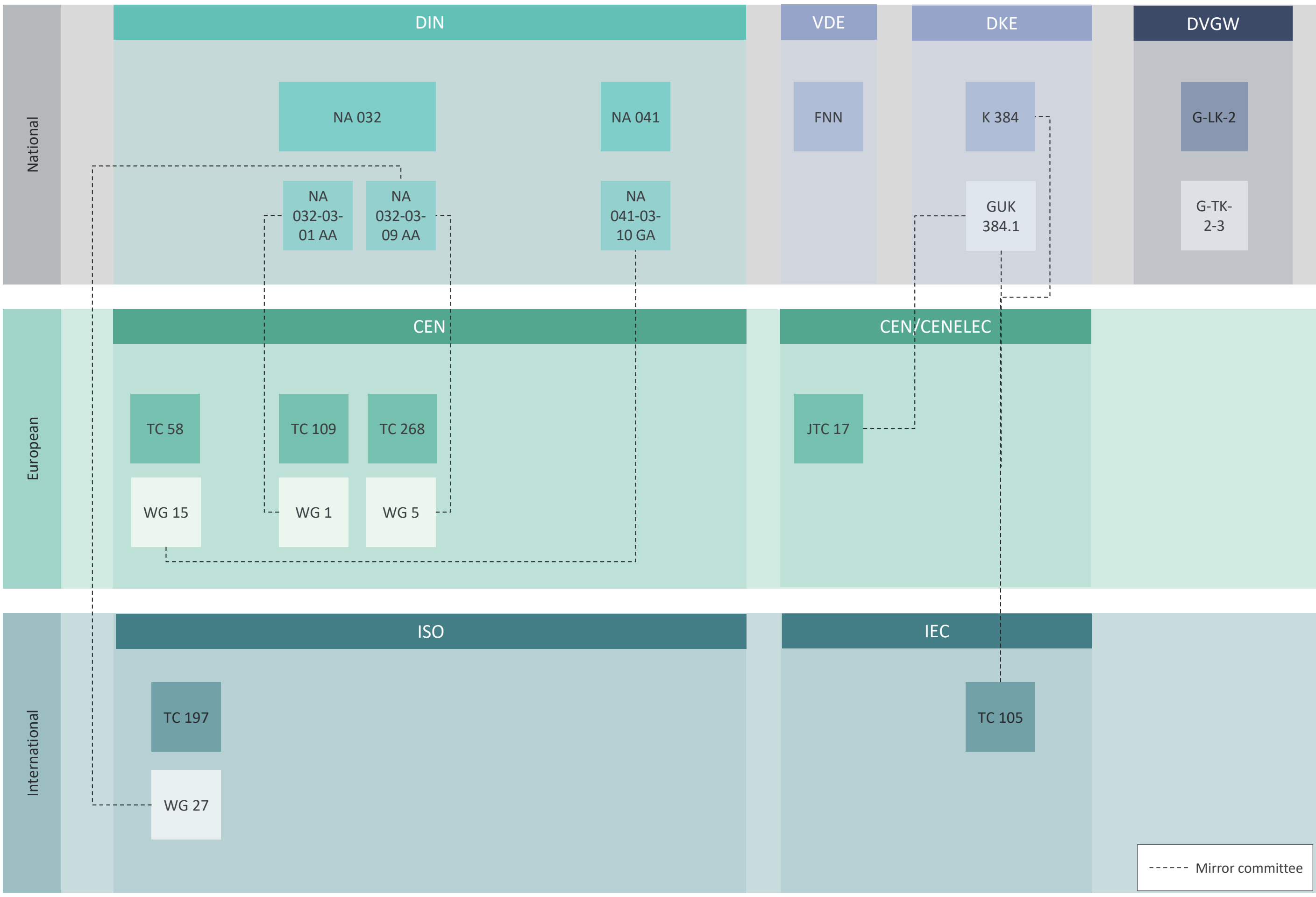

Figure 21: Overview of bodies relevant to technical rule-setting in the area of fuel cells (as of 03-2024) (Source: own illustration)

4.3.1.2 Requirements and challenges

The power density of fuel cell stacks or modules, i.e. the electrical power in relation to their own weight, is an important factor in the development of fuel cell-based road and air vehicles. However, there is as yet no standardized method or common understanding of how power density is to be determined, e.g. which components must be included. This makes it difficult to compare fuel cell modules from different manufacturing companies. This gap has already been recognized at international level, and work on a corresponding standard has begun [169].

Recently, fuel cell energy systems have also been increasingly used or tested in the mobility and machinery sector, including trains, ships and aircraft as well as drones, excavators, industrial trucks and mining machinery (see [170]). A horizontal safety standard with generally applicable requirements for the safety of fuel cell energy systems and modules is considered necessary in order to prevent fragmentation of the body of standards and avoid duplication of content. Such a general safety standard is intended to serve as a basis on which to create vertical standards that specify the special safety requirements for specific applications of fuel cell energy systems.

For the characterization of fuel cell modules through operational tests (e.g. frost start, service life tests and accelerated ageing tests) and the components installed in them, there are some national standards – for example Chinese standards – but as yet no standards that reflect European or German requirements. In order to close this gap, the existing national standards could be examined and adapted to the own needs.

4.3.1.3 Needs analysis

NEED 4.3.1-01:
Fuel cell technologies – General safety requirements

CONTENT: Horizontal safety standard; safety, fuel cells

EXPLANATORY NOTES: In addition to stationary applications, fuel cells are now also used as a standard in passenger trains, cars and machinery. Other areas such as mining vehicles, aircraft, ships and even e-bikes are currently being tested. The planned horizontal safety standard is intended to serve as a basis for defining application-specific (vertical) safety requirements for fuel cells, thereby preventing fragmentation of the body of standards and avoiding duplication of content.

IMPLEMENTATION: International implementation within IEC/TC 105/WG 105 under German leadership. The national mirror body is the DKE body DKE/K 384 Fuel cells.

4.3.1.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.3.2 Power plants, turbines, CHP plants

The focus of WG Power plants, turbines, CHP plants is on thermal power plants or plant units including turbines and CHP plants. This includes all main and auxiliary systems that are necessary for the functionality and safety of production and their elements, including construction materials (such as boilers, burners, pressure vessels, pipelines, valves, safety valves, apparatus, machines, package units and special machines (including motors as CHP plants)) within the plant boundary defined by the technology owners or operators, which is also the interface to other facilities, plants, installations and infrastructure. Taking into account the applicable directives, regulations and harmonized standards, all phases, from the initial study to design, procurement, fabrication and execution of plant construction, including commissioning, through to operation, maintenance and dismantling, are considered in detail. This applies to both new construction and the modernization of machines and plants.

The working group considered thermal power plants or plant components including turbines and CHP plants (combined heat and power plants) as well as heating plants with more than 1 MW rated thermal input. Interfaces to other facilities, plants, installations and infrastructure arise beyond the boundaries of the plant system, which are not part of the scope of consideration described here, but which require close alignment with the consultations in other working groups or working committees. Taking into account the European Community directives on the quality of products such as gas appliances – the GAR [171], the PED [76] and the MD [172] or the new Machinery Regulation [173] and the national requirements for operation such as TA-Luft [174], or the Federal Immission Control Act (BImSchV) [175], the plant life cycle including the modernization of existing plants was considered.

4.3.2.1 Analysis of the status quo

The purpose of the analysis is to identify the relevant standards and technical rules, within the scope of consideration, that already exist or need to be revised for the smoothest possible transition, approval and use of hydrogen technology. In 2023, the existing main standards for hydrogen quality, safety and control equipment for the use of hydrogen as a fuel gas, and standards for peripheral components that are affected by the combustion of hydrogen were compiled. This also includes documents that formulate requirements, e.g. for emissions, as well as globally recognized documents that can serve as guidelines for storage, handling and distribution and can contribute to the pending definition of H_2-readiness in connection with, for example, the German 2026 Power Plant Strategy [176]. The first standards for components are already being recognizably adapted to the use of hydrogen, and the corresponding work status has been recorded. Furthermore, the needs analysis also identified standards that can be omitted from the initial scope after detailed consultation, as they do not require any adaptation with regard to hydrogen [13].

4.3.2.2 Requirements and challenges

The needs analysis for power plants was carried out systematically over the course of four meetings in 2023 to detail the requirements and identify the first concrete implementation projects. The quality of the hydrogen and the admixtures for plants with combustion engines and burners was established for future interdisciplinary coordination within the Roadmap in order to enable the control and thus the performance stabilization of large-scale plants. Ideally, gas supply companies should provide end users with a precise real-time signal of the hydrogen content and calorific value of the final admixture. If this is not possible, the quality must be kept within predefined limits for hydrogen and impurities, and quality-adaptive controls must be ensured upstream of the take-over point. According to confirmation from the network-operating company in WG Distribution networks, there is currently no need to change the pressure ratings previously established for the standardization of uniform network and supply pressures when using hydrogen. This is taken into consideration in the needs analysis. Standards on safety, regulating and control devices for gas burners and gas fuel appliances, as well as other equipment, have been included in the work programme for 2024. To this end, it was decided that these standards should be initiated as implementation projects according to the Roadmap, or that this content should be integrated into new or already initiated standardization processes. The WG is in close contact with the relevant standards committees and monitors standardization activities. The corresponding needs are being closely coordinated with the relevant standards committees, in particular DIN Standards Committee Gas Technology (NAGas), DIN Standards Committee Mechanical Engineering (NAM) and DIN Standards Committee Piping and Boiler Plant (NARD). It is already apparent that changes to the safety requirements in the European Single Market Directives (in particular the GAR [171] and the Pressure Equipment Directive – PED [76]) for harmonized standards will require more stringent processes and greater working capacities in the responsible EU commissions and European standardization organizations in order to meet the ambitious schedules.

4.3.2.3 Needs analysis

NEED 4.3.2-01:
EN 12953-7, Shell boilers – Part 7: Requirements for firing systems for liquid and gaseous fuels for the boiler [177] and EN 12952-8, Water-tube boilers and auxiliary installations – Part 8: Requirements for firing systems for liquid and gaseous fuels for the boiler [178]

EXPLANATORY NOTES: Steam and hot water generators with a rated thermal input of more than 1 MW should make a significant contribution to climate neutrality in the future and/or support the transition to renewable energy sources. This will make it possible to reduce greenhouse gas emissions, more than 30 % of which come only from the energy industry and which, together with the building sector, account for around 50 % of all emissions in Germany [179]. In order to exploit this potential, the targeted adaptation of two harmonized standards with regard to the requirements for firing systems in the standard series for water tube boilers (EN 12952-8 [178]) and shell boilers (EN 12953-7 [177]) is planned. Incorporating the specifics of the use of hydrogen with regard to the safety requirements for the supply and operation of boilers and assessing the thermal design can also be important for the "renewable" but not climate-neutral sectors such as biomass, waste management, heat recovery and some processes of non-separable energy technology in the industrial sector. As determined by the working group together with DIN Standards Committee Piping and Boiler Plant (NARD), this offers an alternative to natural gas.

IMPLEMENTATION: The standards were developed in CEN/TC 269 Shell and water-tube boilers. The German national mirror committee, DIN working committee NA 082-00-21 AA Water-tube boilers of DIN Standards Committee Piping and Boiler Plant (NARD) holds the secretariat for CEN/TC 269/WG 1 Water-tube boilers (standards series EN 12952 [180]). In CEN/TC 269/WG 2 Shell boilers (standards series EN 12953 [181]) Germany is represented by the national mirror committee, working committee NA 082-00-18 AA Boiler plants.

4.3.2.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.3.3 (Petro)chemical industry

The focus of WG (Petro)chem. Industry is on (petro) chemical plants or plant units. This includes all main and auxiliary systems that are necessary for the functionality and safety of production, and their elements including construction materials (including pressure vessels, pipelines, valves, safety valves as well as furnaces, boilers, apparatus, columns, machines, package units and special machines) within the plant boundary defined by technology providers or operators, which is also the interface to other facilities, plants, installations and the infrastructure. Taking into account the applicable directives, regulations and harmonized standards, all phases, from the initial study to design, procurement, fabrication and execution of plant construction, including commissioning, through to operation, maintenance and dismantling, are considered in detail. This applies to both new construction and the modernization of machines and plants.

This industry is in third place with around 20 % of all greenhouse gas emissions in Germany, is closely linked to the energy sector and together responsible for more than half of the total emissions [179]. In 2023, the working group was tasked with determining the requirements for main and secondary systems in the (petro)chemical industry. In particular, the aspects of materials, design and manufacturing as well as their safe operation within the plant boundaries defined by the technology providers or operators were considered.

4.3.3.1 Analysis of the status quo

As part of the analysis, the experts compiled the technical rules and standards applicable to the (petro)chemical industry. Since hydrogen and hydrogen-containing media are known to be the main products or by-products in this area, and the associated damage mechanisms are also known, a basis for the needs analysis could be specifically laid. However, the scope of technical rules and standards is wide-ranging, which means that the needs analysis is still extensive and will certainly not be completed by the planned end of the project in 2025.

The industry is well positioned and standardized, existing value chains are reliable, the systems are generally approvable in terms of manufacturing and operation, and the personnel involved are well-trained.

The first step was to compile the standards and technical rules for the manufacturing and, partly the safe operation of systems and their components for the supply of gaseous and liquid hydrogen. The overlap to other areas was also taken into account. This is an important building block for the further needs analysis for adapting or expanding the standards in the relevant standards committees. With the already identified directive for the promotion of climate-neutral production processes in industry through climate protection agreements [182], they are making an important contribution to the move towards climate neutrality.

4.3.3.2 Requirements and challenges

The working group dealt with the details of the special features of the different technologies, as well as the extended use of hydrogen, also from its own production. The focus is on using existing standards and technical rules as a basis as far as possible and highlighting the necessary adaptations for systems, elements and construction materials, process media and safety requirements in relation to hydrogen. This can then take place in the respective technical committees as projects. Furthermore, general and individual standards for pressure systems and pressure equipment in relation to the European Pressure Equipment Directive (PED) [183] are included, e.g. pressure vessels, storage tanks, industrial pipelines, valves including safety valves, as well as entire assemblies also for cryogenic liquid applications, and semi-finished products for their manufacturing such as sheets, strips, pipes, forgings and their processing.

4.3.3.3 Needs analysis

After further review by the respective working groups in the responsible standardization bodies, the above-mentioned analyzed standards can then be supplemented and harmonized with the (EU) directives. Even if these standards and technical rules are already being used on the subject of hydrogen, it may be possible to define even more precise specific requirements and thus further improve safety. The WG has provided impulses for the development of adaptations and additions to various series of standards, e.g. on unfired pressure vessels (the EN 13445 series of standards [87]) or on industrial piping (EN 13480 series of standards [75]), in relation to hydrogen via this Roadmap. The specified needs will be published in the second version of this Standardization Roadmap Hydrogen Technologies at the end of 2025.

4.3.3.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.3.4 PtX

WG Power-to-X deals with the standardization of power-to-X plants. Power-to-X (PtX) refers to the conversion of electrical energy into an energy carrier (gaseous or liquid) or into a product (raw material). PtX is a collective term for technologies that store electricity in other forms of energy or convert it into products [184]. These technologies lead, among other things, to the production of hydrogen and then to further chemical conversion to secondary products, also using CO_2. PtX offers the possibility of sustainably producing chemical base materials, fuels or heat (see Table 1). Standardization of PtX technologies is necessary to exploit this potential. This can contribute to better integration of PtX in the overall system, greater acceptance and an increase in competitiveness.

4.3.4.1 Analysis of the status quo

PtX plants produce gaseous, liquid or solid chemical base materials, often using production processes already known and established in the chemical industry [184]. Therefore, PtX plants can already be designed quite comprehensively with the existing technical rules. A total of 33 technical rules were identified in this connection.

Hydrogen production by electrolysis is the first step for many of the PtX conversion pathways and has its own working group (WG Electrolysis) in this Roadmap. The task of PtX technologies is to integrate electrolysis into a more advanced form of hydrogen utilization. Carbon sources such as CO_2, plastics or biomass are used for this purpose. For this reason, WG PtX also touches on other technical rules, e.g. for the provision of these carbon sources, for instance CCU [184]. In this way, hydrogen production is combined with CO_2 supply to form an overall system; future standardization needs are being derived for this in WG PtX.

Power-to-gas processes can also produce hydrogen as a final product. The direct application of hydrogen is therefore the most widely represented form of technology, with eleven technical rules. Other power-to-gas plants are already represented by four of the 33 technical rules, and five others describe the interface with natural gas. This makes the production of methane the second most represented power-to-X technology [13].

The other technologies, such as power-to-ammonia or power-to-methanol, are direct and higher-value refinement stages that are achieved via hydrogen from electrolysis processes, but also via other forms of hydrogen generation as an intermediate stage, for which there is also a Roadmap working group (WG Other production methods). The general technical rules on safety aspects for hydrogen mentioned here must also be observed for these process stages.

The analysis currently covers 19 national, five European and eight international documents [13]. Figure 22 presents the identified bodies that are important for the development of technical rules in the field of PtX. An overview of the abbreviations used to describe these bodies is given in Section 9.

PtX

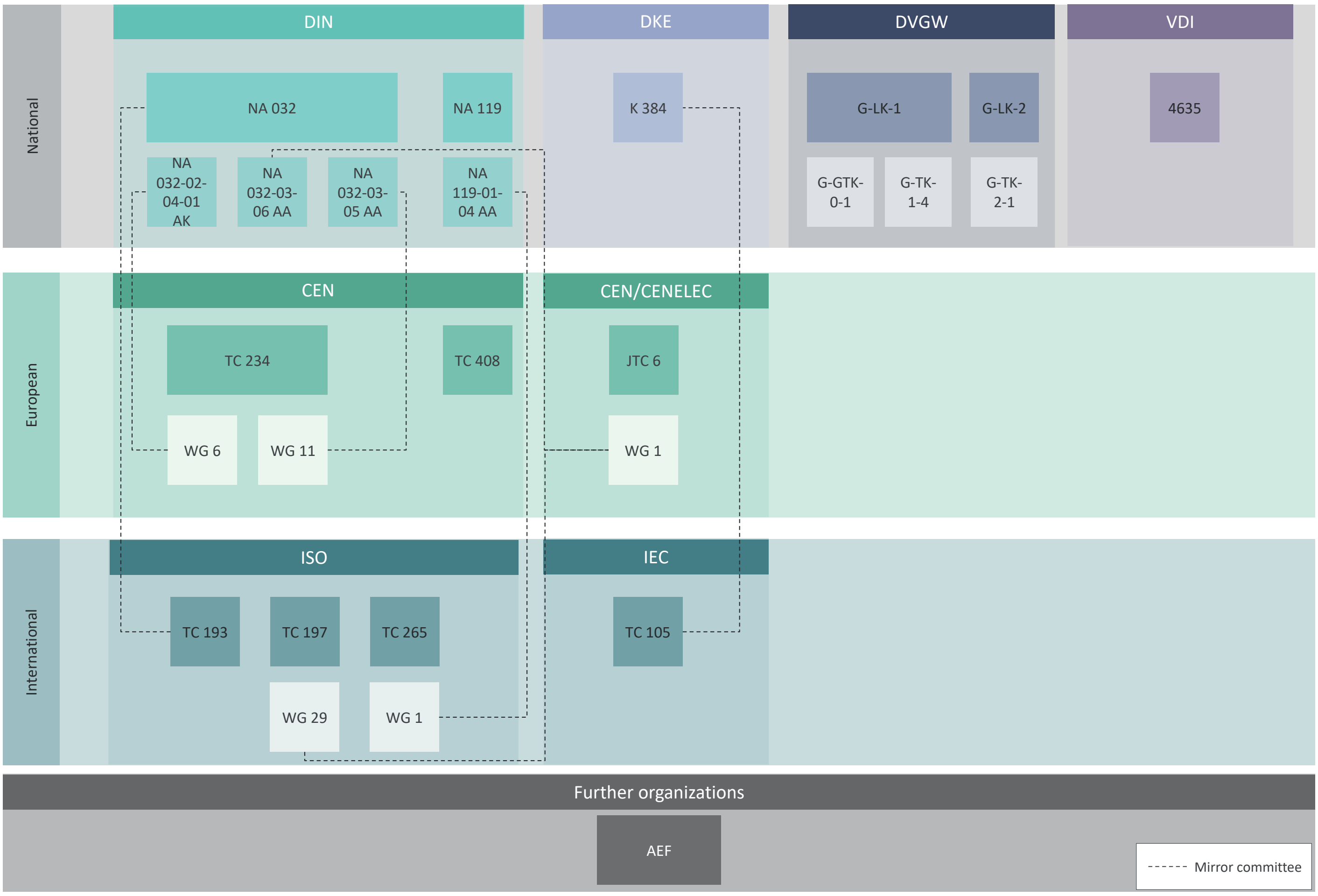

Figure 22: Overview of bodies relevant to technical rule-setting in the area of PtX (as of 03-2024) (Source: own illustration)

4.3.4.2 Requirements and challenges

PtX technologies and their products represent a key building block for the transformation of the chemical sector as well as for other applications in the aviation and shipping sectors (power-to-liquids). The CO_2 required for this can also be covered by carbon capture processes. Their contribution to the short- to long-term hydrogen ramp-up and product transformation is enormous (see Table 1).

The need for research is seen in the flexibilization of continuous production plants for hydrogen downstream products with the integration of renewable electricity sources.

4.3.4.3 Needs analysis

NEED 4.3.4-01:
VDI 4635 Blatt 1, Power to X – Primary aspects [186]

CONTENT: PtX; sector coupling; hydrogen application

EXPLANATORY NOTES: The series of guidelines VDI 4635 Power-to-X is a “modular system” with several parts [186]. The overarching part, Power-to-X – Primary aspects, will define terms that apply to all of the other parts, but will also shed light on general issues such as approval procedures and provide the overall context. This includes the PtX processes, subdivided into power-to-gas, power-to-heat and power-to-liquids. Aspects of planning, design, commissioning,

Table 1: Power-to-X products and scenarios for their ramp-up [185]

PRODUCT	PROCESS CHAIN	BEGIN OF THE TECHNOLOGY RAMP-UP 2030	2040	2045
Ammonia	Hydrogen from electrolysis, nitrogen from air separation; Haber-Bosch method	15 %	50 %	100 %
Urea	Ammonia and CO_2 from suitable sources; classic urea synthesis	15 %	50 %	100 %
Methanol	Hydrogen from electrolysis, CO_2 from suitable sources, methanol from a H_2/CO_2 mixture	15 %	50 %	100 %
Ethylene, propylene, butylene and isomers, aromatics (BTX)	Hydrogen from electrolysis, CO_2 from suitable sources, Fischer-Tropsch synthesis to syn. naphtha, further processing in e-cracker technology	15 %	50 %	100 %
Chlorine	Chlor-alkali electrolysis of NaCl	Mains current		
Base materials and special chemistry	Electricity-based heat supply up to 500 °C and for utilities; hydrogen as a fuel for heat > 500 °C	15 %	50 %	100 %

operation, approval and safety issues as well as systemic aspects will also be addressed. The coordinated and uniform terms in the field of Power-to-X, which are to be defined in this guideline, are essential in order to facilitate the entry into Power-to-X standardization and to achieve increased efficiency.

IMPLEMENTATION: This approved project is currently in the initiation phase and will take 36 months.

NEED 4.3.4-02:
VDI 4635 Blatt 2.2, Power-to-X – Power-to-Liquids

CONTENT: PtL; sector coupling; methanol; liquid hydrocarbons; ammonia

EXPLANATORY NOTES: The guideline "Power-to-Liquids" will evaluate and compare power-to-liquid technologies in combination with all required educt gases. These are considered from a Technology Readiness Level (TRL) > 7 and are used to convert electrical energy into liquid storage media. Power-to-liquid technologies will be described and compared in terms of design, construction, commissioning and operation. In addition, site conditions and process parameters that are necessary for operation will be described, standardized and discussed. In particular, the aim is to provide assistance in comparing the various technologies. At the last level, some individual processes will be described in detail.

IMPLEMENTATION: This approved project is currently in the initiation phase and will take 36 months.

Thermoprocessing equipment

4.3.4.4 Implementation projects

Both of the projects identified in the needs analysis (VDI 4635 Power to X; Blatt 1 – Primary aspects and VDI 4635 Blatt 2.2, Power to X – Power to Liquids) have been approved for implementation. The project VDI 4635 Blatt 2.2, Power to X – Power to Liquids was begun in April 2024.

4.3.5 Thermoprocessing equipment

WG Thermoprocessing equipment focuses on thermoprocessing plants and units. This covers all main and auxiliary systems that are necessary for the functionality and safety of production and their elements, including construction materials (such as furnaces, pipelines, boilers, apparatus, machines, package units and special machines) within the plant boundary defined by the technology providers or operators, which is also the interface to other facilities, plants, installations and the infrastructure. All phases from the initial study, through planning, procurement, fabrication and execution of the plant construction, including commissioning, to operation, maintenance and dismantling are considered in detail, taking into account the applicable directives, regulations and harmonized standards. This applies to both new construction and the modernization of machines and equipment.

One part of this Roadmap covers thermoprocessing equipment [187] in which among others hydrogen will be used as an energy carrier for the thermal treatment of materials in industrial production processes in order to reduce CO_2 emissions. They are categorized thematically into working committee Application and belong to the sub-working committee "Industry". In 2023, the working group considered main standards, product standards and other important aspects for this industry sector.

4.3.5.1 Analysis of the status quo

Industrial thermoprocessing equipment is covered by standards series at European level (EN 746-1 [188], EN 746-2[6] [189] and EN 746-3 [190]) and international level (standards series ISO 13577 [191]). These have been included with the comment that in future there should be an international and European uniform series of standards (EN ISO). In addition, standards were identified that describe the following aspects [13]:

→ the basic safety of hydrogen systems with the control devices of combustion technology;
→ occupational safety, protective measures for hazardous substances that can form after the combustion of hydrogen;
→ potentially explosive atmospheres in gas installations, natural gas installations for analogy, gas composition;
→ pipe materials for installations.

The important (EU) regulations for this area are the Gas Appliance Directive (GAR) [171], the Pressure Equipment Directive (PED) [183] and the Machinery Directive (MD) [172] or the new Machinery Regulation [173].

4.3.5.2 Requirements and challenges

The suitability of forced draught burners and appliance standards for hydrogen and hydrogen-containing fuel gases for determining the values before and after combustion was seen by the WG as important for future coordination with the other responsible WGs within the Roadmap. As part of these activities, the existing measurement technology required for the combustion processes will also be reviewed by the WG.

The committee responsible for ISO 13577-2 [192] has postponed the discussion of the necessary adaptation with regard to hydrogen until 2024 – this was considered to be very relevant by the WG. Therefore, this is part of the work programme for the WG in 2024.

6 This standard has been withdrawn and replaced by EN ISO 13577-2 [191].

4.3.5.3 Needs analysis

NEED 4.3.5-01:
EN 1539, Dryers and ovens, in which flammable substances are released – Safety requirements [193]

EXPLANATORY NOTES: EN 1539 will be reviewed with regard to hydrogen applications from (mid) 2024 concerning:
→ flushing of systems heated with hydrogen burners;
→ concentration measurement in systems heated with hydrogen burners;
→ updating of the normative references (ISO 13577 [191] instead of EN 746 [188], [189], [190])

and will be adapted over the next two years to reflect the (new) EU Machinery Regulation [173].

IMPLEMENTATION: The standard is being developed in CEN/TC 271/WG 4 Surface treatment equipment – Safety/ Dryers, ovens and evaporating equipment, whose secretariat is held by the national mirror body DIN working group NA 060-09-44-01 AK Paint dryers of the DIN Standards Committee Mechanical Engineering (NAM).

NEED 4.3.5-02:
EN 12753, Thermal cleaning systems for exhaust gas from surface treatment equipment – Safety requirements [194]

EXPLANATORY NOTES: EN 12753 will be reviewed with regard to hydrogen applications from (mid) 2024 concerning:
→ flushing of systems heated with hydrogen burners;
→ concentration measurement in systems heated with hydrogen burners;
→ interactions between the H_2 operating gas and the process gas to be cleaned;
→ updating of the normative references (ISO 13577 [191] instead of EN 746 [188], [189], [190])

and will be adapted over the next two years to reflect the (new) EU Machinery Regulation [173].

The responsible standardization body has determined the adaptation of this standard to be even more important than that of EN 1539 [193].

IMPLEMENTATION: The standard is being developed in CEN/TC 271/WG 4 Surface treatment equipment – Safety/ Dryers, ovens and evaporating equipment, whose secretariat is held by the national mirror body DIN working group NA 060-09-44-01 AK Paint dryers of the DIN Standards Committee Mechanical Engineering (NAM).

4.3.5.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.3.6 Steel Industry

WG Steel Industry focuses on reduction processes. This covers all main and auxiliary systems that are necessary for the functionality and safety of production and their elements, including construction materials (such as furnaces, pipelines, boilers, apparatus, machines, package units, and special machines) within the plant boundary defined by the technology providers or operators, which is also the interface to other buildings, plants, installations and infrastructure. Taking into account the applicable directives, regulations and harmonized standards, all phases, from the initial study to design, procurement, fabrication and execution of plant construction, including commissioning, through to operation, maintenance and dismantling, are considered in detail. This applies to both new constructions and the modernization of machines and equipment.

For the European and national steel industry, direct reduction with hydrogen, which has no alternative, is strategically very relevant, also due to several decisions by the EU Commission issued to promote the implementation of these climate-friendly systems worth billions in the last two years.

4.3.6.1 Analysis of the status quo

Steel production is at the beginning of the value chain and also at the end of the entire hydrogen market, when the specific requirements for materials end up at the steel producers. WG Steel Industry first looked at the existing, improved and new technologies, including the post-processing and auxiliary systems, and at the availability of standards in this area. 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. Existing standards for e.g. steel converters and safety devices for fuel appliances are important for modernization processes i.e. in transition phases from coke and natural gas to hydrogen, as well as for material properties and suitability for welding in connection with hydrogen as a medium.

4.3.6.2 Requirements and challenges

The economic feasibility of providing the necessary steels for the hydrogen market ramp-up in connection with the implementation of (new) direct reduction processes is given, so that some members of this working group have derived needs from the technology provider perspective, which will be discussed in the next cycle of meetings. Whether the energy industry loses a source of fuel gas from blast furnaces or will be supplied with other types and forms to be defined cannot be solved easily and quickly, as is the case for other WGs in the Industry sub-working committee of this Roadmap, i.e. WG (Petro)chemical industry, WG PtX, and WG Thermoprocessing equipment. However, it is assumed that small adjustments to these industry standards could have a massive positive impact on the planned transformation from the blast furnace route to alternative manufacturing processes (2018 to 2023 from 100 % to 50 % and from 2030 to 2045 from 50 % to 0 %) [195].

4.3.6.3 Needs analysis

Together with market leaders, the metallurgical industry is being sensitized to this issue. Suitable projects and recommendations for action will be proposed in the further course of the project. The specified needs will be published in the second version of this Standardization Roadmap Hydrogen Technologies at the end of 2025.

4.3.6.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.3.7 Domestic applications

WG Domestic applications deals with the status quo and need for technical rules for the production, distribution and use of hydrogen in the domestic sector. Product standards for gas appliances for heating, cooking, domestic hot water heating and application rules for the installation, operation and maintenance of gas piping systems and for the installation of gas appliances as well as the respective requirements are considered. The relevant component standards and qualification requirements for specialists and experts are considered.

4.3.7.1 Analysis of the status quo

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 [196] considers the relevant DVGW technical rules to be generally recognized rules of technology for hydrogen distribution. An excellent example within the remit of the WG is DVGW technical rule – code of practice G 600 [197]. This has now also been further developed for hydrogen in the first stage of DVGW technical rule – code of practice G 655 [198], taking into account all relevant requirements such as safety, installation and testing conditions.

Apart from certification schemes for components and gas appliances developed specifically for hydrogen, the WG’s entire portfolio of technical rules consists exclusively of revisions and further developments of existing standards and technical rules. As a result, the relevant documents were quickly identified and a clear structure was established in the WG. Open needs were quickly identified, and a timetable and prioritization for a structured revision in the coming months and years were proposed.

There are now 31 technical rules that are H_2-ready in the already published Standards Database for Hydrogen Technologies [13]. Half of these are published European and International Standards. Furthermore, there are 4 DVGW technical rules and three certification schemes that are H_2-ready. The remaining publications are national standards. In addition to the technical standards, the existing official regulations, such as the German Federal Immission Control Act [43], the German Länder building regulations and the German Building Energy Act [199], must also be complied with. The number of laws and regulations to be taken into account totals 16 documents.

Figure 23 presents the identified bodies that are important for the development of technical rules in the field of domestic applications. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.3.7.2 Requirements and challenges

Approximately 41 technical rule needs were identified that still need to be revised with regard to H_2-readiness. Gaps exist in the areas of product standardization for boilers, domestic hot water heaters, gas-fired hot air heaters, gas-fired motor-driven heat pumps and in some installation and application technical rules. Urgent needs have already been dealt with by supplementing the Technical Rules for Gas Installations

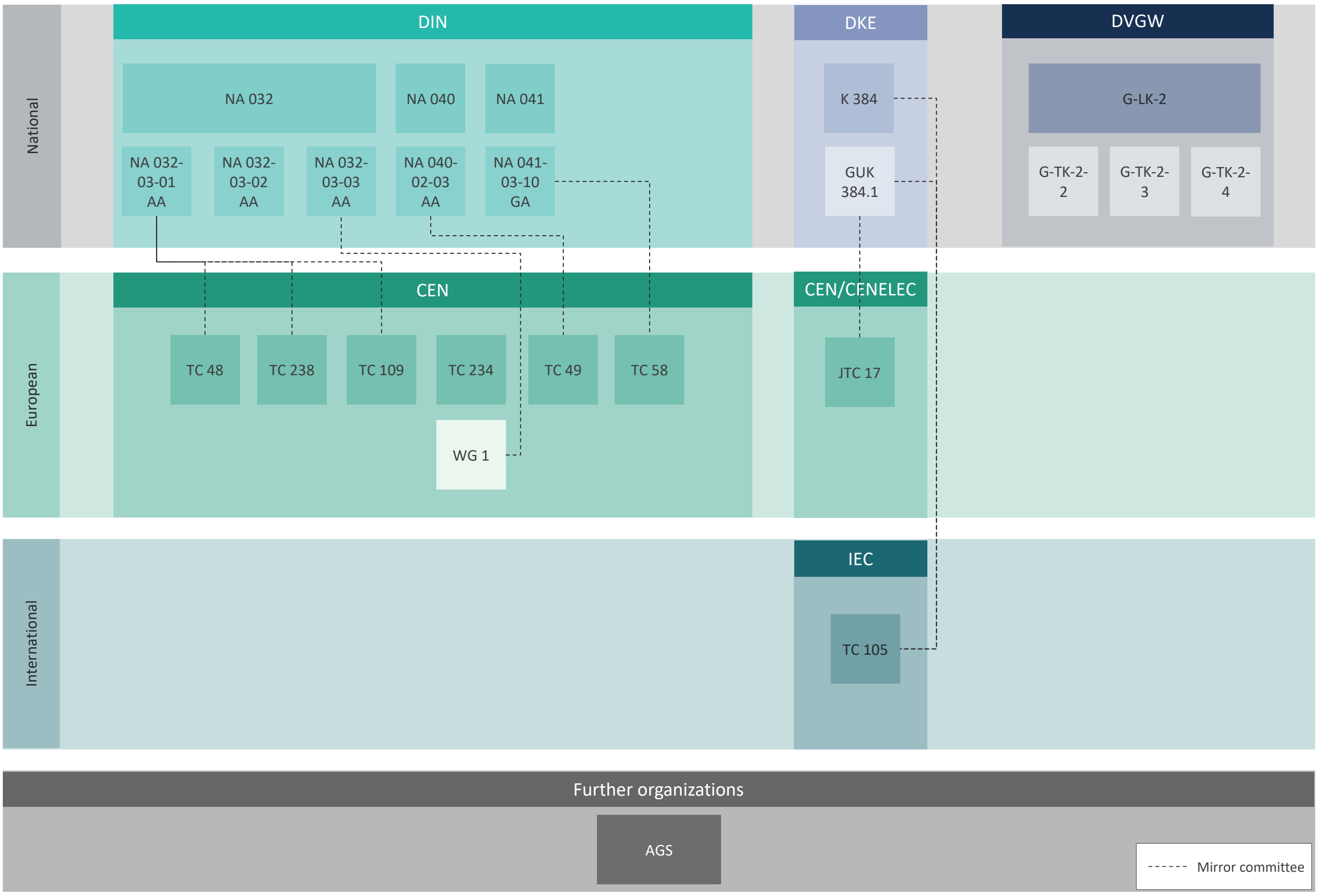

Figure 23: Overview of bodies relevant to technical rule-setting in the area of Domestic applications (as of 03-2024)
(Source: own illustration)

Domestic applications

(DVGW technical rule – code of practice G 600 [197]) and by adapting the national gas quality regulations (DVGW technical rule – code of practice G 260 [53]). As long as there is no H_2-ready standard for gas appliances, the certificate schemes ZP 3100.100 [200] or ZP 3100.20 [201] (supplementary tests for condensing boilers for gaseous fuels for 100 Vol.-% bzw. 20 Vol.-% H_2) can be used.

The determination of the status quo and of needs caused hardly any complications, but in practice the adaptation of the technical rules proved to be very complex. Several research projects such as "Influencing gas installation components by hydrogen content in natural gas, hydrogen in the gas infrastructure/gas application, THyGA" [202], Roadmap Gas 2050 [57] or EclHypse [203] have therefore been launched to enable the H_2 feed-in and conversion of gas installations and gas appliances.

Another requirement was that the scope was continuously adapted to the structure of the overall project. Initially, standards and technical rules for private hydrogen production and storage as well as for materials were also considered. However, it quickly became apparent that these standards and technical rules could be addressed and processed more precisely in the working groups WG Stationary and mobile pressure vessels, WG Fuel cells and WG Metallic materials. In addition, there was an ongoing exchange with WG Components for application and technologies. Cooperation among WGs, e.g. for the detailed classification of technical rules or for answering cross-cutting issues, was very effectively covered by the extensive project network.

4.3.7.3 Needs analysis

Of the 25 standards and technical rules, nine documents were defined as revision projects to be prioritized with regard to hydrogen suitability. An initial implementation is already taking place with the update of DVGW technical rule – code of practice G 655 [198] in the DVGW body TK-2-3 Gas Installation. The current findings of the research project on the safe operation of gas installations and gas appliances with natural gas-hydrogen blends and hydrogen, which was completed in 2023, will be incorporated into the technical rules.

NEED 4.3.7-01:
DVGW technical rule – code of practice G 110, Stationary gas warning devices [204]

CONTENT: Stationary gas warning devices; installations

EXPLANATORY NOTES: Updates and additions to the area of application of stationary gas warning systems to include hydrogen systems, in which odorization is currently not available or not possible, must be incorporated. For example, this is the case in installations for in-house generation and use or for process-related purposes [196].

IMPLEMENTATION: This need has been implemented in DVGW body TK-2-3 Gas installation since the end of 2023.

NEED 4.3.7-02:
DIN EN 15502-1, Gas-fired heating boilers – Part 1: General requirements and tests [205]

CONTENT: Central heating boilers, requirements; test conditions

EXPLANATORY NOTES: As can be deduced from the title of the standard, the boilers must be generally defined and adapted to the conditions of hydrogen.

IMPLEMENTATION: This will be implemented starting in 2024 in DIN working committee NA 032-03-01 AA Domestic, commercial and industrial gas utilisation and at European level within CEN/TS 15502-3-3.

NEED 4.3.7-03:
DIN EN 16905-2, Gas-fired endothermic engine driven heat pumps – Part 2: Safety [206]

CONTENT: HVAC systems; heat pumps, compressors

EXPLANATORY NOTES: The safety aspects must be updated and supplemented to include hydrogen applications.

Domestic applications

IMPLEMENTATION: This will be implemented starting in 2024 in DIN working committee NA 032-03-01 AA Domestic, commercial and industrial gas utilisation and at European level within CEN/TC 299.

NEED 4.3.7-04:
DIN EN 303-1, Heating boilers – Part 1: Heating boilers with forced draught burners – Terminology, general requirements, testing and marking [207]

CONTENT: Heating boilers; central heating; forced draught burners

EXPLANATORY NOTES: At present, this standard does not yet refer to the fifth gas family and therefore needs to be revised in general and editorially. A certification scheme for the approval of forced-air burners applies on a transitional basis.

IMPLEMENTATION: This will be implemented starting in 2025 in DIN working committee NA 041-01-62 AA Central heating boilers and at European level within CEN/TC 57.

NEED 4.3.7-05:
DIN EN 676, Forced draught burners for gaseous fuels [208]

CONTENT: Forced draught burners – construction; operation; test conditions

EXPLANATORY NOTES: At present, this European Standard does not yet refer to the fifth gas family and therefore needs to be revised in general and editorially. A certification scheme for the approval of forced-air burners applies on a transitional basis.

IMPLEMENTATION: This will be implemented starting in 2025 in DIN working committee NA 041-01-63 AA Forced draught burners for gaseous and liquid fuels and at European level within CEN/TC 47 and CEN/TC 131.

NEED 4.3.7-06:
DVGW technical information – guideline G 635, Gas appliances for connection to an air/flue gas system for overpressure operation [209]

CONTENT: Gas appliances; requirements; air/flue gas systems

EXPLANATORY NOTES: The connection of gas appliances of type C(10)/C(10)_x to a multiple-occupancy air/flue gas system requires the individual firing system to be matched to the specific air/flue gas system in terms of firing technology. Replacing a combustion heating device or the connection of a gas heating device with a different output or manufacturer on another storey requires a combustion engineering assessment. This Guideline serves as a standardized procedure for optimized occupancy rates and user-friendly handling for planning as well as for replacement and repair.

IMPLEMENTATION: This will be implemented starting from 2025 in DVGW body TK-2-2 Domestic, commercial and industrial gas applications.

NEED 4.3.7-07:
DVGW technical rule – code of practice G 600, Technical rule for gas installations (TRGI) [197]

CONTENT: Gas installations – design; erection; modification; maintenance; operation

EXPLANATORY NOTES: To date, the topic of admixing hydrogen in gas installations has been covered in addition to the TRGI by DVGW technical rule – code of practice G 655 [198] and its current revision. Furthermore, some specifications are still pending, such as the gas appliance categories for hydrogen in DIN EN 437 [210] as well as in European gas appliance standardization. In future, the corresponding provisions in DVGW technical rule – code of practice G 655 [198] and the aforementioned DIN EN standards, among others, are to be transferred to the installation specifications of the TRGI, thus taking on the status of a DVGW technical rule – code of practice.

IMPLEMENTATION: This will be implemented at the earliest in 2026 in the DVGW body TK-2-3 Gas installation.

NEED 4.3.7-08:
DVGW technical rule – code of practice G 1020, Quality assurance for the design, erection, modification, maintenance and operation of gas installations [211]

CONTENT: Gas installations – design; erection; modification; maintenance; operation

EXPLANATORY NOTES: This necessity arises from the current legal framework for hydrogen networks and their applications. Qualification requirements are hereby placed on executing companies and the references to the technical rules are to be updated. Furthermore, the hydrogen regulations are included and supplemented [212].

IMPLEMENTATION: This is being implemented starting from 2024 in the DVGW body TK-2-3 Gas installation.

4.3.7.4 Implementation projects

Financial support for the revision of DVGW technical rule – code of practice G 655 [198] was approved in spring 2023. The reason for the necessary funding and prioritization was that this document supplements the conversion of industrial pipelines for grid-bound supply (DVGW technical rule – codes of practice G 614 [213]) and domestic pipelines and applications (DVGW technical rule – code of practice G 600 [197]) with regard to H_2 on a transitional basis and thus ensures the ability to act. Extensive research results are available on the suitability of materials as well as installation and testing requirements for H_2, which are incorporated into the update of DVGW technical rule – code of practice G 655 [198].

DVGW technical rule – code of practice G 110 [204] was added in the fall of 2023. This financial support will make it easier for technical standardization to prioritize the most important changes to technical rules relating to the H_2 transformation using the necessary resources. The needs are described in Section 4.3.7.3.

4.3.8 Controls

WG Controls is responsible for determining the standardization needs with regard to safety, design and functional requirements, as well as tests for regulating and control devices for appliances and systems that generate heat through the use of hydrogen. This essentially comprises the following regulating and control devices, including their applications:

→ automatic shut-off valves for gas burners and gas appliances as well as the gas supply;
→ automatic pressure relief valves;
→ pressure regulators for gas burners and gas appliances;
→ thermoelectric ignition fuses;
→ pneumatic gas-air compound regulators for gas burners and gas appliances;
→ manually operated adjustment devices for gas appliances;
→ mechanical temperature regulators for gas appliances;
→ multiple control units for gas appliances;
→ electronic fuel-air compound regulators;
→ pressure regulators;
→ electric ignition devices;
→ automatic burner controls;
→ sensors for the detection of gaseous combustion products;
→ temperature control devices and temperature limiters;
→ valve monitoring systems for automatic shut-off valves.

4.3.8.1 Analysis of the status quo

The WG was able to draw on the work of European committees, in particular the work of CEN/TC 58/WG 15 Advisory Group 1 Hydrogen, in its analysis of the status quo.
CEN/TC 58/WG 15 has prepared a document, CEN/TR 17924 [214], which provides guidance on hydrogen-specific safety, design, construction and performance requirements and for the testing of safety, regulating or control devices for burners and appliances burning hydrogen-containing gases. In addition, the Technical Report identifies the expected need for revision of the existing of CEN/TC 58 Controls and the need for possible further new standardization tasks. The WG identified 41 technical rules in the status quo analysis, of which 34 are European documents, six are International Standards and one is a DVGW technical rule – code of practice, in addition to one set of ZP certification scheme testing principles [13].

[Figure 24](#) presents the identified bodies that are important for the development of technical rules in the field of controls. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.3.8.2 Requirements and challenges

The WG determined that, with regard to controls, the existing technical rules only need to be supplemented to include hydrogen or hydrogen mixtures. This will take place as part of the revision of the technical rules by the responsible bodies. At present it is not necessary to develop new documents. Cross-cutting issues are to be monitored and any findings or effects taken into account.

4.3.8.3 Needs analysis

NEED 4.3.8-01:
Consideration of hydrogen in the standards of CEN/TC 58

CONTENT: Safety devices; control devices; burners; fuel devices; gaseous; liquid

EXPLANATORY NOTES: CEN/TR 17924 [214] was developed to take consideration of hydrogen in the standards of CEN/TC 58. Investigations carried out as part of the development of the Technical Report have shown that there is no urgent need to revise the existing standards and that consideration in the course of the forthcoming revisions on the basis of CEN/TR 17924 [214] is sufficient.

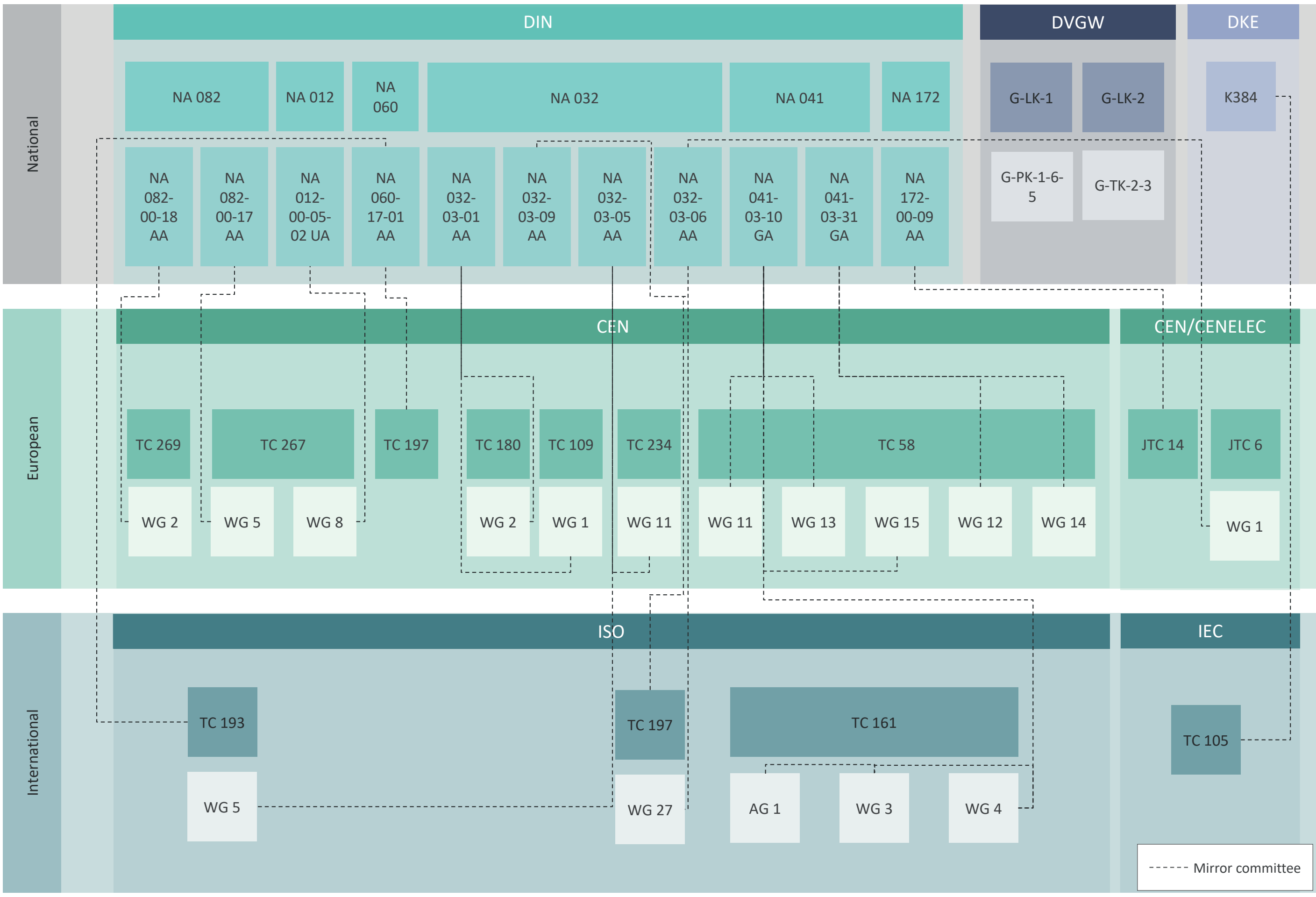

Figure 24: Overview of bodies relevant to technical rule-setting in the area of controls (as of 03-2024) (Source: own illustration)

Controls

IMPLEMENTATION: This revision is being carried out in the WGs of CEN/TC 58. National mirror work in Germany is carried out in DIN Joint committees NA 041-03-10 GA Joint working committee NHRS/NAA/NAGas: Safety and control devices for heating appliances and heat generating systems and for the gas distribution and NA 041-03-31 GA Joint working committee NHRS/DKE: Electrical safety and control devices for heating appliances and heat generating systems.

NEED 4.3.8-02:
Consideration of hydrogen in the standards of ISO/TC 161

CONTENT: Safety devices; control devices; gas burners; gas appliances

EXPLANATORY NOTES: Investigations carried out in Europe have shown that there is no urgent need to revise the existing standards and that consideration in the course of the forth-coming revisions is sufficient.

IMPLEMENTATION: This revision is being carried out in the WGs of ISO/TC 161. National mirror work in Germany is carried out in DIN Joint committees NA 041-03-10 GA Joint working committee NHRS/NAA/NAGas: Safety and control devices for heating appliances and heat generating systems and for the gas distribution and NA 041-03-31 GA Joint working committee NHRS/DKE: Electrical safety and control devices for heating appliances and heat generating systems.

NEED 4.3.8-03:
Consideration of hydrogen in DIN EN 331 Manually operated ball valves and closed bottom taper plug valves for gas installations for buildings [215]

CONTENT: Ball valves; closed bottom taper plug valves; domestic gas installations

EXPLANATORY NOTES: The use of hydrogen or hydrogen admixtures must be taken into account in the next revision of the standard.

IMPLEMENTATION: This is being implemented in CEN/TC 236/WG 1. The work is being mirrored at national level in DIN working committee NA 032-02-06 AA Gas valves.

NEED 4.3.8-04:
Consideration of hydrogen in DIN EN 334, Gas pressure regulators for inlet pressures up to 10 MPa (100 bar) [216]

CONTENT: Gas pressure regulators

EXPLANATORY NOTES: The use of hydrogen or hydrogen admixtures must be taken into account in the next revision of the standard.

IMPLEMENTATION: This is being implemented in CEN/TC 235/WG 1. The work is being mirrored at national level in DIN working group NA 032-02-04-02 AK Mirror committee CEN/TC 235/WG 1.

NEED 4.3.8-05:
Consideration of hydrogen in DIN EN 14382, Gas safety shut-off devices for inlet pressures up to 10 MPa (100 bar) [217]

CONTENT: Gas safety shut-off devices

EXPLANATORY NOTES: The use of hydrogen or hydrogen admixtures must be taken into account in the next revision of the standard.

IMPLEMENTATION: This is being implemented in CEN/TC 235/WG 1. The work is being mirrored at national level in DIN working groupNA 032-02-04-02 AK Mirror committee CEN/TC 235/WG 1.

NEED 4.3.8-06:
Consideration of hydrogen in DIN 33821, Safety relief valves for gas transmission and distribution installations operating at working pressures up to 100 bar [218]

CONTENT: Safety relief valves; gas transmission

EXPLANATORY NOTES: The use of hydrogen or hydrogen admixtures must be taken into account in the next revision of the standard.

IMPLEMENTATION: Revision is being carried out in DIN working committee NA 032-02-06 AA Gas valves.

NEED 4.3.8-07:
Consideration of hydrogen in DIN EN IEC 60730-1, Automatic electrical controls [219] and DIN EN IEC 60730-2-5 [220]

CONTENT: Automatic electrical controls

EXPLANATORY NOTES: The use of hydrogen or hydrogen admixtures must be taken into account in the next revision of these standards.

IMPLEMENTATION: The revision is being carried out in IEC/TC 72. This work is mirrored at national level in the DKE body DKE/K 515 Control units.

4.3.8.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.3.9 Commercial applications

WG Commercial applications deals with the use of hydrogen-powered systems and components in the commercial sector for heating purposes or for heat treatment. This includes: butchery, smokehouse, catering, drying and laundry systems, HVAC appliances such as radiant heaters and forced-air gas burners, as well as laboratory burners. As fuel is also supplied via a distribution network in a commercial context, there are overlaps with domestic gas applications.

4.3.9.1 Analysis of the status quo

It is very beneficial for standardization and technical rule-setting in commercial applications related to the use of hydrogen that this work is already largely known from the natural gas sector and can be transferred from that sector. In general, all the requirements described in each case, such as safety, set-up, installation and testing conditions, must now also be complied with for hydrogen. New technical backgrounds and properties of hydrogen with an influence on the technical rules were also taken into account and included by the WG. Apart from the certification schemes developed specifically for hydrogen, the entire portfolio of technical rules consists exclusively of revisions and further developments of existing technical rules and standards to include hydrogen. As a result, the relevant documents were quickly identified and a clear structure was established in the working group. Open needs were quickly identified and will be gradually adapted in a structured manner over the coming months and years.

14 technical rules from this working group were included in the already published Standards Database for Hydrogen Technologies. Four of these documents are already H_2-ready DVGW technical rules. There are also three certification schemes and seven relevant International and European Standards on the use of hydrogen [13]. In addition to the technical rules, the existing legal regulations such as the EU Gas Appliance Directive [221], the Pressure Equipment Directive (PED) [76], the Machinery Directive (MD) [73], the German Federal Immission Control Act [43], and the relevant building regulations, occupational health and safety regulations and Employers' liability insurance association regulations must also be complied with. Altogether, eight legal regulations were identified for the commercial sector.

Figure 25 presents the identified bodies that are important for the development of technical rules in the field of commercial applications. An overview of the abbreviations used to describe these bodies is given in Section 9.

Commercial applications

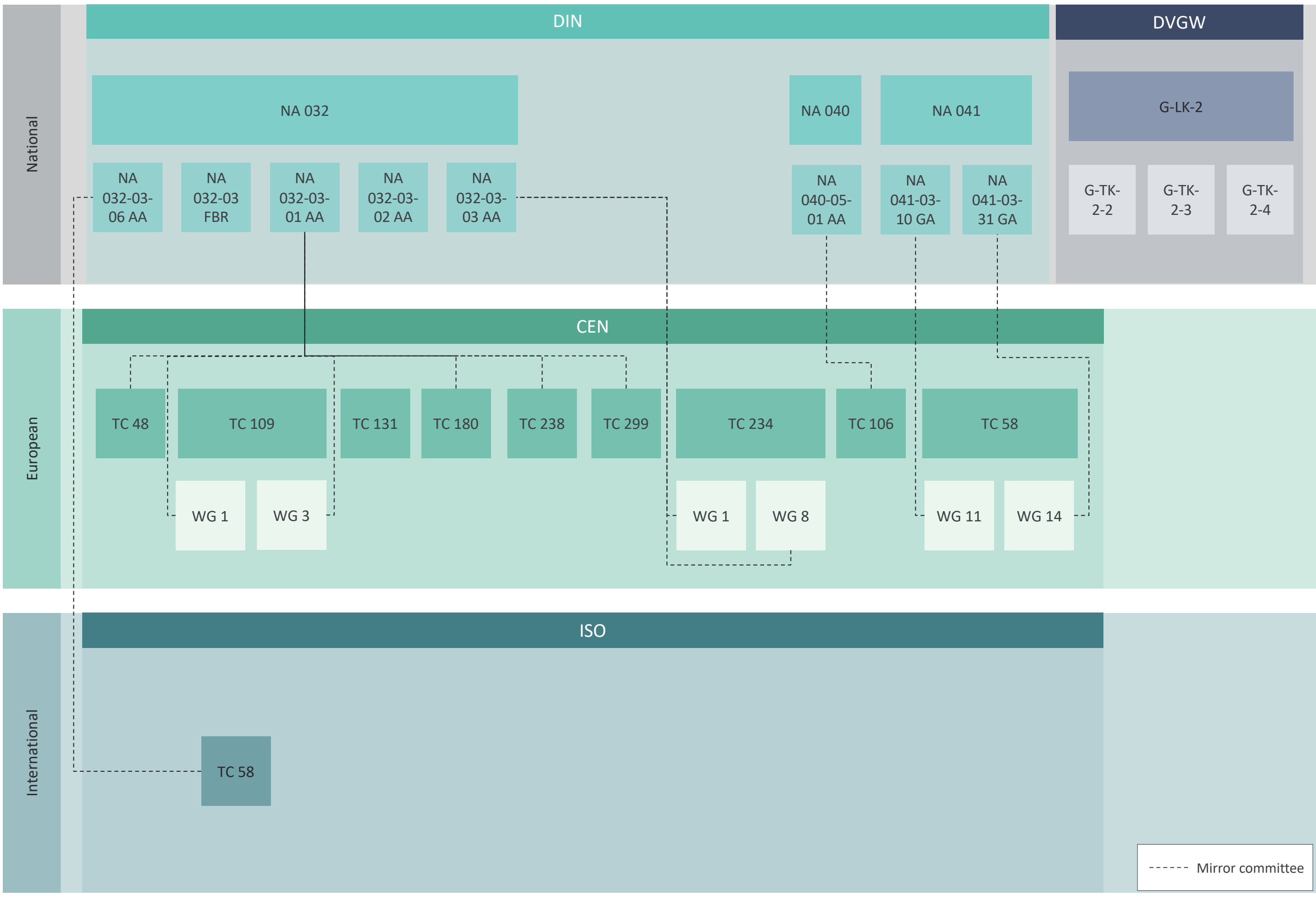

Figure 25: Overview of bodies relevant to technical rule-setting in the area of commercial applications (as of 03-2024) (Source: own illustration)

4.3.9.2 Requirements and challenges

There are 27 technical rules which need to be revised in terms of H_2-readiness. There are gaps in the product standardization of gas appliances for general commercial use, for forced-air burners and radiant heaters and in the sector of forced convection heaters. There is also still a need for revision in the area of certification of radiant tube heaters ("dark radiators"). Urgent needs have already been covered by supplementing the Technical Rules for Gas Installations (TRGI) [222] with the guidelines on H_2 readiness for gas applications [198] and by adapting the national gas quality regulations [223]. For forced draught burners and valves, there are not yet any hydrogen-compatible technical rules, which is why the certification schemes ZP 3502.20 (Supplementary tests for boilers for gaseous fuels for a hydrogen content of up to 20 % by volume) [224] and ZP 4110 (Supplementary tests for valves for gaseous fuels for a hydrogen content of up to 100 % by volume) [225] must be used for these areas.

The determination of the status quo and of needs caused hardly any complications, but in practice the adaptation of the technical rules to include hydrogen proved to be technically very complex. For this reason, research projects such as THyGA [202], H_2 and Valves [226], EclHypse [203] or HydEKuS [227] were commissioned, which made it possible to make existing appliances and systems hydrogen-compatible. A further challenge for WG Commercial applications was the fact that its scope was continually adapted to the overall structure of the Standardization Roadmap Hydrogen Technologies. It became apparent that some specific standardization needs could be addressed and processed more precisely in the working groups WG Controls and WG Domestic applications. The general cooperation among WGs was made possible very effectively and reliably via the extensive project network.

4.3.9.3 Needs analysis

NEED 4.3.9-01:
DIN EN 416, Gas-fired overhead radiant tube heaters and radiant tube heater systems for non-domestic use – Safety and energy efficiency [228]

CONTENT: Gas-fired radiant tube heaters; requirements; test methods

EXPLANATORY NOTES: The requirements and test methods for design, safety and energy efficiency must be defined. The supply of commercial and industrial hall-like buildings will not only be of great importance for room air conditioning, but above all for many production processes in workplaces. The corresponding revision with regard to hydrogen and the harmonization of the aforementioned standards represents a central building block for the transformation of the energy landscape [229].

IMPLEMENTATION: Implemented starting from 2024 in DIN working group NA 032-03-01-04 AK Decentralized gas heating, which is the national mirror body to CEN/TC 180/WG 1.

NEED 4.3.9-02:
DIN EN 419, Gas-fired overhead luminous radiant heaters for non-domestic use – Safety and energy efficiency [230]

CONTENT: Gas-fired overhead luminous radiant heaters; requirements; test methods

EXPLANATORY NOTES: Requirements and test methods for the design, safety and energy efficiency of these appliances must be defined as quickly as possible. The supply of hall-like buildings with a climate-neutral gas will be of great importance in the future for air conditioning and for many production processes in workplaces. The revision with regard to hydrogen and the harmonization of the standard represents a central building block for the transformation of the energy landscape [229].

IMPLEMENTATION: Implemented starting from 2024 in DIN working group NA 032-03-01-04 AK Decentralized gas heating, which is the national mirror body to CEN/TC 180/WG 1.

NEED 4.3.9-03:
DIN EN 17082, Domestic and non-domestic gas-fired forced convection air heaters for space heating not exceeding a net heat input of 300 kW [231]

CONTENT: Gas-fired forced convection air heaters; requirements; safety; efficiency

EXPLANATORY NOTES: Requirements and test methods for the design, safety and energy efficiency of these appliances must be defined as quickly as possible. These systems are often the only option for energy-efficient heating in the energy-efficient refurbishment of hall-like buildings [232]

IMPLEMENTATION: Implemented starting from 2024 in DIN working group NA 032-03-01-04 AK Decentralized gas heating, which is the national mirror body to CEN/TC 180/WG 1.

NEED 4.3.9-04:
ZP 3411.100 Testing of radiant tube heaters for gaseous fuels with a hydrogen content of 100 % by volume

CONTENT: Qualification; gas appliances; certification principles; testing principles

EXPLANATORY NOTES: These certification and testing principles relate to new appliances and describe the tests required to qualify gas appliances for 100 % hydrogen by volume. This document will be applied until there is a uniform European technical rule.

IMPLEMENTATION: This certification scheme will be implemented by DVGW Cert GmbH starting from 2024.

Commercial applications

NEED 4.3.9-05:
DIN EN 676, Forced draught burners for gaseous fuels [208]

CONTENT: Forced draught burners; requirements; construction; test methods

EXPLANATORY NOTES: The terminology and the general requirements for the construction and operation of forced draught gas burners and for the equipment with control and safety devices as well as the test method for these burners must be redefined with regard to H_2.

IMPLEMENTATION: Will be implemented starting from 2024 in DIN working committee NA 041-01-63 AA Forced draught burners for gaseous and liquid fuels, which is the national mirror body to CEN/TC 47 and CEN/TC 131.

NEED 4.3.9-06:
DIN EN 17175, Gas-fired overhead radiant strip heaters and multi-burner continuous radiant tube heater systems for non-domestic use – Safety and energy efficiency [233]

CONTENT: Non-domestic; gas-fired; radiant strip heaters; continuous radiant tube heater systems

EXPLANATORY NOTES: The requirements and test methods for design, safety and energy efficiency must be defined. Heat generators that work on the basis of infrared radiation are the only option for energy-efficient heating in its areas of application. This means that these systems will often be the only option for energy-efficient heating in the energy-efficient refurbishment of hall-like buildings and will be of great importance for many manufacturing processes [232].

IMPLEMENTATION: Implemented starting from 2024 in DIN working group NA 032-03-01-04 AK Decentralized gas heating, which is the national mirror body to CEN/TC 180/WG 1.

NEED 4.3.9-07:
DIN 3372-1, Gas-appliances – Radiant heaters with burners without fan: Stationary heaters for outdoor use and portable heaters for indoor and outdoor use – Part 1: Requirements and tests [234]

CONTENT: Stationary; radiant heaters; burners without fan; gas infrared radiation

EXPLANATORY NOTES: Editorial adjustments to take the necessary hydrogen operation into account are indispensable with increased urgency. The safety aspects must be updated and supplemented. The same applies to test conditions. The use of these appliances in industry and commerce is also of great importance.

IMPLEMENTATION: Starting in 2024 in NA 032-03-01 AA Domestic, commercial and industrial gas utilisation.

NEED 4.3.9-08:
DIN 3372-2, Gas-appliances – Radiant heaters with burners without fan: Stationary heaters for outdoor use and portable heaters for indoor and outdoor use – Part 2: Conformity [235]

CONTENT: Radiant heaters, burners without fan; stationary heaters

EXPLANATORY NOTES: General editorial adjustments to take the necessary hydrogen operation into account are indispensable with increased urgency. The safety aspects must be updated and supplemented to include hydrogen applications. The same applies to test conditions. The use of these appliances in industry and commerce is also of great importance.

IMPLEMENTATION: Starting in 2025 in NA 032-03-01 AA Domestic, commercial and industrial gas utilisation.

NEED 4.3.9-09:
DIN 3372-4, Gas-appliances – Radiant heaters with burners without fan: mobile non-fan assisted radiant heaters for indoor and outdoor use [236]

CONTENT: Radiant heaters, burners without fan; mobile heaters

EXPLANATORY NOTES: General editorial adjustments to take the necessary hydrogen operation into account are indispensable with increased urgency. The safety aspects must be updated and supplemented to include hydrogen applications. The same applies to test conditions. The use of these appliances in industry and commerce is also of great importance.

IMPLEMENTATION: Starting in 2024 in NA 032-03-01 AA Domestic, commercial and industrial gas utilisation.

4.3.9.4 Implementation projects

The European Standards DIN EN 416 [228], DIN EN 419 [230] and DIN EN 17082 [231] were approved for financial support in the second round of proposals in fall 2023.

The needs are described in Section 4.3.9.3 Needs analysis. This financial support will make it easier for technical standardization to prioritize the most important changes to technical rules relating to the hydrogen transformation using the necessary resources.

4.3.10 Filling systems

WG Filling systems is responsible for determining the standardization needs with regard to the (safety-related) requirements for the construction and/or operation of filling plants, suitable connection devices (interfaces), overfill protection and refuelling protocols for use with hydrogen, e.g. gaseous, liquid, and cryogenically compressed. Future mobility with hydrogen as an energy carrier requires the standardization of a filling system consisting of the H_2 source, the delivery system, the connection line and the interface to the filling tank.

4.3.10.1 Analysis of the status quo

A comprehensive list of all hydrogen technical rules researched can be found in the Standards Database for Hydrogen Technologies [13]. To date, around 60 of these standards have been deemed relevant for filling systems. The existing state of technical rule-setting varies depending on the condition of the hydrogen to be filled, whereby the framework national and international system standards usually apply equally to all conditions.

Cross-media (system) standards:
In addition to the generally applicable international directives (such as ATEX [237], OIML R139 [238], PED [76] or TPED [239], AFIR [240]), most of the existing technical rules have so far been developed in the USA or at ISO level. For the filling system, at least the basic framework conditions for construction and operation are also described and available in national TRBS regulations (e.g. TRBS 3151 [241], TRBS 3146 [242]).

Gaseous hydrogen compressed under high pressure:
For historical reasons, around 80 % of existing standards relate to these applications. An ISO standard is about to be published for the dispenser as the most important part and operating interface of the filling system. The individual parts such as fill couplings, hoses, and fittings are usually described in ISO Standards where they are already standardized. Most of the existing ISO Standards are drafts or recent publications, which are often still under revision.

Cryogenic hydrogen (liquid or gaseous):
Only around 20 % of the existing standards describe cryogenic applications and primarily relate to individual parts such as fittings, hose assemblies, pumps and valves. Almost all of these standards have already been adopted at national level as DIN EN ISO Standards.

Figure 26 presents the identified bodies that are important for the development of technical rules in the field of filling systems. An overview of the abbreviations used to describe these bodies is given in Section 9.

Filling systems

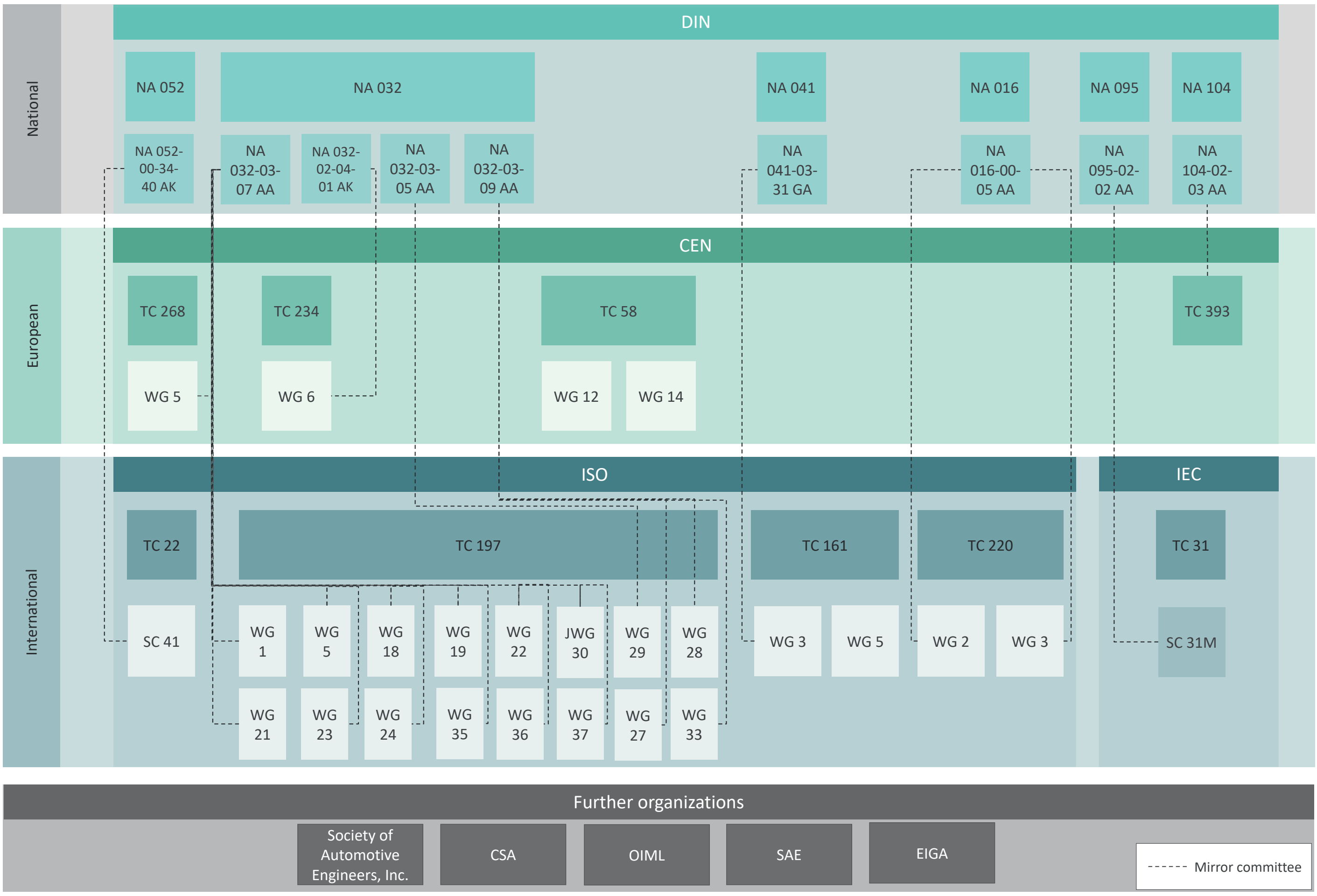

Figure 26: Overview of bodies relevant to technical rule-setting in the area of filling systems (as of 03-2024)
(Source: own illustration)

4.3.10.2 Requirements and challenges

One particular challenge are the interfaces between the filling system and the tank to be filled, which are addressed as cross-cutting issues in the standardization of interdisciplinary solutions.

Some interfaces are neither sufficiently specified nor extensively tested, but are often used in industry as individual solutions. Experience with these interfaces must be evaluated and functional principles defined in order to standardize them. It is important to ensure that the pressure levels and states of the hydrogen cannot be confused and that they can be distinguished from other media. In addition, the need for short filling times must be taken into account by using appropriate cross-sections. There are also phenomena that require communication about the tank status between the filling system and the vehicle (the “refuelling protocol”). In the case of liquefied H_2, these phenomena include thermal stresses during cooling down.

The aim must be to categorize the interfaces (according to pressure, temperature, flow rate, filling/draining, etc.) and to legally prescribe them with the associated refuelling protocols across all applications. All tanks for use under the same medium conditions should ideally use the same interfaces, regardless of whether they are part of a vehicle, a transport tank or a production plant, for example. This universal use simplifies the development of the necessary logistics, while a too narrowly defined area of application leads to a large number of interfaces and inhibits the use of hydrogen. Necessary interfaces should therefore be standardized at international level wherever possible.

For the safe operation of the filling system, general procedural instructions are still lacking in many areas, e.g. for emptying hydrogen tanks. Furthermore, explosion protection has not always been sufficiently taken into account in previous standards, e.g. in the classification of explosion protection zones according to DIN EN IEC 60079-0 [243] or in the overlapping of hazardous areas at filling stations with MPD dispensers.

An enormous amount of work is still required to develop all the necessary filling system standards for safe H_2 mobility.

4.3.10.3 Needs analysis

NEED 4.3.10-01:
Gaseous hydrogen connection devices for refuelling land vehicles

CONTENT: Filling tank interfaces; H_2; low level of purity

EXPLANATORY NOTES: In contrast to fuel cell vehicles, combustion engines have lower fuel purity requirements. The grade F specified for this has a hydrogen purity of 98 %, instead of 99,97 %, in accordance with the Annex to ISO/DIS 14687:2024-01 [69]. The aim is to avoid possible misfuelling by means of a new interface for this fuel quality (similar to DIN EN ISO 17268-1 [244] for fuel cell electric vehicles).

IMPLEMENTATION: This need has already been implemented in the international body ISO/TC 197/WG 5 with EN ISO 17268 [245].

NEED 4.3.10-02:
European filling station standard

CONTENT: European product standard; hydrogen filling stations

EXPLANATORY NOTES: A European product standard is needed for hydrogen filling stations (possibly also compact systems), in which the requirements and standard references for the collection of individual components are brought together, as EN 17127 [246] only deals with the basics. This topic is covered at ISO level with the ISO 19880 [247] standards series.

IMPLEMENTATION: This need is not yet being implemented, as the responsibility between the responsible committees (CEN/TC 393 and CEN/TC 268) is still being clarified.

NEED 4.3.10-03:
Hydrogen filling systems and their components for filling mobile pressure equipment

CONTENT: Hydrogen filling systems; mobile pressure equipment

EXPLANATORY NOTES: There is a need for a European product standard for hydrogen filling systems for filling mobile pressure equipment, in which the requirements and interaction of individual components (e.g. compressors, valves, hose assemblies, fill couplings) are brought together.

IMPLEMENTATION: Clarification is needed of whether the same requirements apply to public filling stations and other dispensing facilities, and as to who is responsible for implementation at European level, based on the ISO 19880 [247] series of standards (CEN/TC 393 and CEN/TC 268).

NEED 4.3.10-04:
Blowers on gas systems for hydrogen

CONTENT: Potentially explosive zones; requirements; H_2 blowers

EXPLANATORY NOTES: The explosion protection requirements for blowers on H_2 gas installations [241] are to be specified in analogy to DVGW technical rule – code of practice G 442 [106].

IMPLEMENTATION: Before implementation, a check is to be made as to what extent this function is/can be covered by existing standards (e.g. EN IEC 60079-10-1 [248] and TRBS 3151 (chapter 4.1.10.3) [241]).

NEED 4.3.10-05:
Procedure for filling a tank with liquefied hydrogen

CONTENT: Filling; tank; liquefied hydrogen

EXPLANATORY NOTES: There is a need for standardization of the procedure for filling a tank with liquefied H_2. The steps for filling a tank with liquefied hydrogen are:
1. record the actual state according to the specifications of the manufacturing company;
2. define operating modes / filling preparation depending on tank status;
3. prepare and implement the selected operating modes (filling).

The steps must be detailed or supplemented/standardized with the help of fire and explosion protection experts.

IMPLEMENTATION: This will be implemented starting in 2024 in DIN working committee NA 032-03-07 AA Gas supply for vehicles operating on natural gas, and in ISO/TC 197/WG 35 as ISO 13984 [249]. It must then be checked whether the needs have been fully covered there.

NEED 4.3.10-06:
Standardization of cryogenic couplings as an interface from filling systems to the application

CONTENT: Geometry; performance; cryogenic couplings

EXPLANATORY NOTES: A detachable, standardized connection (coupling) is required for cryostatic filling with liquefied H_2. This is only generally described in DIN EN 13371 [89]. The applications must be differentiated (e.g. lorry/ship/airplane/train), as different mass flows prevail. The aim is to standardize dimensions, alignment of the coupling and safety measures, among other things.

IMPLEMENTATION: This will be implemented starting in 2024 in DIN working committee NA 032-03-07 AA Gas supply for vehicles operating on natural gas, and in ISO/TC 197/WG 35 as ISO 13984 [249]. The need as regards CCH_2 is being realized in ISO/TC 197/WG 36 as ISO 17268-3 [250]. It must then be checked whether the needs have been fully covered there.

NEED 4.3.10-07:
Interface and protocol for refuelling heavy commercial vehicles with gaseous hydrogen

CONTENT: High flow; refuelling interface; commercial vehicles

EXPLANATORY NOTES: There is a need for a technical rule that specifies the interface and procedure for refuelling heavy commercial vehicles with gaseous hydrogen at high volume flows (> 120 g/s) and prevents misfuelling.

IMPLEMENTATION: This will be implemented in DIN working committee NA 032-03-07 AA Gas supply for vehicles operating on natural gas, and in ISO/TC 197/WG 35 as ISO 17268-2 [251]. Concerning the refuelling protocol there are also activities in ISO/TC 197/WG 24 working on ISO 19885-3 [252] and work on the US-American standard SAE J 2601-5 [253].

4.3.10.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK. It is important to sort through the multitude of topics and prioritize them according to the assessment of the working groups involved. This is particularly difficult for the interfaces mentioned above.

4.3.11 Road vehicles

The remit of WG Road Vehicles covers the development of the Standardization Roadmap Hydrogen Technologies in the area of road vehicles. This includes both passenger cars and trucks on public roads, but does not include special vehicles. All applications of hydrogen as an energy carrier for propulsion are considered, and the corresponding requirements for certain components for use are taken into account. Excluded are specifications for tanks and containers used to transport hydrogen. The interfaces to the relevant working groups are of particular importance.

4.3.11.1 Analysis of the status quo

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 and some which have been adopted as national standards (DIN EN and DIN ISO). The published technical rules also include technical reports (TR), specifications (TS), codes of practice and guidelines. For detailed information on these technical rules go to the Standards Database for Hydrogen Technologies [13].

Figure 27 presents the identified bodies that are important for the development of technical rules in the field of road vehicles. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.3.11.2 Requirements and challenges

The few remaining gaps in standardization for road vehicles are characterized by two main factors. First, technological advances are expanding the technical rules required to meet the demands of the developing mass market. Second, the growing economic importance of hydrogen calls for new technical rules to facilitate market compatibility. This necessity is additionally reinforced by emerging safety aspects in the hydrogen economy. In view of the evolving hydrogen economy, four main reasons can be identified that make it necessary to specifically address the identified needs and close the corresponding gaps: safety, economic efficiency, technological openness and reliability. Ignoring these identified and potentially future requirements would result in hydrogen losing its appeal as a drive technology in the road vehicle sector. This in

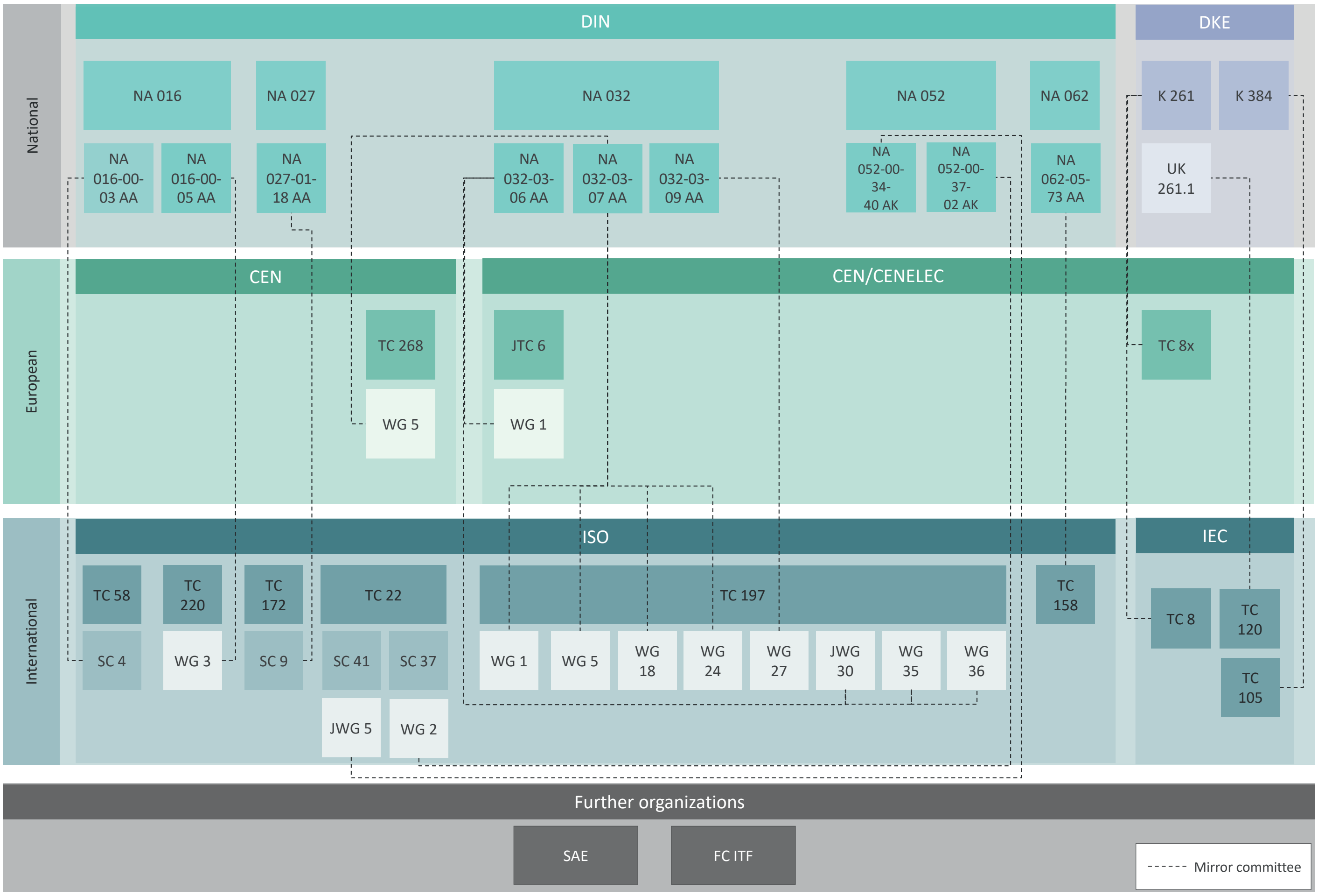

Figure 27: Overview of bodies relevant to technical rule-setting in the area of road vehicles (as of 03-2024)

(Source: own illustration)

turn could hamper progress towards the mobility transition and, in particular, lead to a considerable loss of acceptance of hydrogen as a drive technology. It is therefore essential to proactively address these challenges in order to promote the integration of hydrogen as a future-oriented form of propulsion.

4.3.11.3 Needs analysis

NEED 4.3.11-01:
Interface and procedure for emptying a hydrogen tank at a filling station

CONTENT: Emptying; hydrogen tanks; interface; protocol; boundary conditions

EXPLANATORY NOTES: There is a need for a technical rule that enables the emptying of a hydrogen tank at a refuelling station (including interface, protocol, and boundary conditions) to avoid discharging into the environment when a tank needs to be emptied for repairs or during development.

IMPLEMENTATION: The technical rule is to be developed at international level in the ISO Technical Committee TC 197 Hydrogen technologies in the working groups WG 5 Gaseous hydrogen land vehicle refuelling connection devices and WG 24 Gaseous hydrogen – Fuelling protocols for hydrogen-fuelled vehicles. The proposal for this project (New Work Item Proposal – NWIP) will have to be submitted to ISO/TC 197 via the responsible mirror committee in DIN.

NEED 4.3.11-02:
Line connections for gaseous hydrogen should be standardized in terms of geometry.

CONTENT: Line connections; geometrical

EXPLANATORY NOTES: There is a need for standardized interfaces between the lines and the components (e.g. refuelling nozzle, pressure regulator, fuel cell stack, fuel cell, tank valve) that enable replacement and modularization, such as SAE J2044 [254] in the area of fuel lines. So far, only testing and functions have been standardized. At the moment, the relevant standards (ISO/DIS 19887 [255], CSA/ANSI HGV 3.1 [256]) only describe the functional requirements and the testing of these requirements.

IMPLEMENTATION: The standard should be developed at international level in the ISO Technical Committee TC 197 – TC 22/SC 41 JWG 30. The proposal for this project (New Work Item Proposal – NWIP) will have to be submitted to ISO/TC 197 via the responsible mirror committee in DIN.

NEED 4.3.11-03:
Safety-related requirements and testing of fuel cell modules for road vehicles

CONTENT: Safety; fuel cell modules; road vehicles

EXPLANATORY NOTES: IEC 62282-2-100 [257] defines the safety-related requirements for and testing of fuel cell modules. However, road vehicles are excluded from the scope of the standard, and there is no alternative standard for this scope of application in Europe.

IMPLEMENTATION: Either the scope of IEC 62282-2-100 [257] will have to be extended or a new standard will have to be developed.

4.3.11.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.3.12 Railway vehicles

Rail transport will play a key role in achieving climate targets. The German federal government plans to double rail passenger transport by 2030 and increase the market share of rail freight transport to 25 % [258]. Alternative drive systems are a key component in achieving these goals, especially on non-electrified routes. In addition, hydrogen transportation by rail can help to ensure a nationwide supply. The WG

Railway vehicles has the task of identifying all standardization needs and the status quo for heavy rail and urban rail systems (network, rolling stock, operation) with regard to hydrogen applications.

4.3.12.1 Analysis of the status quo

The state of the art in rail vehicles with alternative drive systems has developed rapidly over the past five to six years. The body of standards and technical rules on hydrogen technologies specifically for rail vehicles is still very small. In the electrotechnical field, there are some technical rules (< 10), which were generally initiated internationally or at European level. Furthermore, standardization work in this area is still in its infancy. Frequently, reference is made to existing standards and technical rules from other sectors, particularly the automotive industry, as this is a related technology [13]. There are already extensive synergies resulting from mobile application. Rail-specific requirements must be considered specifically by the sector and form the basis for the standardization needs.

4.3.12.2 Requirements and challenges

Various manufacturing and operating companies for vehicles and filling installations, as well as maintenance companies are currently facing the challenge of working with an inadequate normative basis. New developments are largely based on risk assessments, which makes them complex, expensive and risky. These planning uncertainties also result in delays in provision. The urgent standardization proposals of the WG Railway vehicles are intended to create planning security and limit project risks in order to make hydrogen technology more attractive for the rail sector in the long term. In addition, a large number of international activities were identified. German participation is of great importance here in order to ensure national competitiveness.

Currently, 18 proposals for standardization needs are already being discussed in the WG Railway vehicles, and the list of topics continues to grow. The topics often interface with other working groups, such as fire protection, strength and hydrogen emissions. Twelve of the proposals need to be further specified in order to evaluate their implementation. Six of the proposals have already passed through the Roadmap bodies once and were presented to the Roadmap steering committee. In terms of content, all proposals were recommended for implementation. In addition, the steering committee believes that three of the projects should be approved for funding by the BMWK.

4.3.12.3 Needs analysis

NEED 4.3.12-01:
VDE/EN/IEC 63341-4 Railway applications – Rolling stock – Fuel cell systems for propulsion – Part 4: Hydrogen refuelling protocols

CONTENT: Refuelling; IT security; errors; protocols; datagrams; verification

EXPLANATORY NOTES: The refuelling process for rail vehicles can be carried out with or without communication. If communication is available, it is also used to transmit safety-related signals between the filling station and the vehicle. The prerequisite for the process is that the vehicle transmits its identifier to the filling station and transmits its readiness. In addition, the process is monitored and relevant parameters are transmitted. This document is intended to define requirements for the communication protocol, security and the approval of corresponding systems.

IMPLEMENTATION: The first step will be developing the project as a VDE pre-standard within DKE/UK 351.1 in order to obtain national consensus. Then, it should be brought into international standardization and published as Part 4 of the IEC 63341 [259] standards series.

NEED 4.3.12-02:
DIN EN ISO 17268-4 Gaseous hydrogen rail vehicle refuelling connection devices

CONTENT: Connection; coupling; flow rate; test criteria; interface

Railway vehicles

EXPLANATORY NOTES: Requirements for connection devices for refuelling with hydrogen are specified in the DIN EN ISO 17268 [260] series of standards. This new document is intended to specify a coupling with a very high flow rate specifically for rail vehicles, which is already being used in practice. In addition, deviating requirements and test criteria for use in rail transport are to be identified in relation to DIN EN ISO 17268 [260]. The interface between the vehicle and the refuelling system and protection against unauthorized access should also be considered.

IMPLEMENTATION: A discussion at European and international level has led to the proposal to extend DIN EN ISO 17268 [260] to include a part specifically for rail vehicles. German participation in the ISO body should be ensured, and the project will be mirrored in the national body NA 087-00-21 GA Joint working committee FSF/NAGas: Hydrogen technologies for rail vehicles.

NEED 4.3.12-03:
ISO 19881-2 Gaseous hydrogen – Land vehicle fuel containers – Part 2: Railway vehicles

CONTENT: Fuel containers; pressurized gas containers; service life; maintenance

EXPLANATORY NOTES: Requirements for hydrogen pressurized gas containers for land vehicles are specified in ISO 19881 [261]. In future, the contents of ECE R134 [262] will also be included in that standard. As both documents are designed to meet the requirements of the automotive industry, a new document is also to be drawn up that specifies deviating requirements and special features for the design, service life, maintenance and control of potential damage events specifically for large, permanently installed containers on rail vehicles.

IMPLEMENTATION: A discussion at international level has led to the proposal to extend ISO 19881 [261] to include a part specifically for rail vehicles. German participation in the ISO body should be ensured, and the project will be mirrored in the national body NA 087-00-21 GA Joint working committee FSF/NAGas: Hydrogen technologies for rail vehicles.

NEED 4.3.12-04:
ISO 19887-2 Gaseous hydrogen – Fuel system components for hydrogen fuelled vehicles – Part 2: Railway vehicles

CONTENT: Fuel systems; components; service life; maintenance

EXPLANATORY NOTES: ISO/DIS 19887 [255] is currently being developed and specifies requirements for gas-carrying fuel system components for the operation of land vehicles with hydrogen. Rail-specific requirement criteria have not yet been taken into account. A new document is to be drawn up that defines deviating requirements, special features for the design, service life, maintenance and control of potential damage events, as well as any electrical requirements with regard to EMC, insulation resistance and earthing specifically for railway applications.

IMPLEMENTATION: A discussion at international level has led to the proposal to extend ISO/DIS 19887 [255] to include a part specifically for rail vehicles. German participation in the ISO body should be ensured, and the project will be mirrored in the national body NA 087-00-21 GA Joint working committee FSF/NAGas: Hydrogen technologies for rail vehicles.

NEED 4.3.12-05:
DIN Standard “Railway applications – Acceptance criteria for leak tests on permanently installed hydrogen systems of railway vehicles – Test requirements and acceptance criteria

CONTENT: Leak test; acceptance criteria; test methods

EXPLANATORY NOTES: In practice, existing methods for leak testing lead to disproportionate corrective measures due to unspecific test criteria. This new document is intended to derive practical acceptance criteria for the commissioning and testing of permanently installed hydrogen systems from recognized leak test methods. For this purpose, the release quantities at joints and surfaces, as well as the different visual and measured characteristics of the release are to be investigated, and generic acceptance criteria and test rules are to be defined.

IMPLEMENTATION: The project requires further research in parallel. Criteria and methods are to be derived from the results, which will be summarized in a DIN Standard. The project will be developed in the national body NA 087-00-21 GA Joint working committee FSF/NAGas: Hydrogen technologies for rail vehicles.

NEED 4.3.12-06:
DIN Standard Railway applications – Alternative detection methods for thermal pressure relief devices of hydrogen storage systems for rail vehicles

CONTENT: Thermal pressure relief devices (TPRD); Detection methods

EXPLANATORY NOTES: Gas pressure vessels must be equipped with pressure relief valves (TPRDs for short) to protect them from bursting in the event of a fire. Existing detection methods are based on the track width of passenger cars. The existing methods are not directly applicable to the rail sector due to particularly long containers and lead to a large number of TPRDs. The new document is intended to define a railway-specific detection method for thermal pressure relief devices of hydrogen storage systems.

IMPLEMENTATION: The project requires further research. Methods are to be derived from the results, which will be summarized in a DIN Standard. The project will be developed in the national body NA 087-00-21 GA Joint working committee FSF/NAGas: Hydrogen technologies for rail vehicles. Later, the document should be developed into a European Standard.

4.3.12.4 Implementation projects

To develop the planned implementation projects from the Standardization Roadmap Hydrogen Technologies that have been approved for funding:

→ DIN EN ISO 17268-4 Gaseous hydrogen rail vehicle refuelling connection devices
→ ISO 19887-2 Gaseous hydrogen – Fuel system components for hydrogen fuelled vehicles – Part 2: Railway vehicles

and any other future projects on the subject of hydrogen technologies for railway vehicles, the national body NA 087-00-21 GA Joint working committee FSF/NAGas: Hydrogen technologies for rail vehicles has been founded, which will be led by DIN Standards Committee Railway (FSF) and DIN Standards Committee Gas Technology (NAGas). Electrotechnical subjects will be dealt with in DKE body DKE/UK 351.1 Vehicles. These include the implementation project VDE/EN/IEC 63341-4 Railway applications – Rolling stock – Fuel cell systems for propulsion – Part 4: Hydrogen refuelling protocols.

4.3.13 Shipping

The remit of WG Shipping covers the development of the Standardization Roadmap Hydrogen Technologies in the area of shipping and marine technology. This includes all areas of application for hydrogen associated with shipping and marine technology, including its transportation by ship, use for propulsion and bunkering. The interfaces to the relevant working groups are of particular importance here. These are, in particular, WG Stationary and mobile pressure vessels and WG Filling systems.

4.3.13.1 Analysis of the status quo

In the analysis of the status quo, WG Shipping identified 30 documents. These are divided into DIN, EN and ISO Standards on the one hand, and shipping-related technical rules for inland and maritime shipping on the other hand [13]. The former primarily address special land- and sea-based applications, citing a generally applicable standard on safety requirements (ISO/TR 15916 [263]). In inland navigation, the European Committee for Drawing Up Standards in the Field of Inland Navigation (CESNI) [264] is responsible for the technical rules. This is where the technical rules (ES-TRIN, European Standard laying down Technical Requirements for Inland Navigation Vessels) are drawn up. The technical rules for maritime shipping are drawn up and adopted by the International Maritime Organization (IMO) [266].

Shipping

In both organizations, existing codes are reviewed, supplemented and further developed for the extension of hydrogen (gaseous, liquid) and its derivatives for use as a fuel. Among other things, gap analyses on fossil-based fuels are used for this purpose. Interim guidelines will be published until the technical rules are finalized. The stowage of hydrogen and its derivatives as cargo is covered by international conventions (SOLAS [267]) and Codes of the IMO (IBC [268], IGC [269] and IMDG Codes [270]) with regard to technical manageability and safety requirements. Here safety aspects are top priority. The use of alternative fuels in maritime shipping is regulated in the IGF Code [271]. Existing ISO standards are referenced in the conventions and codes, classification-specific technical rules, working documents, guidelines and transitional documents.

Figure 28 presents the identified bodies that are important for the development of technical rules in the field of shipping. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.3.13.2 Requirements and challenges

The development of hydrogen-related standards and guidelines for the shipping sector is based on existing fossil gaseous or liquid energy carriers (e.g. CNG, LNG), e.g. through gap analyses. The physical properties typical of hydrogen and different storage conditions (e.g. pressure, temperature) result in substance-specific behavioral characteristics. This is evident, for example, in release scenarios of gaseous hydrogen

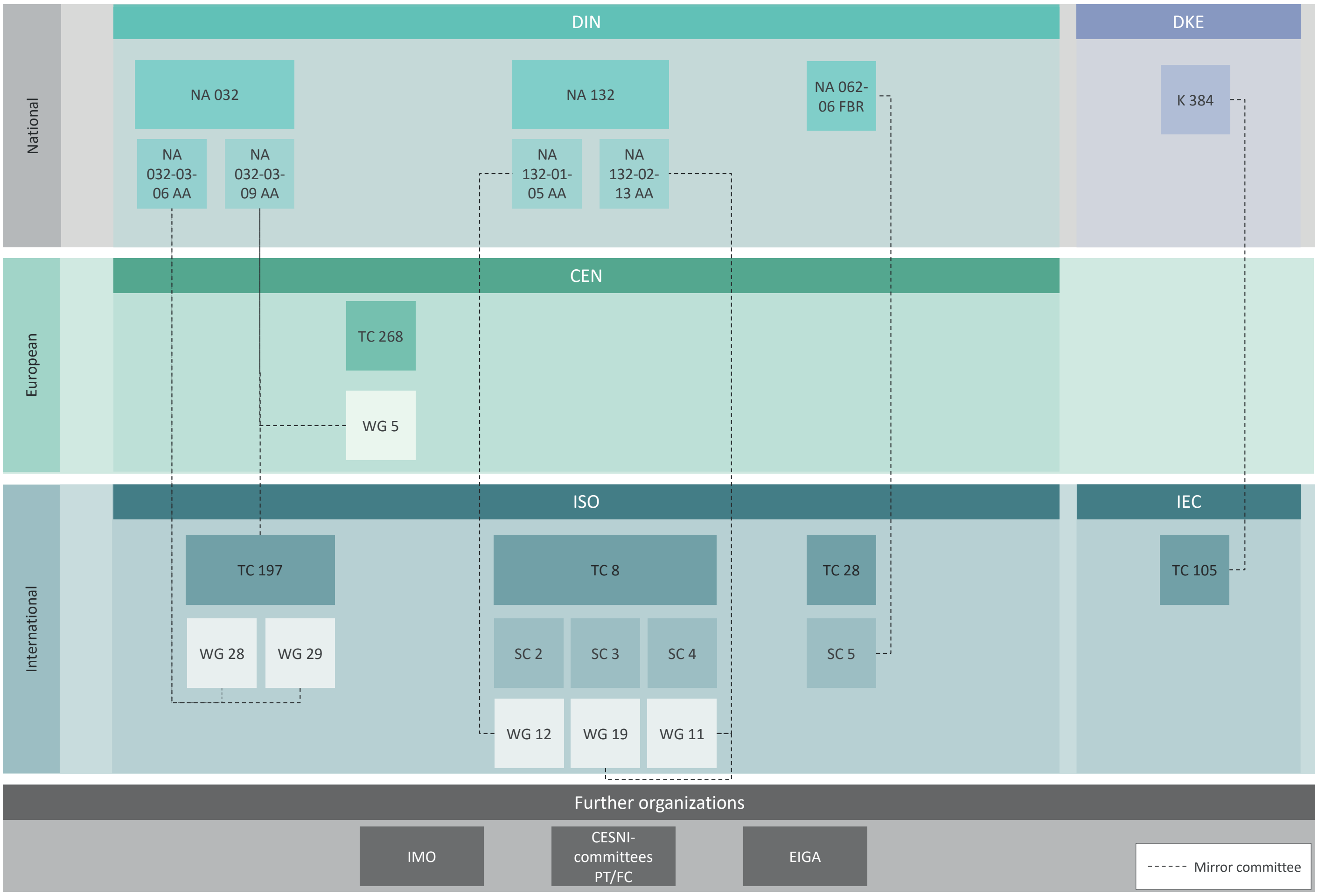

Figure 28: Overview of bodies relevant to technical rule-setting in the area of shipping (as of 03-2024) (Source: own illustration)

above and below deck in the event of a controlled discharge or an accident/collision. Risk analyses, for example supported by the use of simulation software, can be used to define hazardous areas/zones and derive structural safety measures. Uniform standards and technical rules make it possible for testing institutes to provide uniform certification; thus, there is a need for the development of standards and technical rules. The findings from the development of standards and technical rules for hydrogen can be used for the development of standards and technical rules for hydrogen derivatives or other hydrogen-binding media. In summary, there is a need to develop standards and technical rules for alternative fuels, for example on the basis of risk analyses.

4.3.13.3 Needs analysis

The following topics were identified as part of the needs analysis and are to be fleshed out during further development:

NEED 4.3.13-01:
Storage type-specific standardization for maritime hydrogen storage systems

CONTENT: Storage systems; gaseous; liquid; carrier materials; danger zones

EXPLANATORY NOTES: Many of the currently applicable hydrogen-related standards and guidelines were originally developed for CNG and LNG. Therefore, special properties of hydrogen (e.g. different dispersion and flame behavior than CNG and LNG) are often disregarded. Gaseous or liquid hydrogen storage or in liquid or solid hydrogen carrier materials have completely different ways of releasing hydrogen. This leads, for example, to unrealistic hazardous zones around gas inlets and outlets. Research projects should identify realistic danger scenarios and derive corresponding standards for storage systems.

IMPLEMENTATION: Simulative and experimental realistic dispersion scenarios for hydrogen above and below deck must be investigated and corresponding rules and standards developed.

NEED 4.3.13-02:
Couplings for bunkering hydrogen

CONTENT: Coupling; mass flow rate; fuel system

EXPLANATORY NOTES: A standard for couplings for bunkering hydrogen (liquid, gaseous, derivatives) based on existing standards such as ISO 13984 [168], DIN EN 13371 [89] and DIN EN ISO 21593 [272] is needed. However, a special focus must be placed on the challenges of maritime use, such as high flow rates, ship movement and a saline atmosphere. A detachable connection is required for filling cryostats with liquid hydrogen. Although couplings for cryogenic operation are described in EN 13371 [89], this description is very general. For the ramp-up of the hydrogen economy, it would be more than desirable if the connections were standardized. A distinction must be made here between the different applications or systems to be filled (lorry/ship/airplane/train), as different mass flows are useful for filling.

IMPLEMENTATION: Due to the international nature of shipping, implementation is ideally recommended at international level (ISO), or at least at European level (EN).

NEED 4.3.13-03:
Transport locks for mobile storage containers

CONTENT: MEGC; cylinder racks; mobile storage containers

EXPLANATORY NOTES: Interchangeable storage tanks for hydrogen-based fuels require on-board structural measures for safe storage, transportation and logistics. Interchangeable mobile fuel containers, such as standardized cylinder racks and multiple element gas containers (MEGC) for compressed gaseous hydrogen, require safe integration into the ship's structure, e.g. during ship movements. The aim is to ensure a reliable fuel supply through constructional and structural measures.

IMPLEMENTATION: Due to the international nature of shipping, implementation is ideally recommended at international level (ISO), or at least at European level (EN). In addition, the development of a standardized container exchange system similar to the deposit system, e.g. for civil LPG cylinders, is recommended as a practical solution.

NEED 4.3.13-04:
Harmonization of notations for fuel-readiness

CONTENT: Harmonization; fuel-readiness

EXPLANATORY NOTES: Testing institutes, such as classification societies in the maritime sector, certify a fuel-ready notation for new and existing ships [273]. The certification of fuel readiness for alternative fuels depends on the company-specific regulations. Efforts should be made to harmonize the assessment base for different types of hydrogen storage and use.

IMPLEMENTATION: Due to the international nature of shipping, implementation is ideally recommended at international level (ISO), or at least at European level (EN).

NEED 4.3.13-05:
Specification of fuel quality incl. admixtures

CONTENT: Fuel quality

EXPLANATORY NOTES: As with fossil fuels, there is a need for specifications for alternative fuels, including admixtures. It must be possible to store fuels of a minimum quality regardless of location, thus enabling smooth use in on-board energy conversion. The publication of ISO/FDIS 8217:2024-02 [274], which is currently being revised, should be reviewed for this purpose.

IMPLEMENTATION: ISO Standards are being developed for alternative fuels. Fuel producing companies are responsible for production in line with requirements. Competent authorities and certification bodies are responsible for quality control.

4.3.13.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.3.14 Aviation

WG Aviation is responsible for determining the standardization needs in the aviation sector. The focus here is on the system structure within the aircraft, i.e. in particular the handling and use of hydrogen within the aircraft, along the chain: Filler nozzle, feed to the tank, storage in the tank, distribution to the consumers, conversion in the consumer, recirculation, discharge, residues and removal from the tank (defueling). Hydrogen is considered in both its gaseous and its liquid form.

4.3.14.1 Analysis of the status quo

The scope of aviation-specific rule-setting is currently still very limited. At present there are nine documents (European Standards, International Standards, Codes of Practice) [13].

Figure 29 presents the identified bodies that are important for the development of technical rules in the field of aviation. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.3.14.2 Requirements and challenges

As there are currently hardly any standards and technical rules for this sector, there is a need for standardization in several areas, such as refuelling, test methods and cleanliness. There are many standards for the operation or use of kerosene, but there are no equivalent standards for hydrogen. The use of hydrogen in aviation is something new. In order to increase people’s confidence in the new technology, it is important to show that a similar basis has been created as for gasoline or kerosene, and that corresponding safety is therefore guaranteed. For example, the filler nozzles need to be standardized, as attaching an adapter to the aircraft can be very difficult. Clear refuelling protocols in turn ensure the necessary safety during the refuelling process (apron and passengers). Standardized test methods simplify the comparison and guarantee the quality of the results. At present, it is still too early for concrete broad-based standardization or rule-setting. For this reason, some areas should initially be excluded from technical rule-setting. These areas are liquid

Aviation

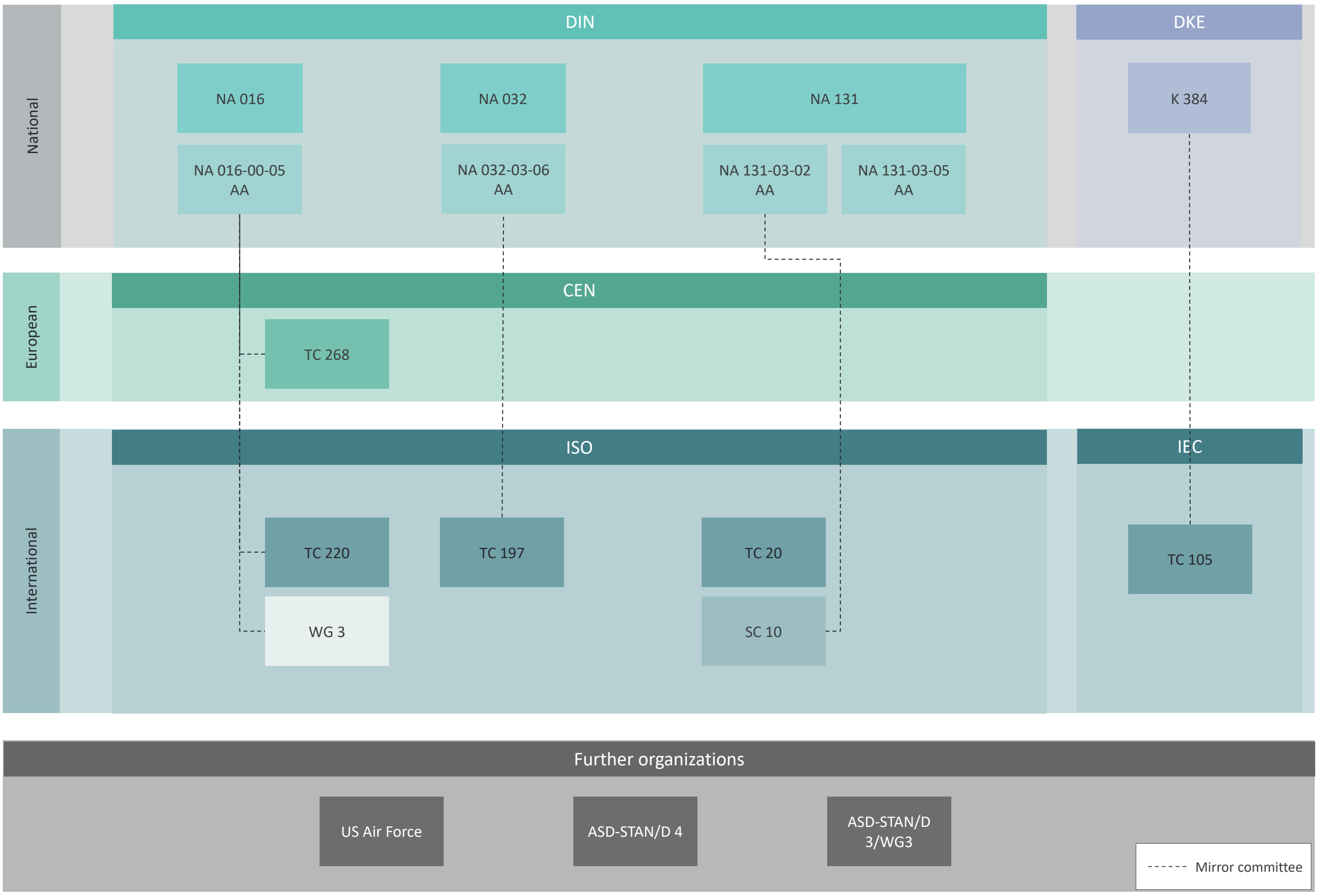

Figure 29: Overview of bodies relevant to technical rule-setting in the area of aviation (as of 03-2024) (Source: own illustration)

hydrogen tanks (highly customized, probably developed by OEMs), piping, valves, sensors, etc.

4.3.14.3 Needs analysis

No concrete implementation projects have yet been formulated. The following topics were identified as part of the needs analysis and are to be fleshed out during further development:

NEED 4.3.14-01:
Filler nozzles (gaseous and liquid)

CONTENT: Specification connections filler nozzles; aircraft

EXPLANATORY NOTES: As explained in 4.3.14.2 standardized filler nozzles are necessary to guarantee refuelling at airports around the world [260].

IMPLEMENTATION: Due to the international nature of aviation, implementation is ideally recommended at international level (ISO), or at least at European level (EN).

NEED 4.3.14-02:
System behavior / refuelling protocol

CONTENT: Refuelling/defuelling process; safety measures; fuel safety zones

EXPLANATORY NOTES: Currently, the aviation legal basis for the refuelling process is regulated by ED Decision 2014/012/R of the EU (EASA – European Union Aviation Safety Agency), but there is currently no regulation of hydrogen [275]. The IATA (International Air Transport Association) also has "Guidance Material" on refuelling protocols. Here there is also nothing on the subject of hydrogen [276]. The same picture can be seen with the JIG (Joint Inspection Group), which carries out on-site audits at airports [277]. There are already standards in this area for the automotive industry: ISO 19880-1 [278] and ISO/DIS 19885-1 [279].

IMPLEMENTATION: Contact will have to be made with the ADV (German Airports Association) [280]. In principle, implementation is also conceivable in the form of a collection of relevant standards (such as the AD 2000 Code) [281]. The very important documents SAE ARP 4754 B [282] and SAE ARP 4761 A [283] must serve as the basis for the new technical rule. Existing explosion protection standards should also be observed.

NEED 4.3.14-03:
Leak test/permeability determination

CONTENT: Leak test; components; material systems

EXPLANATORY NOTES: Standardized methods for leak testing enable a quantitative and qualitative comparison of components.

IMPLEMENTATION: Due to the international nature of aviation, implementation is ideally recommended at international level (ISO), or at least at European level (EN).

NEED 4.3.14-04:
Fire protection and lightning protection testing

CONTENT: Environmental conditions; test methods; on-board equipment; fire resistance in fire hazard zones

EXPLANATORY NOTES: Specification of test conditions for all components, devices and structures installed in "fire zones" [284], [285].

IMPLEMENTATION: Discussion with OEMs and test laboratories that already carry out such tests.

NEED 4.3.14-05:
Cleanliness of lines (inside and outside)

CONTENT: Cleanliness; lines; cleaning process

EXPLANATORY NOTES: It is necessary to define standardized purity classes for the lines operating with hydrogen (gaseous and liquid). The cleanliness classes of oxygen are also relevant for standardization; a uniform process for cleaning would be useful [54].

IMPLEMENTATION: Due to the international nature of aviation, implementation is ideally recommended at international level (ISO), or at least at European level (EN).

Cross-cutting topics

There are overlaps with WC Production with regard to the grade of purity of hydrogen mentioned in ISO 14687 [54]. Grade D should not only apply to rail vehicles, as this is also of interest for fuel cells in aviation. There is also a need for coordination with WG Special vehicles regarding the definition of a technical rule for certain mass flows of couplings during the refuelling of aircraft, preferably at European level.

4.3.14.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.3.15 Special vehicles

In the future, hydrogen will not only be used in conventional means of transportation, but also in special vehicles such as mining vehicles and industrial trucks. Typically, these vehicles are subject to special conditions due to their area of application, such as use in airports, warehouses, open-cast mines, underground, tunnel construction, at other construction sites and in the agricultural sector. WG Special vehicles is dedicated to the question of how the use of hydrogen in special vehicles can be made safe and reliable through standards and technical rules, and which changes to the existing portfolio of technical rules are needed. To this end, the various technologies (electric drive with fuel cell, combustion engine) and framework conditions can be described and standards and technical rules can be aligned accordingly. This should also include tank interfaces that go beyond the pure refuelling connection, e.g. data communication (wireless or wired), water drainage. These standardization potentials are to be recorded and documented.

4.3.15.1 Analysis of the status quo

As part of the analysis of the status quo, 124 standards and technical rules were reviewed for the WG Special vehicles and classified as relevant to the topic. These were exclusively European or international documents. National standards and technical rules were not identified. Standards, technical specifications and technical rules are mainly relevant to the topic of special vehicles. About 65 % of the identified standards and technical rules are DIN EN ISO, DIN EN IEC or ISO Standards. Nearly 25 % of the standards and technical rules are currently at draft stage. The identified titles can be seen in the Standards Database for Hydrogen Technologies [13].

4.3.15.2 Requirements and challenges

Identifying needs is a key challenge that has not yet been fully resolved. This difficulty is due to various factors, including the lack of clarity in political provisions and the uncertainty and complexity of the market. Of particular relevance here is the market's interest in hydrogen solutions, which also influences the identification and prioritization of needs.

4.3.15.3 Needs analysis

The WG is still working on concrete needs. The requirements and challenges mentioned above make it difficult to identify needs. The specified needs will be published in the second version of this Standardization Roadmap Hydrogen Technologies at the end of 2025. However, there was a discussion about drawing up a European technical rule on the subject of hydrogen mass flows for couplings in aircraft refuelling. This technical rule is necessary because there is always a dead volume flow when connecting the coupling between the aircraft and the refuelling system, which can lead to minor explosions or even icing. There was also a discussion about harmonizing the approval process for road vehicles in accordance with UN ECE R-134 [262] for classes N and M with the approval process for special vehicles.

4.3.15.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.4 Quality infrastructure

Working committee Quality infrastructure deals with the aspects of analysis, measurement technology, safety, service life and reliability, and thus mainly with basic standards that can be referenced by other working committee s. These include the area of gas analysis and the area of hydrogen meters and other measurement technologies. Also included are test methods for determining characteristic values under the influence of hydrogen, and media in the environment of hydrogen technologies, as well as the selection of materials and the design of components for use in contact with hydrogen. The detection of hydrogen leakage is also being dealt with.

4.4.1 Gas analysis

WG Gas analysis deals with issues relating to the chemical composition of hydrogen-containing gas mixtures, high purity hydrogen and hydrogen of highest purity throughout the analytical process. This includes, in particular, method selection, sampling, qualification of measurement devices and analysis technology, production and use of calibration gases, measurement and data treatment strategy, conversion and documentation as well as quality assurance.

4.4.1.1 Analysis of the status quo

Initially, around 80 standards and technical rules were identified, of which about 50 standards and technical rules relating to the analysis of hydrogen were identified following a critical review by the WG. There are already comprehensive standards and technical rules for the analysis of high purity hydrogen and hydrogen of highest purity and mixtures containing hydrogen, some of which are based on long-established and proven standards for the analysis of high purity gases and gas mixtures. In the last ten years in particular, standards on analysis have been added in connection with fuel cell applications in road vehicles. The majority of standards and technical rules comprise DIN, DIN EN, DIN EN ISO or ISO Standards, as well as ASTM standards and DVGW technical rules. In addition, some PTB technical guidelines were identified [13].

Figure 30 presents the identified bodies that are important for the development of technical rules in the field of gas analysis. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.4.1.2 Requirements and challenges

Many standards and technical rules in the field of gas analysis are generic in nature and do not need to be adapted or need only be slightly expanded. There are gaps for standards that specifically target the analysis of hydrogen. Specification standards do exist for the use of very pure hydrogen in particular. For these specification standards, there are hardly any corresponding process standards available for laboratory analysis, let alone for online analysis. The results of research projects are necessary for the development of these process standards. If it is not possible to close this gap in the missing process standards, the defined specifications cannot be properly verified by measurement, which will slow down or even prevent the market ramp-up of hydrogen technology. The corresponding pre-normative research can hardly be carried out in the standardization bodies due to the breadth and effort involved. There is also a lack of process standards especially in the area of calibration for measuring devices

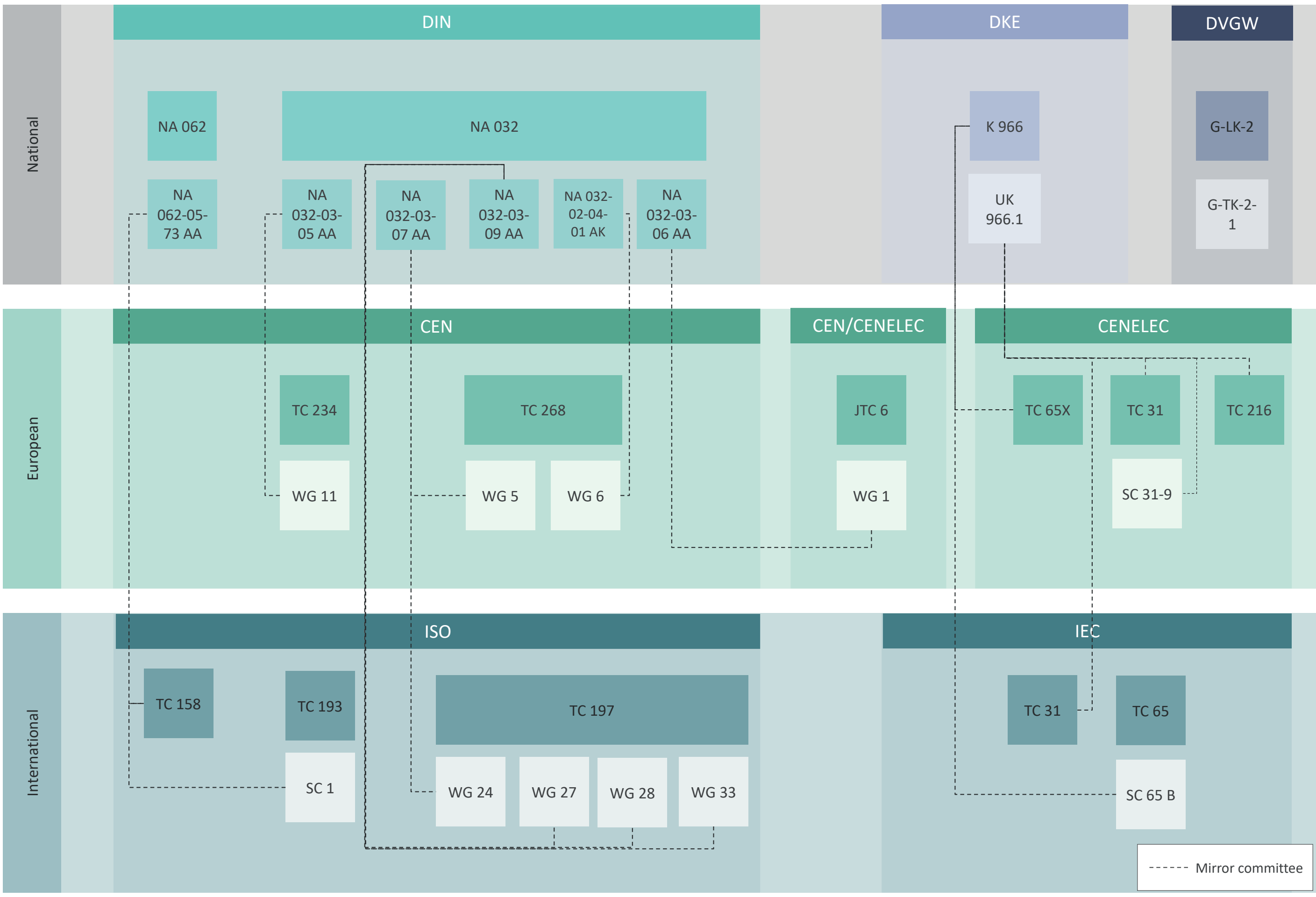

Figure 30: Overview of bodies relevant to technical rule-setting in the area of gas analysis (as of 03-2024)

(Source: own illustration)

for hydrogen analysis, as well as rules and process standards for testing laboratories in legal metrology. In addition, the major challenge is to specify practicable field and laboratory deployable measurement requirements and to ensure the cost-effectiveness of the gas analysis to be used. Economically scalable systems are required for the successful market ramp-up of hydrogen technology.

4.4.1.3 Needs analysis

NEED 4.4.1-01:
Extension along the lines of ISO 21087:2019-06, Gas analysis – Analytical methods for hydrogen fuel – Proton exchange membrane (PEM) fuel cell applications for road vehicles [66]

CONTENT: Methods; trace analysis; references; laboratory analysis

EXPLANATORY NOTES: In addition to slow and time-consuming laboratory analysis, fast and simple online analysis is also required. Even more than laboratory analysis, online analysis for hydrogen of highest purity is the subject of pre-normative research.

IMPLEMENTATION: It would be sensible to wait until the end of 2025 for the results of pre-normative research, such as those being developed in the BMVI project (Federal Ministry for Digital and Transport) RingWaBe [286]. Thereafter, the extension of ISO 21087 or a separate document should be discussed. ISO 21087 is developed in ISO/TC 158 Analysis of gases, the national mirror body of which is DIN working committee NA 062-05-73 AA Gas analysis and gas quality.

4.4.1.4 Implementation projects

To date, no implementation projects have been proposed by the WGfor financial support by the BMWK.

4.4.2 Hydrogen measurement technology and billing methods

WG Hydrogen measurement technology and billing methods deals with the hydrogen suitability of different types of gas meters used, various methods for the metering procedure, and the conversion for the verification and calibration of meters in the domestic, commercial and industrial sectors. Furthermore, component devices (e.g. volume correctors) and additional equipment for hydrogen-containing gases up to 100 % hydrogen are considered. Billing procedures must also be adapted to the new circumstances of the hydrogen transformation.

4.4.2.1 Analysis of the status quo

A total of 18 documents have been identified in the published Standards Database for Hydrogen Technologies [13]. 13 of these documents have been published. The remaining documents are currently being revised and are either available as a draft or as a preliminary working document. The requirements for metering and the procedure for determining and billing energy from gases (or hydrogen) at all entry and exit points are largely H_2-ready. Some technical rules on topics such as the billing of pure hydrogen in hydrogen networks will be published in the near future. The H_2-readiness of the measurement technology and billing is a long-term project. There are many different research projects covering this topic and the results can be incorporated into DVGW technical rules as well as national, European and International Standards [287], [288], [289], [290].

The first revisions of the product standards on meters with regard to hydrogen are in the planning stage or have already begun. The revision of a product standard with maximum technology sensitivity is seen as a kind of “pilot standard” in this respect. Accordingly, the results will be subsequently incorporated into the other product standards. Due to a lack of technical rules, there are currently almost no volumetric measuring devices on the market with a type examination certificate for the measurement of pure hydrogen. H_2-readiness is currently achieved mainly through declarations by manufacturers. However, there is a DVGW information document that describes the current state of the art for hydrogen measurement for various types of measuring devices [291].

In addition to the technical rules, the statutory regulations, such as the German Measurement and Calibration Act, the German Measurement and Calibration Ordinance and the European Measuring Instruments Directive, must also be complied with. There are currently various PTB technical guidelines and various test instructions that have been or are being revised with regard to hydrogen.

Figure 31 presents the identified bodies that are important for the development of technical rules in the field of hydrogen measurement technology and billing methods. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.4.2.2 Requirements and challenges

The integration of hydrogen into the gas grid represents a challenge that requires extensive adjustments to existing standards and technical rules. The adaptations range from the measuring devices and additional equipment involved to basic safety aspects and specific billing procedures. In terms of safety, it is essential to take into account corrosion risks in accordance with DIN EN 1776 [292] in order to ensure the integrity of the gas infrastructure with varying hydrogen concentrations. Targeted adaptation of the materials and components to the physical and chemical properties of hydrogen is crucial for their longevity and reliability.

In measurement technology, the focus is on precision. Specifications and directives such as PTB-A 7.4 [293], PTB-TR G 9 [294], PTB-TR 29 [295] as well as the Measuring Instruments Directive (MID) [296], and the harmonized standards developed by CEN/TC 237 focus on the approval, placing on the market, installation and operation of volume correctors and gas meters. Careful adaptation and validation of these measuring devices for use in hydrogen-containing environments is essential in order to guarantee accurate consumption measurement. This ensures that the measurement accuracy is maintained even with fluctuating gas compositions. To ensure correct billing, DVGW technical rule – code of practice G 685 [297] provides the necessary guidelines for reliable energy determination even where not all measured values are available. The focus is on determining the k-number and the billing calorific value. These guidelines therefore make a decisive contribution to the acceptance and efficiency of hydrogen

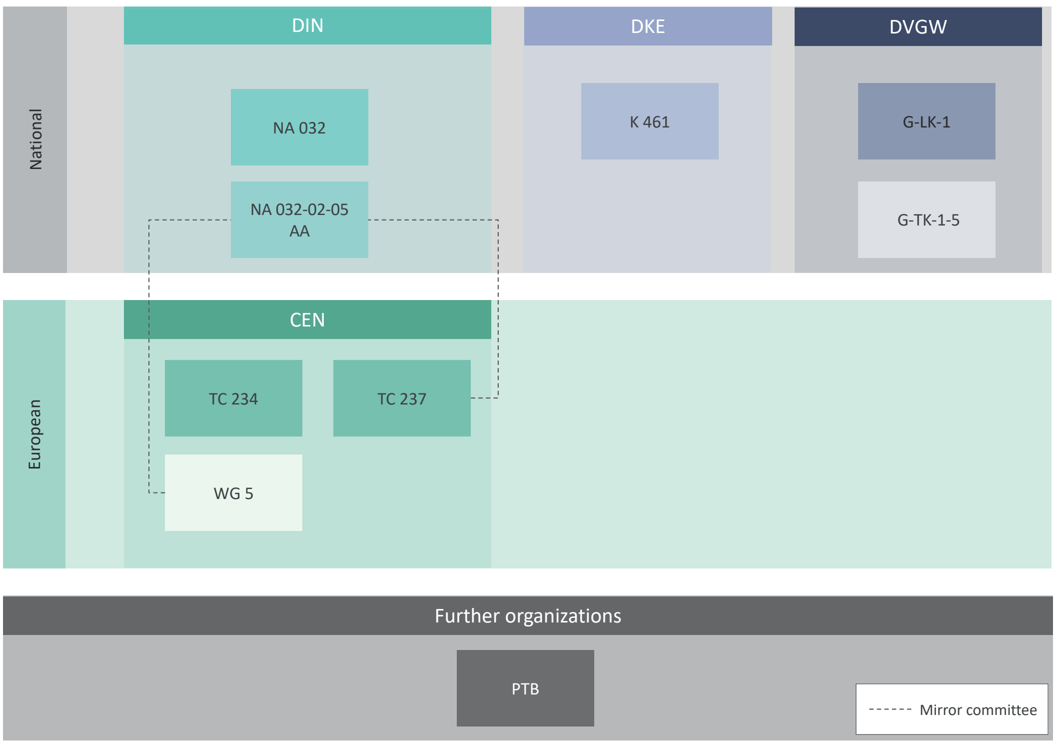

Figure 31: Overview of bodies relevant to technical rule-setting in the area of hydrogen measurement technology and billing methods (as of 03-2024) (Source: own illustration)

integration. These normative adjustments are essential for the safe, precise and efficient integration of hydrogen into the gas grid and thus will make an important contribution to the energy transition.

4.4.2.3 Needs analysis

There are 11 needs relating to the adaptation of the gas infrastructure to hydrogen with regard to metering technology and billing procedures. Of these, seven needs have already been specified so that corresponding recommendations for action could be made. Five needs were summarized in Need 4.4.2-01, all of which relate to the review and adaptation of the Measuring Instruments Directive (MID) [296] and harmonized standards for various meter types. It is also necessary to check the additional functions of domestic gas meters and to adapt converters. To this end, two needs are combined in Need 4.4.2-02.

NEED 4.4.2-01:
Gas meters (DIN EN 1359, Gas meters – Diaphragm gas meters [298], DIN EN 12480, Gas meters – Rotary displacement gas meters [299], DIN EN 12261, Gas meters – Turbine gas meters [300], DIN EN 14236, Ultrasonic domestic gas meters [301], DIN EN 17526, Gas meters – Thermal-mass flow-meter-based gas meters [302])

CONTENT: Thermal-mass flow-meter-based gas meters; diaphragm gas meters; rotary displacement gas meters; turbine gas meters; ultrasonic domestic gas meters

EXPLANATORY NOTES: The various types of meters used in Germany and Europe, both domestically and in industry, may have to meet special standards for converting the gas grid to hydrogen. This needs to be examined and included in the technical rules. At European level, the standard for thermal-mass flow-meter-based gas meters has been identified as a pilot standard, and its revision has begun. The results will be subsequently incorporated into the other product standards. The WG proposes that DIN EN 1359 [298] be defined as a pilot standard for measuring devices.

IMPLEMENTATION: The revision is being carried out in CEN/TC 237. The work is being mirrored at national level in DIN working committee NA 032-02-05 AA Gas measuring.

NEED 4.4.2-02:
Standards series DIN EN 12405, Gas meters – Conversion devices [303], DIN EN 16314, Gas meters – Additional functionalities [304]

CONTENT: Gas meter conversion devices; gas meter additional functionalities

EXPLANATORY NOTES: In line with the revision of the documents on gas meters, the technical rules for conversion devices and additional functionalities must also be adapted to hydrogen.

IMPLEMENTATION: The revision is being carried out in CEN/TC 237. The work is being mirrored at national level in DIN working committee NA 032-02-05 AA Gas measuring.

4.4.2.4 Implementation projects

Financial support for the revision of DIN EN 1359, Gas meters – Diaphragm gas meters [298] has been approved.

This European Standard specifies the requirements and tests for the construction, operation, safety and manufacture of diaphragm gas meters of accuracy class 1,5 with coaxial single or double nozzle connections for volume measurement of fuel gases of the first, second and third family according to EN 437:2003+A1:2009 [210] at maximum operating pressures up to 0,5 bar and a maximum flow rate up to 160 m^3/h. Due to the great importance of diaphragm gas meters for German and European households, trade and industry, adaptation to hydrogen is necessary. The WG proposes that DIN EN 1359 [305] be defined as a pilot standard for measuring devices. In Germany, there are new results on the hydrogen suitability of new diaphragm gas meters, which are to be incorporated into this standard. The first type examination certificates for diaphragm gas meters for hydrogen have been issued based on the results of the research project.

4.4.3 Metallic materials

WG Metallic materials deals with test methods for determining material characteristics under the influence of gaseous and liquid hydrogen[7] on metallic materials. Corrosion phenomena and leaks caused by the effects of hydrogen are also taken into account, as are coatings that counteract the diffusion of hydrogen. The focus is on product-unspecific mechanical material characterization. This includes the measurement of hydrogen content in the metal, the definition of test media and test methods for determining mechanical material characteristics, such as tensile testing. Product-specific needs are dealt with in WC Production, WC Infrastructure and WC Application.

4.4.3.1 Analysis of the status quo

Within the framework of this Roadmap, it was determined that many of the available standards were not developed with regard to the testing of hydrogen-loaded metal or in a hydrogen atmosphere and would therefore have to be adapted [13]. Standardization work still needs to be carried out, particularly in the area of measuring the hydrogen content and defining the test media. There is therefore not only a need to revise existing standards and technical rules, but also to close identified gaps by means of new projects. For example, international work is being carried out on a standard for hydrogen-filled hollow tensile specimens, in which German experts are actively involved. For specific examples, please refer to the needs below.

4.4.3.2 Requirements and challenges

Standards and technical rules are needed to ensure the comparability of measurement results. For this purpose, test methods must be defined, whereby a distinction must be made between test methods for specific components and test methods for various materials. There are currently many test standards in which the requirements for hydrogen are not yet specified. Standards relating to hydrogen embrittlement have been established in the USA and Canada (ASME B31.12 [77] and CSA CHMC 1-2014 [306]). However, there are no comparable technical rules in Europe. Many experts in WG Metallic Materials consider the permeation properties of metals with and without coatings to be essential for component design and the design process in order to ensure safe use and operation. The permeation from the gas phase is considered and not that from the electrolytic charge. The development of a standard for measuring the permeability of plastics and metals was proposed. This standard should be suitable for testing barrier layers. In order to draft such a standard, the required test method must be validated in advance by means of interlaboratory tests.

One challenge is to develop needs that affect several WGs. For example, this WG identified the need to standardize small product shapes such as tubes with thin walls. The current DVGW technical rule only considers large transmission pipelines/long-distance gas pipelines in the range > 16 bar. However, thin tubes with small diameters (precision tubes) are also of interest for mobile applications. The proposed new standard will make it possible to produce high-quality tubes at low cost. WG Piping has been informed as regards the next steps to be taken.

Figure 32 presents the identified bodies that are important for the development of technical rules in the field of metallic materials. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.4.3.3 Needs analysis

NEED 4.4.3-01:
Tensile test (slow tensile tests, SSRT tests) under compressed hydrogen

CONTENT: Tensile test; SSRT tests

EXPLANATORY NOTES: In Germany, there are currently no valid technical rules for tensile tests under compressed hydrogen. At present, use is made of the US standards ASTM G129

7 The definition of the ambient atmosphere (composition of the hydrogen atmosphere) is specified in technical rules.

Metallic materials

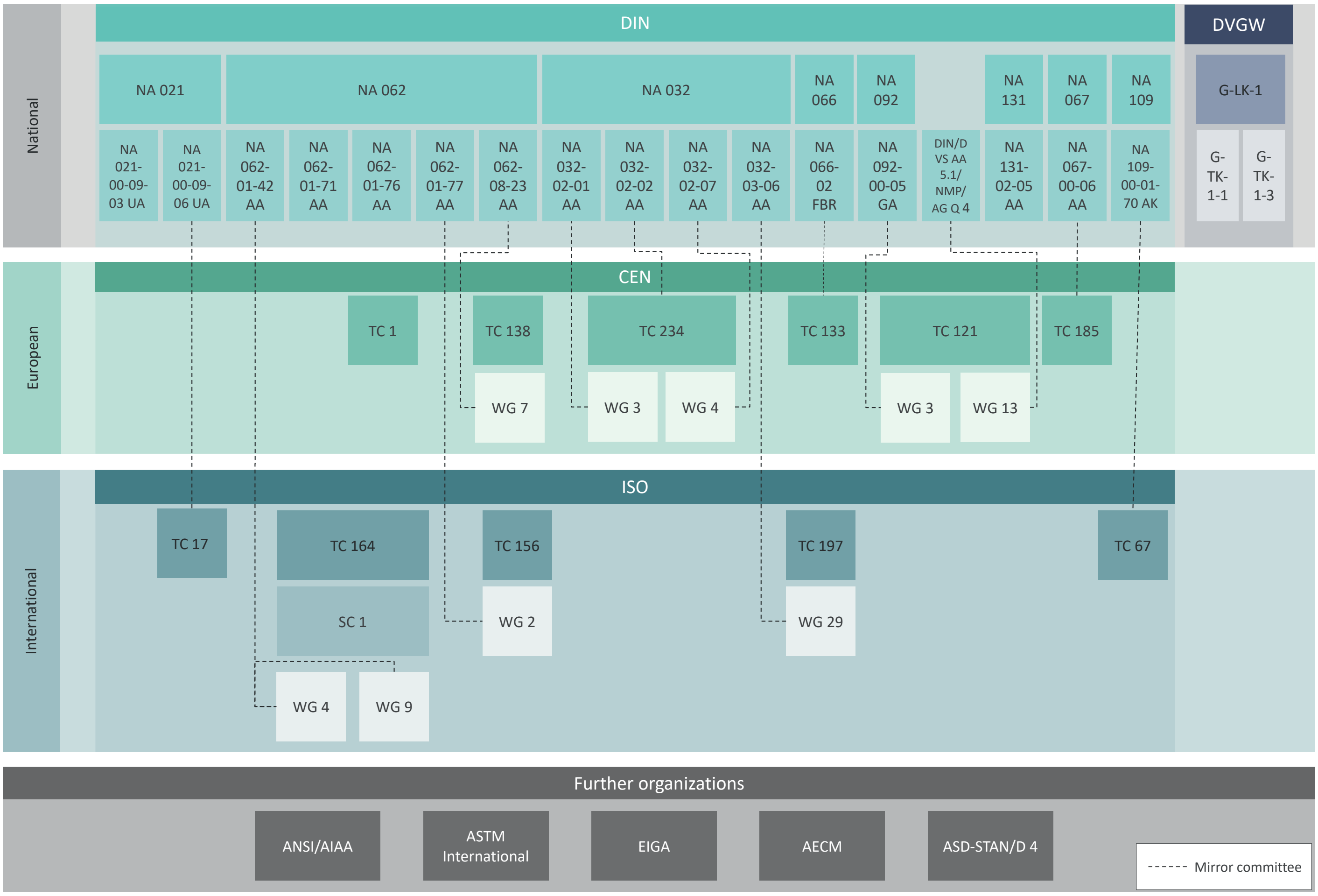

Figure 32: Overview of bodies relevant to technical rule-setting in the area of metallic materials (as of 03-2024)
(Source: own illustration)

[307] and ASTM G142 [308]. Therefore, there are technical rules for tensile tests under compressed hydrogen as a basis for the hydrogen economy. New technical rules can be based on existing technical rules for tensile tests on air, see ISO 6892 [309]. In particular, there are no provisions regarding the test atmosphere, any necessary pre-loading or the test speed. This also includes a parameter for calculating the relative hydrogen damage for better comparability.

IMPLEMENTATION: Initiation of an ISO standardization project in the DIN working committee NA 062-01-42 AA Tensile and ductility testing of metals and at international level in a working group of SC 1 Uniaxial testing in ISO/TC 164 Mechanical testing of metals.

NEED 4.4.3-02:
Crack growth test under compressed hydrogen atmosphere

CONTENT: Crack growth test; da/dN under compressed hydrogen

EXPLANATORY NOTES: For the hydrogen economy, the evaluation of crack growth plays a central role in the safe design of cyclically loaded technical structures. Standards and technical rules that define the boundary conditions for crack growth tests under compressed hydrogen are essential for this. Previous standards and technical rules for crack growth tests (ASTM E647 [310] and ISO 12108 [311]) do not include these tests for compressed hydrogen or under corrosive atmospheres, so that no independently reproducible material properties for crack growth can currently be determined on the basis of German or European Standards.

IMPLEMENTATION: Initiation of an ISO standardization project within DIN working committee NA 062-01-45 AA Fatigue testing and at international level in a working group of SC 4 Fatigue, fracture and toughness testing in ISO/TC 164 Mechanical testing of metals.

NEED 4.4.3-03:
Quasi-static fracture toughness and the J-integral

CONTACT: Quasi-static fracture toughness (KIC, KIH); J-integral

EXPLANATORY NOTES: There are no German or European technical rules for the measurement of quasi-static fracture toughness or the J-integral under the influence of compressed hydrogen. This means that no comparable and reliable material characteristics can be determined for the design and safe operation of technical structures. New technical rules should be drawn up or existing technical rules, such as ISO 12135 [312], ASTM E399 [313] and ASTM E1820 [314], should be supplemented with gas environment conditions. In particular, this also includes a parameter for calculating the relative hydrogen damage as a simplifying quantity for better comparability of materials.

IMPLEMENTATION: Initiation of an ISO standardization project in the DIN working committee NA 062-01-46 AA Fracture Mechanics and at international level in a working group of SC 4 Fatigue, fracture and toughness testing in ISO/TC 164 Mechanical testing of metals.

NEED 4.4.3-04:
Impact testing

CONTENT: Impact testing

EXPLANATORY NOTES: Impact tests in a compressed hydrogen atmosphere are not practical to carry out. Furthermore, there is a well-founded assumption that the test is too fast to see hydrogen embrittlement in the test result due to in-situ loading. Therefore, a standard for impact tests under corrosive compressive gas atmospheres should currently be avoided.

IMPLEMENTATION: Initiation of an ISO standardization project in the DIN working committee NA 062-01-44AA Impact testing of metals and at international level in a working group of SC 4 Fatigue, fracture and toughness testing in ISO/TC 164 Mechanical testing of metals.

NEED 4.4.3-05:
Fatigue testing / Wöhler fatigue test

CONTENT: Fatigue testing; Wöhler fatigue test; strain-controlled; force-controlled

EXPLANATORY NOTES: There are no German or European technical rules for the measurement of fatigue behavior under the influence of compressed hydrogen. A standard is required for carrying out force- or strain-controlled fatigue tests in compressed hydrogen. Specifications must be made for the gas quality, the specimen geometry and its production quality, as well as the test speed (exposure time, strain rate or test frequency), as these parameters influence the cyclic material properties. In particular, it may be necessary to preload the samples in a compressed gas atmosphere when carrying out tests in the LCF range, which must be specified in more detail. Existing standards for strain-controlled fatigue tests (ISO 12106 [315]) and force-controlled fatigue tests (DIN 50100 [316]) can be used by extending them to include the influence of compressed hydrogen.

IMPLEMENTATION: Initiation of an ISO standardization project within DIN working committee NA 062-01-45 AA Fatigue testing and at international level in a working group of SC 4 Fatigue, fracture and toughness testing in ISO/TC 164 Mechanical testing of metals.

NEED 4.4.3-06:
Internal pressure tests (tensile and fatigue tests)

CONTENT: Tensile and fatigue test; hollow test piece; fatigue test

Metallic materials

EXPLANATORY NOTES: At present, ISO 7039 [317] on tensile testing with hollow test pieces is being developed. Based on the current state of science and technology, standardization of hollow specimen tests with fatigue loading does not make sense, as too many questions regarding the influence of the inner surface on fatigue life remain unanswered. The project should therefore be postponed until further R & D results are available. Furthermore, a specification for calculating the relative hydrogen damage (property under corrosive atmosphere / property under reference conditions) is to be defined.

IMPLEMENTATION: Results from research and development are awaited. Following that, an ISO standardization project can be initiated in DIN working committee NA 062-01-42 AA Tensile and ductility testing of metals and at international level in a working group of SC 1 Uniaxial testing in ISO/TC 164 Mechanical testing of metals.

NEED 4.4.3-07:
Hydrogen compatibility tests of small, thin pipes

CONTENT: Small tubes; thin pipes

EXPLANATORY NOTES: A standardized test method for the hydrogen compatibility of small/thin pipes (outer diameter < 150 mm, wall thickness < 12 mm) is to be developed. Experience with the influence of hydrogen, particularly in applications under high internal pressure (> 200 bar) and cyclic loads, is limited. Testing for hydrogen compatibility is therefore essential. Some technical rules (e.g. ISO 11114-4 [318], CHMC 1 [306]) offer material compatibility tests, which are intended to prove safe application under compressed hydrogen. Common test specimens are used for this. However, such specimen geometries are not feasible for small and/or thin-walled pipes. For this reason, sampling from the final component is only possible to a limited extent. Tests on alternative materials are often not representative.

IMPLEMENTATION: A standard to be developed in ISO/TC 164 Mechanical testing of metals is to be initiated. The responsible national committee is DIN working committee NA 062-01-53 AA Mechanical testing of metallic tubes.

NEED 4.4.3-08:
Measurement of hydrogen content in metals (hydrogen analysis)

CONTENT: Hydrogen content in metals

EXPLANATORY NOTES: The risk of hydrogen embrittlement increases as the hydrogen content rises. The precise determination of the hydrogen content in metals is therefore essential. Currently, there are standards for measuring the hydrogen content in arc welding materials (e.g. DIN EN ISO 3690 [319]), but none for metal specimens in general. There are various methods for measuring the hydrogen content in metal, each of which has advantages and disadvantages. There is little consensus about the use of these methods. For this reason, there is a need for standardization of measurement methods, e.g. sample preparation and calibration methods, as well as the interpretation of results and nomenclature.

IMPLEMENTATION: The DIN Joint working committee NA 092-00-05 GA Joint working committee NAS/NMP: Destructive testing of welds (DVS AG Q 4/Q 4.1), should be contacted because DIN EN ISO 3690 [319] could serve as a basis for meeting this need.

NEED 4.4.3-09:
Measurement of a diffusion coefficient of gaseous hydrogen or hydrogen-containing gases

CONTENT: Permeability; diffusion coefficient

EXPLANATORY NOTES: In the hydrogen economy, knowledge of hydrogen diffusion is essential for the safe operation of technical systems. Existing standards only consider behavior in aqueous media. The effect of barrier layers or composite materials on diffusion behavior in a gaseous hydrogen environment is very important, as they are increasingly being used. The standard should therefore enable the evaluation of different material classes.

IMPLEMENTATION: DIN working committee NA 062-01-77 AA Corrosion testing should be contacted because DIN EN ISO 17081 [320] could serve as a basis for meeting this need.

NEED 4.4.3-10:
Test media for the qualification of materials, components and products in corrosive atmospheres

CONTENT: Test media; ammonia; LOHC; methane

EXPLANATORY NOTES: The current technical rules for material characterization and material qualification do not contain any specifications for corrosive test media. However, the composition of the test media has a significant effect on the measured material characteristics. For compressed hydrogen, it is known that impurities of oxygen in the ppm range can lead to a considerable reduction in hydrogen damage. The aim of the standard is therefore to define the provisions for conservative environmental conditions for the most severe material damage. The aim is to define important media for the hydrogen industry, i.e. ammonia, LOHC (Liquid Organic Hydrogen Carrier), methane. It is useful to define the ambient atmospheres once, as otherwise they would have to be redefined and described in the standard for each type of test, e.g. tensile tests, fatigue tests and compression tests on pipes. Otherwise there is a risk that all standards will have different provisions.

IMPLEMENTATION: No relevant standardization bodies are known. Working committees may have to be initiated in parallel.

NEED 4.4.3-11:
Testing the susceptibility of metallic materials to weakening through hydrogen reaction products

CONTENT: Susceptibility; metallic materials

EXPLANATORY NOTES: Development of test methods including evaluation methods/standards, as to whether damage can occur in the metal due to H_2 and at what concentration of (bound) elements that form reaction products with hydrogen. The embrittling effect of diffusible hydrogen has been extensively researched for various material groups (such as high-strength steels), and the existing test scenarios focus on the IHE (internal hydrogen embrittlement) damage mechanism, where absorbed hydrogen enables and accelerates crack growth. At the same time, the damage mechanisms HRE (hydrogen reaction embrittlement) and HTHA (high temperature hydrogen attack) are forms of attack by hydrogen in which the matrix of the metal is weakened by the reaction of the hydrogen with precipitates (e.g. oxides/carbides). In addition to the hydrogen supply, these reactions generally require elevated temperatures and special conditions (e.g. oxygen contents > 10 ppm in pure copper or < 4 % Cr in C-containing steels). Nevertheless, testing the general susceptibility of metallic alloys to these damage mechanisms has not yet been described.

IMPLEMENTATION: Contact will be made with DIN working committee NA 062-01-46 AA Fracture Mechanics regarding this need.

NEED 4.4.3-12:
Pressure test on thin layers (fuel cell/electrolyser cell)

CONTENT: Thin layers; thin sheet

EXPLANATORY NOTES: For metallic components/thin sheet in hydrogen fuel cells/electrolysers, there is no International Standard for mechanical testing, especially for pressure testing of this type of thin (µm range) components/sheet, e.g. which have higher requirements for parallelism and temperature resistance.

IMPLEMENTATION: At the upcoming meeting of the DIN working committee NA 062-01-42 AA Tensile and ductility testing of metals, the possibility of developing a standard at ISO level in SC 1 Uniaxial testing in ISO/TC 164 Mechanical testing of metals will be discussed.

NEED 4.4.3-13:
Requirements for WPSs for metals and their alloys contaminated with compressed hydrogen

CONTENT: WPS; welding; toughness

EXPLANATORY NOTES: Many safety-relevant components for the hydrogen industry are joined by welding. Requirements for welds are formulated using a welding procedure specification (WPS) as in DIN EN ISO 15614-1 [321] and are checked using a WPQR (Welding Procedure Qualification Record).

As compressed hydrogen causes particularly significant deterioration in the mechanical properties of welds, the ductility and toughness requirements in particular must be adapted.

IMPLEMENTATION: The toughness of weld seams is determined in DIN EN ISO 15614-1 [321] as standard using the Charpy pendulum impact test (DIN EN ISO 148-1 [322]), which is unsuitable for testing under H_2. As an alternative, the fracture mechanics test under compressed hydrogen in accordance with ASTM E1681 [323], ASTM E1820 [314] or ISO 12135 [312] should be introduced to qualify the toughness of welded materials. Contact will be made with DIN working committee NA 062-01-46 AA Fracture Mechanics regarding this need.

NEED 4.4.3-14:
SSRT testing with alternative loading possibilities

CONTENT: SSRT tests; alternative loading possibilities (without compressed hydrogen)

EXPLANATORY NOTES: The NACE Code (Statistical Classification of Economic Activities) [324] is a successful example of how metallic materials can be qualified for use in a hydrogen atmosphere using alternative loading methods. Alternative loading methods such as electrochemical loading or preloading have the advantage over testing under compressed hydrogen of being scalable and accessible to a broad public. This allows materials to be tested and classified in advance for their suitability and hydrogen resistance. The implementation of a DIN Standard for alternative loading and testing options could be based on the SSRT test in accordance with DIN EN ISO 7539-7 [325]. This test is increasingly being used to evaluate the hydrogen embrittlement sensitivity of steels, especially ultra-high-strength multiphase steels. Here, test parameters have a major influence on the test result. In order to ensure that the test results are fundamentally comparable and robust, both with each other and with tests under compressed hydrogen, it should be examined whether the test parameters mentioned should be specified within the framework of the existing standard.

IMPLEMENTATION: This need is being covered by DIN working committee NA 062-01-77 AA Corrosion testing. Work is currently underway to increase the number of experts on this topic in the committee. The possibility of revising DIN EN ISO 7539-7 [325] will then be discussed.

4.4.3.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.4.4 Composites and plastics

WG Composites and plastics deals with test methods for determining material characteristics under the influence of gaseous and liquid hydrogen and other media in the context of hydrogen technologies relating to composites and plastics. These are used in many hydrogen applications. Hydrogen can influence material resistance and permeates a variety of plastics. Test methods are required to maintain the function and integrity of the components for each area of application.

4.4.4.1 Analysis of the status quo

There is already a certain amount of standardization, which does make reference to composites and plastics in hydrogen applications here and there, but for the most part focuses on other media or component testing. Material characteristics are described in the existing standards according to exposure to gaseous hydrogen. The collection of standards and technical rules can be researched and accessed in standards databases, for example in [13]. In most cases, they are European or International Standards. At international, European and national level, there is a need for standards on the material resistance of composites and plastics under the influence of hydrogen, especially in the liquid state, but also in the gaseous aggregate state. Existing standards can serve as a template, which can be expanded and adapted and subsequently adopted worldwide.

Figure 33 presents the identified bodies that are important for the development of technical rules in the field of composites and plastics. An overview of the abbreviations used to describe these bodies is given in Section 9.

Composites and plastics

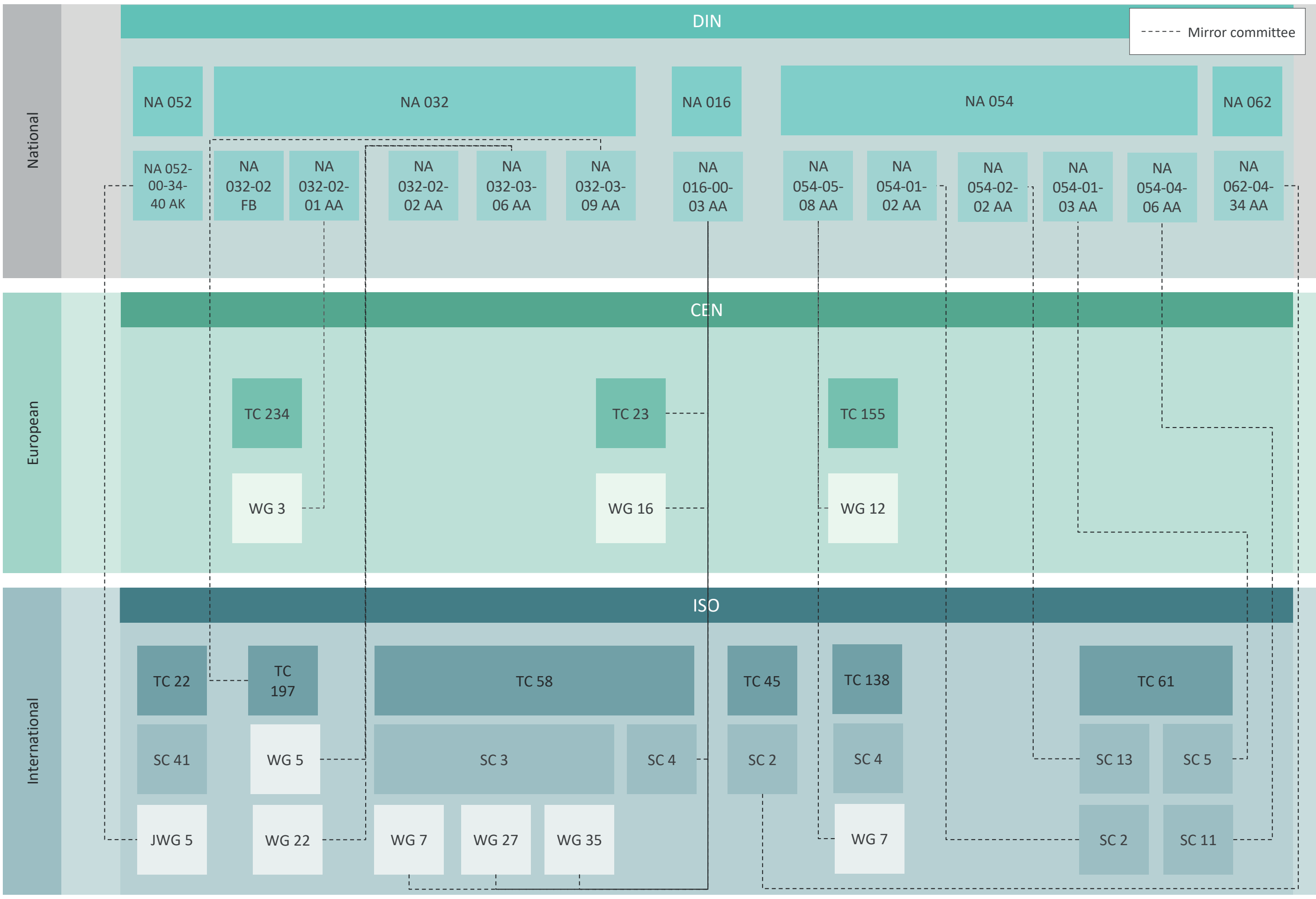

Figure 33: Overview of bodies relevant to technical rule-setting in the area of composites and plastics (as of 03-2024)
(Source: own illustration)

4.4.4.2 Requirements and challenges

The German Federal government's Hydrogen Strategy [14] envisages the wider use of hydrogen as an energy carrier. For this reason, the safe use of hydrogen must be made possible in a wider range and scope of applications. As a result, a greater variety of plastics and composites will come into contact with hydrogen. In addition, plastics and composites are an alternative to metallic materials. For both reasons, the materials must be tested for their suitability in accordance with normative specifications. The challenge in determining the material behavior of plastics and composites is the dependence on many parameters of the atmosphere in which the materials are located. These are, for example, the aggregate state of the hydrogen and the ambient atmosphere (pressure, temperature and composition created by other gases or liquids) [326], [327]. In particular, the material behavior of plastics and composites when exposed to liquid hydrogen is currently not standardized. Furthermore, the measurement technology for in-situ measurements in liquid and gaseous hydrogen is, in some cases, not available or standardized. Cooperation should be sought at international level to develop and refine documents on technical rule-setting.

4.4.4.3 Needs analysis

NEED 4.4.4-01:
Density determination under H_2 atmosphere in-situ

CONTENT: Testing; volumetric measurement; density determination

Composites and plastics

EXPLANATORY NOTES: Any test specifications from CSA/ANSI CHMC 2 [328] can also be used for ex situ density determination. A new method for determining the change in density in situ (e.g. using optical methods or laser technology) should be described in a standard. Elastomers in particular change their density reversibly under the influence of hydrogen, which is why it is necessary to standardize density determination in situ.

IMPLEMENTATION: Initiation of an ISO standardization project within DIN working committee NA 054-01-03 AA Physical, rheological and analytical test methods and ISO/TC 45/SC 2 Testing and analysis.

NEED 4.4.4-02:
Tensile test under H_2 atmosphere in situ

CONTENT: Testing; tensile test

EXPLANATORY NOTES: Under H_2 atmospheres, tensile tests must be carried out in situ. A test method would have to be developed for this, and a corresponding standard drawn up in which the tensile test is carried out in an autoclave suitable for hydrogen, for example. The test environment should not only be able to be subjected to different pressures, but should also be temperature-controlled.

IMPLEMENTATION: Initiation of an ISO standardization project within DIN working committee NA 054-01-02 AA Mechanical properties and preparation of test specimens and ISO/TC 61/SC 2 Mechanical behavior (possible integration in the standards series DIN EN ISO 527 [329]) and in DIN working committee NA 062-04-34 AA Test procedures for physical properties of rubber and ISO/TC 45/SC 2 Testing and analysis (possible integration in ISO 37 [330]).

NEED 4.4.4-03:
Bend test under H_2 atmosphere in situ

CONTENT: Testing; bend test

EXPLANATORY NOTES: Under H_2 atmospheres, bend tests must be carried out in situ. A test method would have to be developed for this, and a corresponding standard drawn up in which the bend test is carried out in an autoclave suitable for hydrogen, for example. The test environment should not only be able to be subjected to different pressures, but should also be temperature-controlled.

IMPLEMENTATION: Initiation of an ISO standardization project within DIN working committee NA 054-01-02 AA Mechanical properties and preparation of test specimens and ISO/TC 61/SC 2 Mechanical behavior (possible integration in ISO 178 [331]) and in DIN working committee NA 054-02-02 AA Reinforced plastics and thermosetting materials and ISO/TC 61/SC 13 Composites and reinforcement fibres (possible integration in ISO 14125 [332]).

NEED 4.4.4-04:
Charpy pendulum impact test under H_2 atmosphere in situ

CONTENT: Testing; Charpy pendulum impact test

EXPLANATORY NOTES: Under H_2 atmospheres, Charpy pendulum impact tests must be carried out in situ. A test method would have to be developed for this, and a corresponding standard drawn up in which the Charpy pendulum impact test is carried out in an autoclave suitable for hydrogen, for example. The test environment should not only be able to be subjected to different pressures, but should also be temperature-controlled.

IMPLEMENTATION: Initiation of an ISO standardization project within DIN working committee NA 054-01-02 AA Mechanical properties and preparation of test specimens and ISO/TC 61/SC 2 Mechanical behavior (possible integration in the standards series ISO 179 [333] and ISO 8256 [334]).

NEED 4.4.4-05:
Permeability of H_2

CONTENT: Testing; permeability

EXPLANATORY NOTES: In CSA/ANSI CHMC 2 [328], which deals with the topic of hydrogen permeation in the field of plastics and elastomers, the test set-up and the measurement conditions are sufficiently described.

IMPLEMENTATION: CSA/ANSI CHMC 2 is to be taken as a basis for an ISO standardization project within DIN working committee NA 054-04-04 AA Plastics films and plastics coated fabrics (artificial leather); General test methods and ISO/TC 61/SC 11 Products (possible integration in ISO 15105-1 [335]); possible revision of DIN 53536 [336] in DIN working committee NA 062-04-34 AA Test procedures for physical properties of rubber and DIN 53380 [337] in DIN working committee NA 054-04-04 AA Plastics films and plastics coated fabrics (artificial leather); General test methods.

NEED 4.4.4-06:
Tribology under H_2 atmosphere in situ

CONTENT: Testing; tribology

EXPLANATORY NOTES: Under H_2 atmospheres, determination of tribological characteristics must be carried out in situ. A test method would have to be developed for this and a corresponding standard drawn up. The test arrangement and geometry also play an important and material-dependent role and must be taken into account accordingly.

IMPLEMENTATION: Initiation of an ISO standardization project within DIN working committee NA 062-04-34 AA Test procedures for physical properties of rubber and ISO/TC 45/SC 2 Testing and analysis (possible integration in ISO 15113 [338]).

NEED 4.4.4-07:
Outgassing under H_2 influence

CONTENT: Testing; outgassing

EXPLANATORY NOTES: The ageing of plastics and composites in a hydrogen environment at various parameters (temperature, pressure, etc.) can cause substances to desorb or outgas both in situ and ex situ. A test method will have to be developed for this and a corresponding standard drawn up.

IMPLEMENTATION: Use CSA/ANSI CHMC 2 [328] as a basis for an ISO standardization project within DIN working committee NA 032-03-09 AA Fuel composition and ISO/TC 197 Hydrogen technologies (possible integration in ISO 14687 [54]).

NEED 4.4.4-08:
Leaching

CONTENT: Testing; leaching

EXPLANATORY NOTES: Leaching of materials under the influence of hydrogen (including additives and reaction residues from polymerization) can lead to soiling or functional restrictions. The mechanical properties of leached materials can change, which can lead to damage. This also includes products resulting from the use of hydrogen (e.g. process water).

IMPLEMENTATION: No body has yet been identified for implementation. This need should be implemented at international and national level.

NEED 4.4.4-09:
Test methods for plastics and composites in liquid hydrogen

CONTENT: Testing; liquid hydrogen

EXPLANATORY NOTES: Test methods for plastics and composites in liquid hydrogen must be developed, and the corresponding standards drawn up.

IMPLEMENTATION: Initiation of standardization projects in DIN Standards Committee Materials testing (NMP) and/or DIN Standards Committee Plastics (FNK) as well as in bodies of ISO/TC 61 Plastics with reference to thermoplastics (national mirror committee NA 054-01-02 AA Mechanical properties and preparation of test speciemens), elastomeres (national mirror committee NA 062-04-34 AA Test procedures for physical properties of rubber) and composites (national mirror committee NA 054-02-02 AA Reinforced plastics and thermosetting materials).

NEED 4.4.4-010:
Blistering

CONTENT: Testing; blistering; crack formation

EXPLANATORY NOTES: A standardized test method for composites and plastics (especially elastomers) is required to describe the material behavior after rapid gas decompression. The test environment should not only be able to be subjected to different pressures, but should also be temperature-controlled.

IMPLEMENTATION: A new testing standard could be developed along the lines of Norsok Testing Standard M710 [339] and/or CSA/ANSI CHMC 2 [328]. Initiation of a standardization project in DIN Standards Committee Materials testing (NMP) and/or DIN Standards Committee Plastics (FNK) as well as ISO/TC 61 Plastics.

4.4.4.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.4.5 Components for infrastructure

WG Components for infrastructure deals with the question of the hydrogen suitability of components of the pipeline-based gas infrastructure. This includes valves for hydrogen transmission, hydrogen distribution and the hydrogen installation. Components in hydrogen supply and in gas installations are also considered.

4.4.5.1 Analysis of the status quo

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. There are already preliminary working documents for many standards and technical rules, which are to be published as drafts in the near future. According to the analysis of the status quo there are currently 18 documents, two of which are at working or draft stage. Four national standards and technical rules are listed, as are about 15 European or international documents. A detailed list can be found in the already published Standards Database for Hydrogen Technologies [13]. Relevant political regulations include the Pressure Equipment Direcitve 2014/68/EU (PED) [76], the German Energy Industry Act (EnWG) [36] and the German High-Pressure Gas Pipeline Ordinance [340].

Figure 34 presents the identified bodies that are important for the development of technical rules in the field of components for infrastructure. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.4.5.2 Requirements and challenges

Currently, 24 general needs for standardization and technical rule-setting have been determined. These are already being revised for future operation with hydrogen or are in the process of being recommended for action by the Steering Committee. There are technical gaps in the assessment of existing valves, tapping saddles, bag setting devices, stop-off bags, isolating joints and components of gas installations. The evaluation of these components with regard to operation with hydrogen is essential for the conversion of existing natural gas networks to hydrogen or for the construction of new hydrogen grids. If corresponding assessments of the components are not possible due to missing or incomplete standards and technical rules, this may lead to the replacement of components in existing grids, which would mean higher financial expenditure. An urgent, fundamental need, such as the evaluation of existing valves, has already been implemented in a timely manner thanks to the funding of implementation projects for technical rule-setting as part of this Roadmap.

Further urgent action is required to improve general design guidelines for component strength to take account of the influence of hydrogen. The FKM guidelines, which are already firmly established in many companies, are an ideal starting point. These include the general analytical strength assessments [341], a verification method with explicit use of non-linear material deformation behavior [342], a fracture mechanics concept [343], and a guideline for spring components [344]. The guidelines offer small and medium-sized enterprises (SMEs) in particular the opportunity to design their components simply and cost-effectively without additional material or component tests. In their current form, however, the scope of the guidelines completely excludes use in a hydrogen atmosphere.

Components for infrastructure

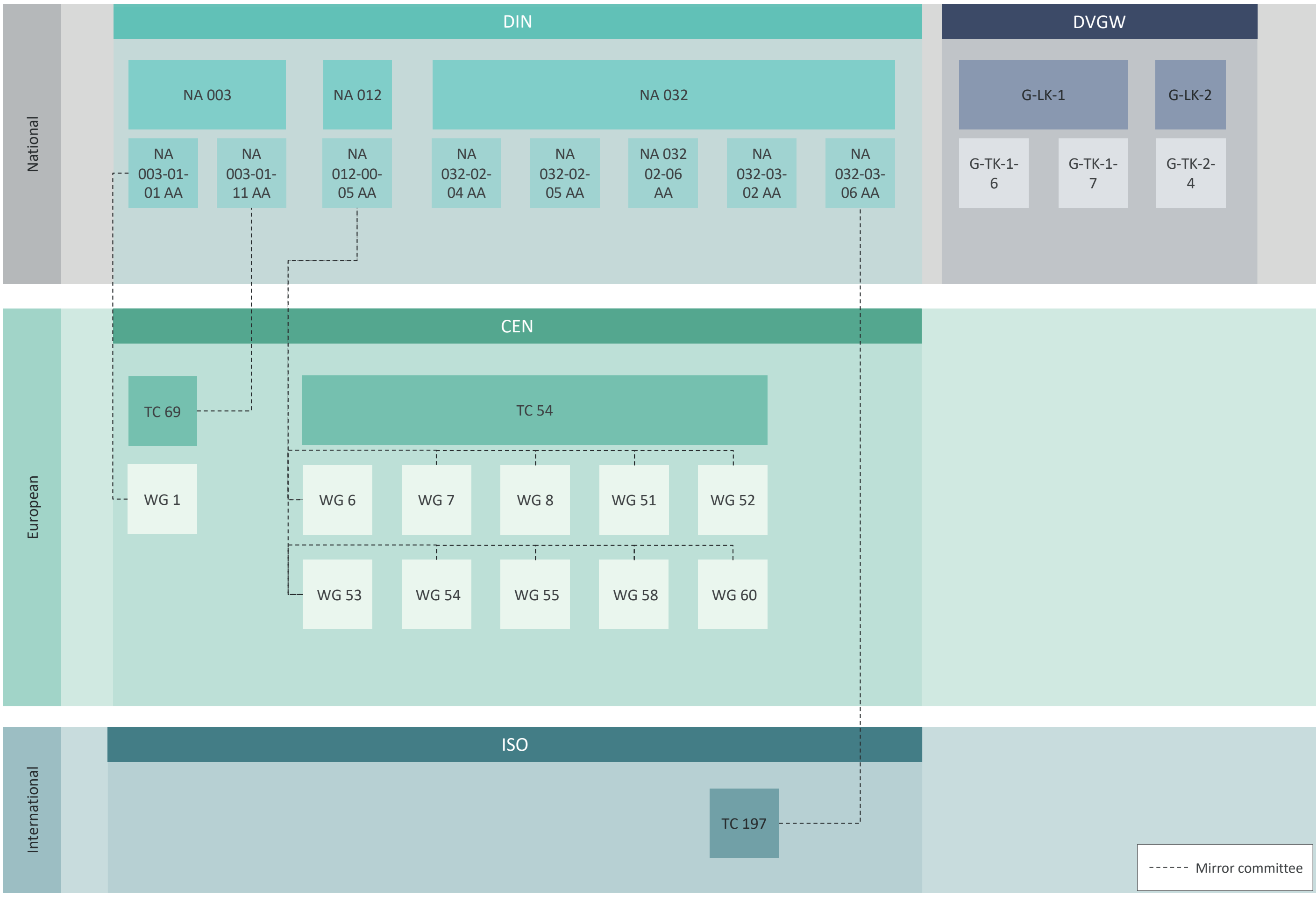

Figure 34: Overview of bodies relevant to technical rule-setting in the area of components for infrastructure (as of 03-2024) (Source: own illustration)

4.4.5.3 Needs analysis

NEED 4.4.5-01:
DVGW technical information – guideline G 405, Conversion of existing valves to hydrogen [104]

CONTENT: Existing valves; steel; gas infrastructure; > 16 bar; transmission

EXPLANATORY NOTES: This DVGW technical information – guideline applies to the conversion of existing steel valves in the gas infrastructure with a design pressure > 16 bar to the transmission of hydrogen of the fifth gas family of DVGW technical rule – code of practice G 260 [53]. Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. The suitability of existing valves for use with hydrogen is to be described in the specified scope and thus provide information for operators regarding the conversion of the infrastructure. At the same time, application of this Guideline will help gather experience in the conversion of existing valves that can be included in the next revision of this document. This is the first edition of the Guideline.

IMPLEMENTATION: This need is being implemented in DVGW G-TK-1-6 Gas valves and will be completed in 2024.

Components for infrastructure

NEED 4.4.5-02:
DVGW technical rule – code of practice G 441, Shut-off Valves for Maximum Operating Pressures up to 100 bar for Gas Infrastructure – Examples of Use, Operation and Maintenance [149]

CONTENT: Examples of use; operation; maintenance; valves; transmission pipelines; distribution lines; service lines

EXPLANATORY NOTES: The scope of this document encompasses public gas supply via pipelines which have been erected in accordance with DVGW technical rule – codes of practice G 462 [85], G 463 [100], G 465-1 [123], G 466-1 [345], G 472 [136] and which are operated with second family gases in accordance with DVGW technical rule – code of practice G 260 [53] and at pressures ≤ 100 bar. This DVGW technical rule – code of practice requires urgent revision with regard to gases of the fifth gas family in accordance with DVGW technical rule – code of practice G 260 [53]. Furthermore, it has become apparent that ball valves (with double block and bleed) and gate valves must be separated, especially in view of the EU Methane Regulation [346] that is about to be published (which will also apply to hydrogen).

IMPLEMENTATION: This will be implemented starting from 2024 in DVGW G-TK-1-6 Gas valves.

NEED 4.4.5-03:
DVGW Test Principles G 5620-1, Bag Setting Devices for Maximum Operating Pressures up to 1 bar for Gas Distribution [347], DVGW Test Principles G 5620-2, Bag Setting Devices for Maximum Operating Pressures up to 5 bar for Gas Distribution [348] and DVGW Test Principles G 5621 (all parts), Stop-off Bags for Bag Setting Devices up to 1 bar (Part 3 up to 5 bar) [349].

CONTENT: Requirements; testing; bag setting devices; stop-off bags

EXPLANATORY NOTES: These test principles apply to the requirements and tests for bag setting devices intended for blocking steel and polyethylene gas pipes with a temporary shut-off device. These devices are operated with gases in accordance with DVGW technical rule – codes of practice G 260 [53] (but not with liquid gas in the liquid phase) and G 262[8] [133]. The blocking pressure depends on the internal diameter of the pipe to be blocked and is max. 1 bar (in DVGW Test Principles G 5620-2 [348] it is max. 5 bar).

These test principles apply to requirements and tests for type A and B stop-off bags intended for the temporary shut-off of gas pipes made of steel and polyethylene, and for the diameter-dependent shut-off pressures up to a maximum of 1 bar (in DVGW Test Principle G 5621-3 [350] it is 5 bar). These are used in bag setting devices in accordance with DVGW Test Principle G 5620-1 [347] for blocking gas pipelines that are operated with gases in accordance with DVGW technical rule – codes of practice G 260 [53] (but not with liquid gas in the liquid phase) and G 262 [133].

Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the following two points: First, the test programme must be revised with regard to the operation of the bag setting devices and stop-off bags with pure hydrogen. Second, safe suitability for operation with hydrogen must be demonstrated for bag setting devices and stop-off bags.

IMPLEMENTATION: This will be implemented starting from 2025 in DVGW G-TK-1-6 Gas valves.

NEED 4.4.5-04:
DIN EN 14141, Valves for natural gas transportation in pipelines – Performance requirements and tests [351]

CONTENT: Valves (taper plug valves, ball valves, gate valves and check valves); onshore long-distance pipelines; transmission; natural gas

EXPLANATORY NOTES: This standard covers all valves that are part of a long-distance pipeline. Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the revision of the standard with regard to the use of pure hydrogen.

8 In 2021 replaced by G 260 [53]

IMPLEMENTATION: This will be implemented starting from mid-2024 in DIN working committee NA 003-01-09 AA Valves for the petroleum industry and in CEN/TC 69 Industrial valves.

NEED 4.4.5-05:
Standards series DIN EN 12266, Industrial valves – Testing of metallic valves [352]

CONTENT: Requirements; testing; test method; acceptance criteria; testing during production; industrial valves; metallic materials

EXPLANATORY NOTES: Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the revision of the standard with regard to the use of pure hydrogen.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 003-01-01 AA Basic standards and in CEN/TC 69 Industrial valves.

NEED 4.4.5-06:
DIN EN 334, Gas pressure regulators for inlet pressures up to 10 MPa (100 bar) [117]

CONTENT: Requirements; construction; function; testing; marking; measuring; documentation; gas pressure regulators

EXPLANATORY NOTES: The scope of the standard applies to:

→ inlet pressures up to 100 bar and nominal sizes up to DN 400;
→ an operating temperature range of -20 °C to +60 °C;

if they are operated with fuel gases of the first and second gas family according to DIN EN 437 [210] in pressure regulating stations according to DIN EN 12186 [353] or DIN EN 12279 [116] in gas transmission and gas distribution networks as well as in commercial and industrial installations.

Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the revision of the standard with regard to the use of pure hydrogen.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 032-02-04 AA Gas systems engineering and in CEN/TC 235 Gas pressure regulators and associated safety devices for use in gas transmission and distribution.

NEED 4.4.5-07:
DIN EN 331 Manually operated ball valves and closed bottom taper plug valves for gas installations for buildings [215]

CONTENT: Properties/characteristics; construction; function; safety; ball valves; closed bottom

EXPLANATORY NOTES: The nominal sizes of valves according to this European Standard are: 6, 8, 10, 12, 15, 20, 25, 32, 40, 50, 65, 80, 100.

Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the revision of the standard with regard to the use of pure hydrogen and harmonization with the Pressure Equipment Directive 2014/68/EU (PED) [76].

IMPLEMENTATION: This will be implemented starting from 2026 in DIN working committee NA 032-02-06 AA Gas valves and in CEN/TC 236 Non industrial manually operated shut-off valves for gas and particular combinations valves-other products.

NEED 4.4.5-08:
EN 13774, Valves for gas distribution systems with maximum operating pressure less than or equal to 16 bar – Performance requirements [354]

CONTENT: Shut-off valves; metal

EXPLANATORY NOTES: The scope of the standard applies to valves which are used in gas distribution systems with a maximum operating pressure of up to 16 bar and which are operated with fuel gases of the first, second and third family in accordance with DIN EN 437 [210]. Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the revision of the standard with regard to the use of pure hydrogen and harmonization with the Pressure Equipment Directive 2014/68/EU (PED) [76].

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 003-01-08 AA Valves for gas transmission and in CEN/TC 69 Industrial valves.

NEED 4.4.5-09:
DIN 3537-1, Gas stop valves for domestic gas installations up to 5 bar – Part 1: Requirements and tests [355] and DIN 3434, Gas valves for gas installations – Straight pattern conical plug valves with screw connection – Nozzles with conical connection [356] and DIN 3435, Gas valves for gas installations – Angle pattern ball valves with screw connection – Nozzles with conical connection [357] and DIN 3436, Gas valves for gas installations – Nozzles with conical sealing and gasket [358]

CONTENT: Valves; gas installations

EXPLANATORY NOTES: In particular, these standards cover types, dimensions and designations. These valves are only operated with gases according to DVGW technical rule – code of practice G 260 [53]. This does not apply to liquefied gas. Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the revision of the standard with regard to the use of pure hydrogen and harmonization with the Pressure Equipment Directive 2014/68/EU (PED) [76].

IMPLEMENTATION: This will be implemented starting from 2025/2026 in DIN working committee NA 032-02-06 AA Gas valves.

NEED 4.4.5-10:
Standard series DIN 3389, Ready-made insulated joint [359]

CONTENT: Requirements; tests; insulating couplings

EXPLANATORY NOTES: These standards also apply to insulating couplings, as an integral part of a valve, which are suitable for use in gas pipes and systems, grid connection lines and gas installations. Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the fact that gas grids should also be suitable for the transmission of hydrogen in variable proportions in the future. This requires revision of this standard.

IMPLEMENTATION: This will be implemented starting from 2026 in DIN working committee NA 032-02-06 AA Gas valves.

NEED 4.4.5-11:
Standards series DIN 3588, Gas tapping tees [360]

CONTENT: Requirements; tests; tapping tees

EXPLANATORY NOTES: These standards apply to tapping tees with service shut-off valves used in PE pipe networks and tapping tees made of metallic materials for cast iron or steel pipes to be tapped with or without a built-in service shut-off valve and any auxiliary shut-off device. Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the fact that gas grids should also be suitable for the transmission of hydrogen in variable proportions in the future. This requires revision of this standard.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 032-02-06 AA Gas valves.

NEED 4.4.5-12:
DIN EN 12516-2, Industrial valves – Shell design strength – Part 2: Calculation method for steel valve shells [361]

CONTENT: Calculation method; strength; valve shells; internal pressure

EXPLANATORY NOTES: The DIN EN 12516 [362] series of standards is a means of fulfilling the essential requirements of the Pressure Equipment Directive 2014/68/EU (PED) [76] with regard to construction, design for load capacity, corrosion, materials and marking. As these standards are not yet hydrogen-related, they must be revised with regard to the use of hydrogen or hydrogen/natural gas blends.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 003-01-01 AA Basic standards and in CEN/TC 69 Industrial valves.

NEED 4.4.5-13:
DIN EN 1349, Industrial process control valves [363]

CONTENT: Control valves; industrial process

EXPLANATORY NOTES: It specifies requirements for design and performance including material, pressure/temperature values, dimensions, testing and marking. DIN EN 1349 is a product standard [363] which is harmonized with the Pressure Equipment Directive 2014/68/EU (PED) [76] but which does not yet cover hydrogen. Thus, a revision must be made with regard to the use of hydrogen or hydrogen-natural gas blends.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 003-01-11 AA Valves and special valves for the process industry, gas transmission and gas distribution, as well as the petroleum industry and in CEN/TC 69 Industrial valves.

NEED 4.4.5-14:
DIN EN 13709, Industrial valves – Steel globe and globe stop and check valves [364]

CONTENT: Requirements; globe valves; globe stop and check valves; steel

EXPLANATORY NOTES: These valves are forged, cast or welded, have straight, angle or slanted designs and flanged, weld-on, socket-weld or threaded ends. DIN EN 13709 is a product standard [364] which is harmonized with the Pressure Equipment Directive 2014/68/EU (PED) [76] but which does not yet cover hydrogen. Thus, a revision must be made with regard to the use of hydrogen or hydrogen-natural gas blends.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 003-01-03 AA Valves and in CEN/TC 69 Industrial valves.

NEED 4.4.5-15:
DIN EN 16668, Industrial valves – Requirements and testing for metallic valves as pressure accessories [365]

CONTENT: Metallic valves; head standard; requirements; design; manufacture; testing; materials; documentation

EXPLANATORY NOTES: This document applies to metallic valves as pressure equipment for industrial applications with a maximum allowable pressure (PS) greater than 0,5 bar according to the European Pressure Equipment Directive, and specifies minimum requirements that apply to design, manufacture, testing, materials and documentation. DIN EN 16668 [365] is a head standard for metallic industrial valves for meeting the basic safety requirements, and is harmonized with the Pressure Equipment Directive 2014/68/EU (PED) [76], but does not yet refer to hydrogen. Thus, a revision must be made with regard to the use of hydrogen or hydrogen-natural gas blends.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 003-01-01 AA Basic standards and in CEN/TC 69 Industrial valves.

NEED 4.4.5-16:
DIN EN 13397, Industrial valves – Diaphragm valves made of metallic materials [366]

CONTENT: Requirements; diaphragm valves; metallic shell materials

EXPLANATORY NOTES: DIN EN 13397 is a product standard [366] which is harmonized with the Pressure Equipment Directive 2014/68/EU (PED) [76] but which does not yet cover hydrogen. Thus, a revision must be made with regard to the use of hydrogen or hydrogen-natural gas blends.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 003-01-16 AA Valves for water supply, diaphragm valves, check valves and fire hydrants as well as gate valves, globe valves, butterfly valves and ball valves and in CEN/TC 69 Industrial valves.

NEED 4.4.5-17:
DIN SPEC 3456, Industrial valves – Guideline on requirements for metallic valves for hydrogen application within European standardization [367]

CONTENT: Requirements; industrial valves

EXPLANATORY NOTES: This document contains information on provisions for metallic industrial valves for hydrogen applications and specifies additional requirements for material selection, design, manufacture and testing. This new DIN SPEC 3456, which is in the process of development, covers hydrogen applications.

IMPLEMENTATION: This will be implemented starting from 2024 in DIN working group NA 003-01-11-02 AK Valves for hydrogen applications and networks.

NEED 4.4.5-18:
DIN 30690-1, Construction elements in the gas supply system – Part 1: Requirements for construction elements in gas supply systems [101]

CONTENT: Requirements; construction elements

EXPLANATORY NOTES: These are components in systems for the pipeline-based supply of gas to the general public (gas supply systems). This standard does not apply to gas installations within the scope of DVGW technical rule – code of practice G 600 [197]. Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the fact that gas grids should also be suitable for the transmission of hydrogen in variable proportions in the future. This requires revision of this standard.

IMPLEMENTATION: This will be implemented starting from 2024 in DIN working committee NA 032-02-04 AA Gas systems engineering.

NEED 4.4.5-19:
DIN 33821, Safety relief valves for gas transmission and distribution installations operating at working pressures up to 100 bar [218]

CONTENT: Requirements; tests; safety relief valves

EXPLANATORY NOTES: This standard applies to requirements and tests of safety relief valves and pressure relief valves in gas supply systems with operating pressures up to 100 bar for gas, in accordance with DVGW technical rule – code of practice G 260 [53]. Gas grids should also be suitable for the transmission of hydrogen in variable proportions in the future. Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the revision of the standard with regard to the use of pure hydrogen and harmonization with the Pressure Equipment Directive 2014/68/EU (PED) [76].

IMPLEMENTATION: This will be implemented starting from 2024 in DIN working committee NA 032-02-04 AA Gas systems engineering.

NEED 4.4.5-20:
DIN EN 14382, Gas safety shut-off devices for inlet pressure up to 10 MPa (100 bar) [217]

CONTENT: Requirements; gas safety shut-off devices

EXPLANATORY NOTES: This document specifies requirements for the design, function, testing, marking and dimensioning as well as the documentation of gas safety shut-off devices for inlet pressures up to 100 bar and nominal sizes up to DN 400. Various adjustments must be made with regard to the possible use of hydrogen or hydrogen-natural gas blends. This includes the fact that gas grids should also be suitable for the transmission of hydrogen in variable proportions in the future. This requires revision of this standard. Furthermore, this standard does not yet cover fifth family gases. A corresponding revision is thus urgently needed.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 032-02-04 AA Gas systems engineering and in CEN/TC 235 Gas pressure regulators and associated safety devices for use in gas transmission and distribution.

4.4.5.4 Implementation projects

In spring 2023, the implementation project for the revision of DVGW technical information – guideline G 405 [104] was applied for and financial support for implementation was approved. The urgency of implementation was due to the fact that valves are a significant factor in the conversion of existing natural gas networks to hydrogen. The publication of this Guideline in April 2024 marks an important milestone in this implementation project.

In the fall of 2023, the application for the fundamental revision of DVGW technical rule – code of practice G 441 [149] was submitted. This application was approved so that the revision by the Gas-PK-1-6-1 G 441 project group of DVGW began in spring 2024. This DVGW technical rule – code of practice requires urgent revision with regard to gases of the fifth gas family in accordance with DVGW technical rule – code of practice G 260 [53], as these gases are not included in the current version. Furthermore, it has become apparent that ball valves (with double block and bleed) and gate valves must be separated, especially in view of the EU Methane Regulation [346] that is about to be published (which will also apply to hydrogen). The revision of this Code of Practice is not expected to be completed until 2025 at the earliest. In addition, the development of DIN SPEC 3456 has been approved and initiated.

4.4.6 Components for application and technologies

WG Components for application and technologies considers standards and technical rules on components for gas supply and utilization. These components include pipes made of metallic and non-metallic materials as well as the associated connection systems and safety devices such as gas flow detectors and sockets, hoses for various applications, filters, elastomers, flat gasket materials, lubricants and sealants (e.g. anaerobic adhesives, PTFE sealing tapes or strips).

4.4.6.1 Analysis of the status quo

A major advantage of the standardization and technical rule-setting of WG Components for applications and technologies related to the use of hydrogen is that this work is already largely known from the conventional field of gas and can be derived from this field. This is so in particular because Section 113c et seq. of the German Energy Industry Act [196] considers the relevant DVGW technical rules to be generally recognized rules of technology for hydrogen distribution. New aspects of hydrogen have also been taken into account and included. Apart from the certification schemes for components and gas appliances developed specifically for hydrogen, the entire standardization portfolio consists exclusively of revisions and further developments of standards and technical rules. The preliminary investigations and technical discussions of the experts in DIN working committee NA 032-03-02 AA Components and auxiliary supplies – Gas (DVGW committee G-TK-2-4) made it possible to directly identify and address the relevant technical rules.

Open needs were quickly identified and will be adapted in a structured manner in the coming months and years. At the end of 2023, this working group had around 40 technical rules. A fourth of these are already published H_2-ready documents of the DVGW collection of technical rules, as well as nine national DIN Standards. In addition, there are 14 European or International Standards or technical rules, three certification schemes and three American ANSI or ASME Standards. This collection also includes a technical rule published with the cooperation of the VdTÜV. In addition to the technical standards, compliance with existing legal regulations and provisions such as the EU Gas Appliance Directive, the EU Pressure Equipment Directive and the German Product Safety Act is required. The standards and technical rules are listed in the Standards Database for Hydrogen Technologies [13] (Database of standards for hydrogen technologies, in German only).

Figure 35 presents the identified bodies that are important for the development of technical rules in the field of components for applications and technologies. An overview of the abbreviations used to describe these bodies is given in Section 9.

Components for application and technologies

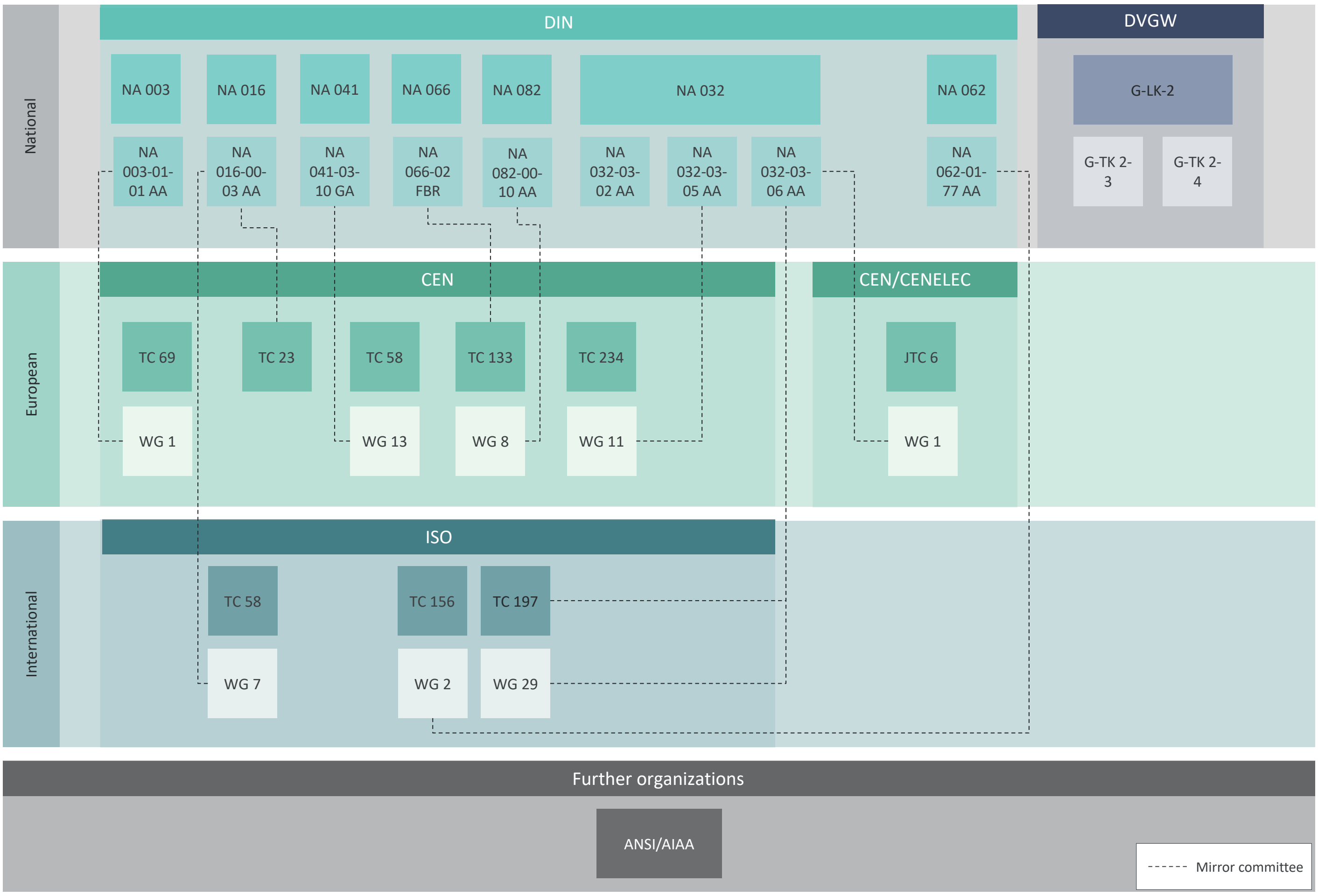

Figure 35: Overview of bodies relevant to technical rule-setting in the area of composites and technologies (as of 03-2024) (Source: own illustration)

4.4.6.2 Requirements and challenges

44 general needs for standardization and technical rule-setting were identified, eight of which were specified in detail. There are gaps in the areas of product standardization of seals or sealants and diaphragms, lubricants, gas flow monitors, gas filters and valves. Urgent needs have already been covered by supplementing the Technical Rules for Gas Installations (DVGW-TRGI) [222], with the Guidelines for H_2-readiness for gas applications [198] and with the revision of DVGW technical rule – code of practice G 260 [53], as well as by the adaptation of DIN EN 437 [210]. As long as there are no H_2-ready technical rules for valves, elastomer materials for seals, diaphragms and plastic pipes (multilayer composite pipes), the certification schemes ZP-4110 (Supplementary tests for valves for gaseous fuels up to 100 % H_2 by volume) [225] and ZP-5101 (Compatibility and permeation properties of elastomer materials for seals and diaphragms in gas appliances and systems up to 100 % H_2 by volume) [368] apply.

Although the analysis of the status quo and of needs posed hardly any difficulties in terms of technical rules, the H_2 transformation has proven to be a major technical challenge in practice. For this reason, research projects such as HydEKuS (G 202208) [227], H_2-Umstell (G 202312) [369], ECLHYPSE (G 202138) [203], F&E für H_2 (G 202021) [370] or the Roadmap Gas 2050 (G 201824) [57] were launched to test the conversion to hydrogen.

At the beginning, technical rules for domestic hydrogen production and storage and materials were also considered. However, it quickly became apparent that these needs could be addressed more precisely in the working groups WG Domestic applications, WG Metallic materials, WG Composites and plastics and WG Piping. Cooperation across WGs on the detailed classification of technical rules or cross-cutting issues was very reliably covered by the Standardization Roadmap Hydrogen Technologies network.

4.4.6.3 Needs analysis

NEED 4.4.6-01:
DIN EN 549:2023-07, Rubber materials for seals and diaphragms for gas appliances and gas equipment [371]

CONTENT: Seals; diaphragms; material requirements

EXPLANATORY NOTES: The specific explanation of this need arises from the fact that elastomers are used in almost all applications across all sectors and therefore play a key role from a technical perspective. Extensive research results on the suitability of materials and substances as well as test requirements for elastomers for hydrogen use are now available and are to be incorporated into the updating of this standard [372].

IMPLEMENTATION: This project will be implemented starting in 2024 in DIN working committee NA 032-03-02 AA Components and auxiliary supplies – Gas and/or at European level in CEN/TC 208.

NEED 4.4.6-02:
DIN 30652-1:2021-06, Excess flow valves – Part 1: Excess flow valves for gas installation [373] and DIN 30652-3:2021-06, Excess flow valves – Part 3: Conformity assessment of excess flow valves for gas installation [374]

CONTENT: Excess flow valves; gas installation

EXPLANATORY NOTES: This standard represents a very high significance of all needs for the WG Components for application and technologies and substantially advances the hydrogen ramp-up in the area of components. Gas flow valves are required as an essential part of all gas installation systems and play a key role from a technical point of view. Extensive research results are now available on the technical suitability of gas flow valves for gas installations, which must be incorporated into the updating of this standard. The research results of the DVGW project Roadmap Gas 2050 [57], [375] form the basis for this revision.

IMPLEMENTATION: This project will be implemented starting in 2024 in DIN working committee NA 032-03-02 AA Components and auxiliary supplies – Gas.

NEED 4.4.6-03:
DIN 30652-2:2022-09, Excess flow valves – Part 2: Excess flow valves for service lines [132] and DIN 30652-4:2022-09, Excess flow valves – Part 4: Conformity assessment of excess flow valves for service lines [376]

CONTENT: Excess flow valves; service lines

EXPLANATORY NOTES: This standard represents a very high significance of all needs for the WG Components for application and technologies and substantially advances the hydrogen ramp-up in the area of components. Gas flow valves are required as an essential part of gas distribution and play a key role from a technical point of view. Extensive research results are now available, which must be incorporated into the updating of this standard. The research results of the DVGW project Roadmap Gas 2050 [57] and the already approved project H_2-Umstell [369] form the basis of this revision.

IMPLEMENTATION: Will be implemented in parallel with the revision of Part 1 and Part 3 and will start in 2024 in DIN working committee NA 032-03-02 AA Components and auxiliary supplies – Gas.

NEED 4.4.6-04:
DIN 3535-6:2019-04, Gaskets for gas supply – Part 6: Gasket materials based on fibres, graphite or polytetrafluoroethylene (PTFE) for gas valves, gas appliances and gas mains [377]

CONTENT: Gaskets (fibre, graphite, PTFE); gas valves; gas appliances; gas mains

Components for application and technologies

EXPLANATORY NOTES: Investigations into the possible effects of hydrogen on gaskets used in components are currently still underway for this standard. These must be finally evaluated and the respective influences on hydrogen taken into account in the standard through appropriate measures. Similar to flow monitors, gaskets play a key technical role in all applications across all sectors. In addition, this standard does not yet refer to the fifth gas family and therefore needs to be revised in general and editorially.

IMPLEMENTATION: This will be implemented starting from 2025 in DIN working committee NA 032-03-02 AA Components and auxiliary supplies – Gas and/or in CEN/TC 208, until then the relevant certification scheme applies.

NEED 4.4.6-05:
DIN EN 377:1999-04, Lubricants for applications in appliances and associated controls using combustible gases except those designed for use in industrial processes [378]

Content: Requirements; tests; lubricants; gas appliances

Explanatory notes: Investigations into the possible effects of hydrogen on lubricants used in components are currently still underway for this standard. It is clear that this standard must be adapted to hydrogen applications.

Implementation: This will be implemented starting from 2025 in DIN working committee NA 032-03-02 AA Components and auxiliary supplies – Gas and/or in CEN/TC 208.

NEED 4.4.6-06:
Standards series DIN EN 751, Sealing materials for metallic threaded joints in contact with 1st, 2nd and 3rd family gases and hot water [379]

CONTENT: Sealing materials; metallic threaded joints

EXPLANATORY NOTES: Here, too, investigations into the possible effects of hydrogen on sealing materials used in components are currently still underway for this standard. These must be finally evaluated and the respective influences on hydrogen taken into account in the standard through appropriate measures. Similar to flow monitors, sealing materials play a key technical role in all applications across all sectors.

IMPLEMENTATION: This project will be implemented starting from 2026 in DIN working committee NA 032-03-02 AA Components and auxiliary supplies – Gas and/or in CEN/TC 208.

NEED 4.4.6-07:
DIN 3386:2012-10, Gas filters having a maximum working pressure of less than or equal to 5 bar – Requirements and testing [380]

CONTENT: Gas filters; nominal sizes up to and including DN 250

EXPLANATORY NOTES: At present this standard does not yet refer to the fifth gas family and therefore needs to be revised in general and editorially. Here, too, investigations into the possible effects of hydrogen on sealing materials used in components are currently still underway for this standard. These must be finally evaluated and the respective influences on hydrogen taken into account in the standard through appropriate measures. Similar to gaskets and flow monitors, filters play a key technical role in all applications across all sectors.

IMPLEMENTATION: This will be implemented starting from 2024 in DIN working committee NA 032-03-02 AA Components and auxiliary supplies – Gas and/or at European level in CEN/TC 208.

NEED 4.4.6-08:
DIN EN 682:2006-10, Elastomeric seals – Material requirements for seals used in pipes and fittings carrying gas and hydrocarbon fluids [381]

CONTENT: Elastomer materials; seals; supply lines; components

EXPLANATORY NOTES: This standard urgently requires specifications to be defined for hydrogen for the elastomer materials used for seals for supply lines and components.

IMPLEMENTATION: This will be implemented starting from 2028 in DIN working committee NA 032-03-02 AA Components and auxiliary supplies – Gas and/or at European level in CEN/TC 208.

4.4.6.4 Implementation projects

In fall 2023 financial support for the revision of DIN EN 549:2023-07 [371] and funding for the adaptation of the standards series DIN 30652 [373], [132], [374], [376] were approved. The needs are described in Section 4.4.6.3. This financial support will make it easier for technical standardization to prioritize the most important changes to technical rules relating to the hydrogen transformation using the necessary resources.

4.5 Further training, safety and certification

Hydrogen will play a key role as a raw material and energy carrier in many areas of industry. It is also used in areas where there is little experience with this high-energy material.

Against the background of this development, it is a top priority to guarantee the safety aspects. A comprehensive understanding of safety is essential, from basic safety standards, effective safety management and explosion protection to further training and the certification of products for hydrogen use.

Particularly in the context of sector coupling, it is the responsibility of operators and manufacturers to exercise their respective rights and obligations and to protect the integrity of these systems from cyber threats.

4.5.1 Safety design principles

WG Safety design principles deals with safety-related aspects that are relevant to hydrogen technologies across all disciplines. The general principles for the safe design and use of products and systems as well as general requirements with regard to functional safety are considered. On the one hand, this creates a basis for manufacturers, operators and processors to work and act, and on the other hand, the foundations on which specialist standards and technical rules can be developed.

4.5.1.1 Analysis of the status quo

There are a large number of relevant technical rules, mainly from the petrochemical, nuclear and chemical industries. However, these only include hydrogen as a partial aspect and can only be transferred to other fields of application to a limited extent. Standards developed at international level do not fully cover the necessary safety framework, for example if they refer to non-European national standards that are not generally applicable or accessible and are not in line with European directives. Harmonized standards and technical rules usually are applied in such a way that by meeting their requirements, manufacturing companies automatically comply with the directives, and these standards and technical rules are thus standardized in the European context. In contrast, the requirements for operators and approval procedures vary greatly, which is why they cannot be applied universally. In addition, there are a wide range of national and international technical rules and industry codes of practice that are not always coordinated with each other and sometimes compete or are used in parallel. In most cases, this is also due to the heterogeneous distribution of the people and interest groups involved.

The over 80 standardization documents listed in the Standards Database for Hydrogen Technologies (Database of standards for hydrogen technologies, in German only) are in the main available. However, the context of these documents only becomes clear after detailed study. Generally applicable safety rules for hydrogen applications can only be derived from these to a limited extent [13]. In addition, 17 documents from the legal framework[9] were identified that specify objectives but not the technical implementation. Furthermore, the WG identified nine ongoing and completed research projects focusing on Safety design principles, the results of which still need to be translated into application knowledge [382], [383], [384], [385], [386], [387], [388], [389], [390]. The highly dynamic market ramp-up and technical innovations in hydrogen technologies mean that a further number of relevant research projects can be expected that have not yet been recorded. It is desirable to quickly integrate new findings into existing standards and technical rules.

Examples of applications where standards and technical rules are lacking include non-atmospheric conditions and liquid hydrogen, which are not covered by classic explosion protection (see WG Explosion protection).

Figure 36 presents the identified bodies that are important for the development of technical rules in the field of safety design principles. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.5.1.2 Requirements and challenges

Hydrogen is classified as a hazardous substance and poses a high risk to people and equipment due to fire or explosion in the event of uncontrolled leakage or unexpected operating conditions. The chemical and physical parameters are well characterized [391], but differ considerably from hydrocarbon gases, both in normal operation and in the event of a fault. Large-scale hydrogen plants have been in operation in the chemical industry for decades [392], [393]. There is therefore a very good level of development of standards and technical rules, and a high level of safety-related experience [394], which means that safe operation of hydrogen systems can be expected.

However, the transformation to a hydrogen economy entails many changes, which manifest themselves in particular in:

- → applications in new industries and as a storage technology;
- → innovative system concepts;
- → a greater 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.

Each of these innovations increases the risk of errors in design, installation and operational management, which can lead to hazardous situations.

9 See [418], [419], [420], [43], [413], [403], [76], [421], [422], [423], [424], [425], [173], [426], [427], [428], [68]

Safety design principles

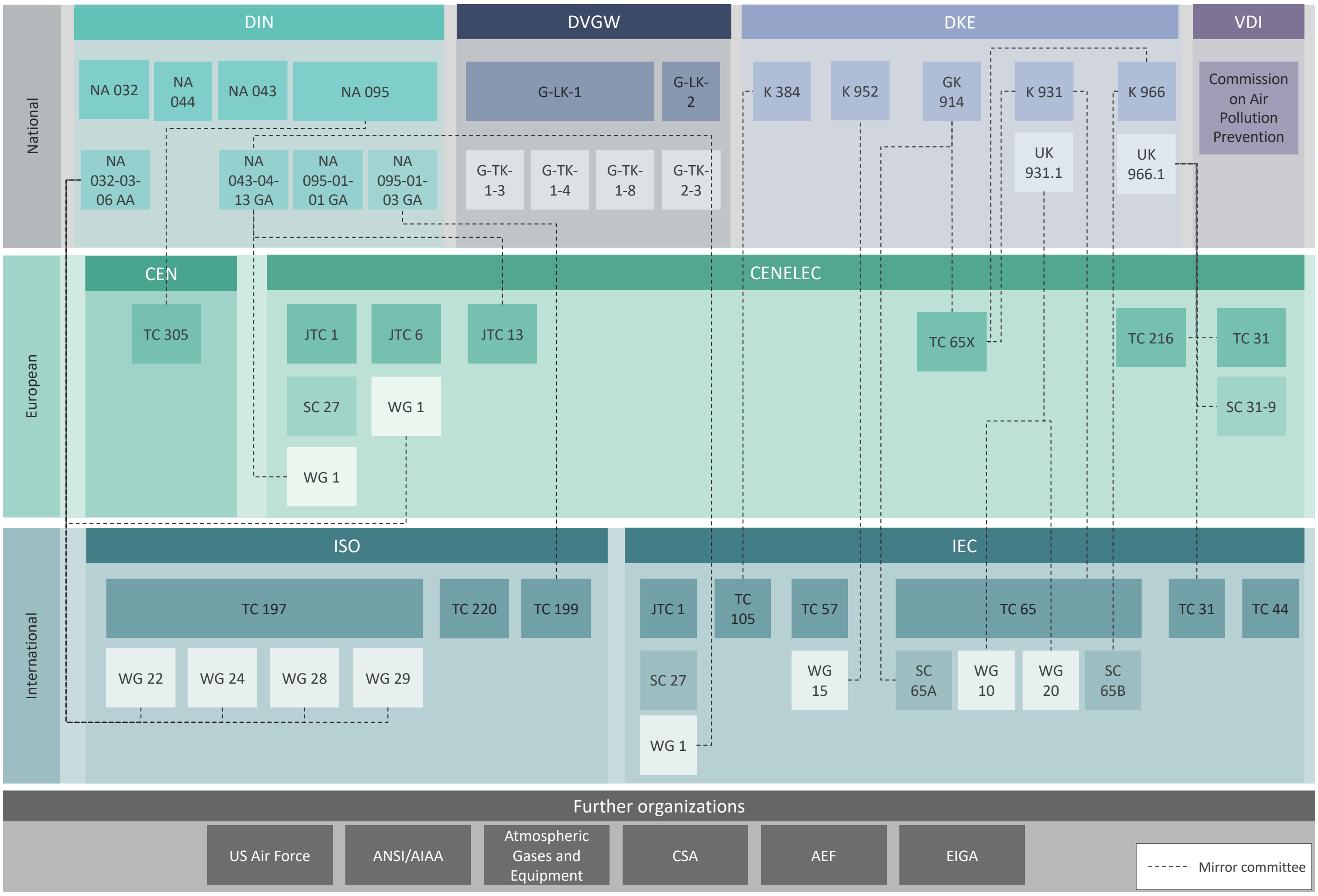

Figure 36: Overview of bodies relevant to technical rule-setting in the area of safety design principles (as of 03-2024)
(Source: own illustration)

The analysis of the existing standards and technical rules results in the following needs:

→ promoting the transfer of experience from "lessons learned";
→ provision of aids and guidelines;
→ making expertise for the qualification of persons available;
→ using methods of developing safety concepts;
→ setting up harmonized principles for the evaluation of safety concepts for manufacturers, operators and approval authorities

4.5.1.3 Needs analysis

NEED 4.5.1-01:
Manual on accidents and incidents at hydrogen plants

CONTENT: Manual; guide

EXPLANATORY NOTES: Establishing a standardized fault classification system that segments faults according to the system functions or system modules involved and their effects helps to identify problem areas and implement the necessary safety measures in a targeted manner. This also enables uniform criteria to be applied in the design, development, approval and certification of such systems, machines and components. Illustrative examples will be shown that can be used in training and further education.

IMPLEMENTATION: A manual on accidents and incidents at hydrogen plants is to be drawn up, in which a standardized classification is to be made on the basis of clearly defined criteria. This can be based on the HIAD-2.0 database [395]

NEED 4.5.1-02: Ready-to-use systems – general requirements

CONTENT: Minimum requirements contract; ready-to-use systems

EXPLANATORY NOTES: In the case of ready-to-use systems/products (i.e. standardized systems manufactured at the manufacturer's plant and commissioned on site), national differences in standards between operators hinder the free movement of goods and safety. The aim is therefore to develop a standard that defines the minimum content of contracts in order to guarantee a fair division of responsibility with regard to safety between the interest groups (customers, manufacturers, etc.) and transparency between the stakeholders.

IMPLEMENTATION: This will be implemented as a new standardization need, preferably at European level. The responsible body still needs to be defined.

NEED 4.5.1-03: Vent stacks and flare stacks, exhaust systems

CONTENT: Design requirements; estimation aids for necessary heights

EXPLANATORY NOTES: Previous standards for vent stacks/flare stacks and exhaust systems originate mainly from the (petro)chemical industry. Due to high density differences and interactions with other air components when using cryogenic hydrogen, there are weaknesses in the standard design specifications. The ignition tendency of hydrogen is also relevant in its gaseous form, as ignition can occur due to electrostatic charging under otherwise unproblematic conditions.

IMPLEMENTATION: Development of a guideline that provides clear specifications for a safety-oriented design even when using hydrogen.

NEED 4.5.1-04: Release models/impact assessments

CONTENT: Model descriptions with application limits; description of the procedures

EXPLANATORY NOTES: There are many models for describing the release of substances. These are usually based on much heavier molecules than hydrogen and are therefore only usable to a limited extent. The modelling of the release of cryogenic hydrogen must take into account the affected air components and phase changes, which have not yet been adequately covered by standards.

IMPLEMENTATION: This will be implemented in the VDI/DIN-Commission on Air Pollution Prevention (KRdL) – Standards Committee. The topic of "liquid hydrogen" is being developed as an expert recommendation to supplement VDI 3783-1. The topic of "gaseous hydrogen" will be included in the next revision of VDI 3738-1.

NEED 4.5.1-05: Catalytic recombiners

CONTENT: Catalytic recombiners; safety measures

EXPLANATORY NOTES: Catalytic recombiners convert hydrogen into water vapour and do not require an external power supply when used passively. They are already used worldwide as a safety measure in nuclear power plants. They should be used as a general explosion protection measure. Possible applications include the control of hydrogen leaks in closed or poorly ventilated system areas, the extension of intervention times after detection of hydrogen leaks and the redundant safety function in the event of failure of active measures (e.g. in the event of a black-out).

IMPLEMENTATION: This will be implemented as a standardization project in CEN/TC 305. The national mirror body is NA 095-02 FB Section on fire and explosion prevention and protection.

4.5.1.4 Implementation projects

WG Safety design principles has evaluated and prioritized the specific implementation projects derived from the identified needs according to their importance for supporting the hydrogen market ramp-up in Germany, their scope and the urgency of their implementation.

In the first and second initiation rounds (summer and autumn 2023), no project proposals for standardization or technical rule-setting were submitted to the WG for financial support in the standardization bodies. For many of the identified needs, the right standardization body still needs to be found.

4.5.2 Cyber security

The topic of cyber security is already established. Everyone involved in the hydrogen value chain must make their contribution. As a rule, companies have an IT infrastructure that naturally needs to be secured according to its tasks and criticality (e.g. according to DIN EN ISO/IEC 27000 standards series [396]). Automated and networked control technology – Operational Technology (OT) – has been used in the process industry for many decades. This OT infrastructure must also be secured according to its tasks and criticality (e.g. in accordance with DIN EN IEC 62443 standards series [397]). The combination of both infrastructures (IT and OT) results in efficiency and synergy effects as well as the need for a holistic view of cyber security, as otherwise there will be "weak points" and thus points of attack for cyber attacks.

In terms of the future hydrogen industry and infrastructure, this primarily means building on existing standards and technical rules with regard to cyber security and expanding these to include specific challenges. In particular, the longevity of systems and components must be taken into account. For hydrogen as a critical infrastructure sector, there are numerous regulatory requirements, including IT security legislation, which must be met by complying with standards and technical rules.

4.5.2.1 Analysis of the status quo

Around 40 different national and international standards and technical rules [13] were identified that deal with the topic of cyber security to varying degrees and that may be relevant for the WG. This results in a large amount of available information from different perspectives. The contents identified are normative documents and recommendations for action on general topics that can be extended to hydrogen applications or are already applicable to them. It still needs to be clarified which of these documents and any clauses contained therein should actually become part of the Standardization Roadmap Hydrogen Technologies. In addition to these technical principles, potential legal requirements were also identified. These are primarily the respective national implementations of the EU NIS 2 Directive [398] with regard to the question of which hydrogen applications are included in the area of critical energy generation infrastructures. Furthermore, requirements from other areas of legislation, for example those with regard to machine safety, such as the new Machinery Regulation [173], may be applicable to individual hydrogen applications and should therefore also be considered.

Figure 37 presents the identified bodies that are important for the development of technical rules in the field of cyber security. An overview of the abbreviations used to describe these bodies is given in Section 9.

4.5.2.2 Requirements and challenges

The aspects listed below are aimed at the industry products to be created and launched on the market. The relevant companies have an IT/OT infrastructure that must be secured in accordance with its tasks and criticality [396], [397]. The following requirements are aimed in particular at the durability of systems and components; furthermore, aspects of use in non-industrial environments (e.g. private use) must be taken into account.

→ **Requirement for autonomy:** All H_2 systems are fully functional in terms of safety, regardless of central organizations, manufacturers or central IT systems. Operation must be ensured for an unlimited period of time even without access to a data network. No standard currently stipulates specific operating times or the necessary

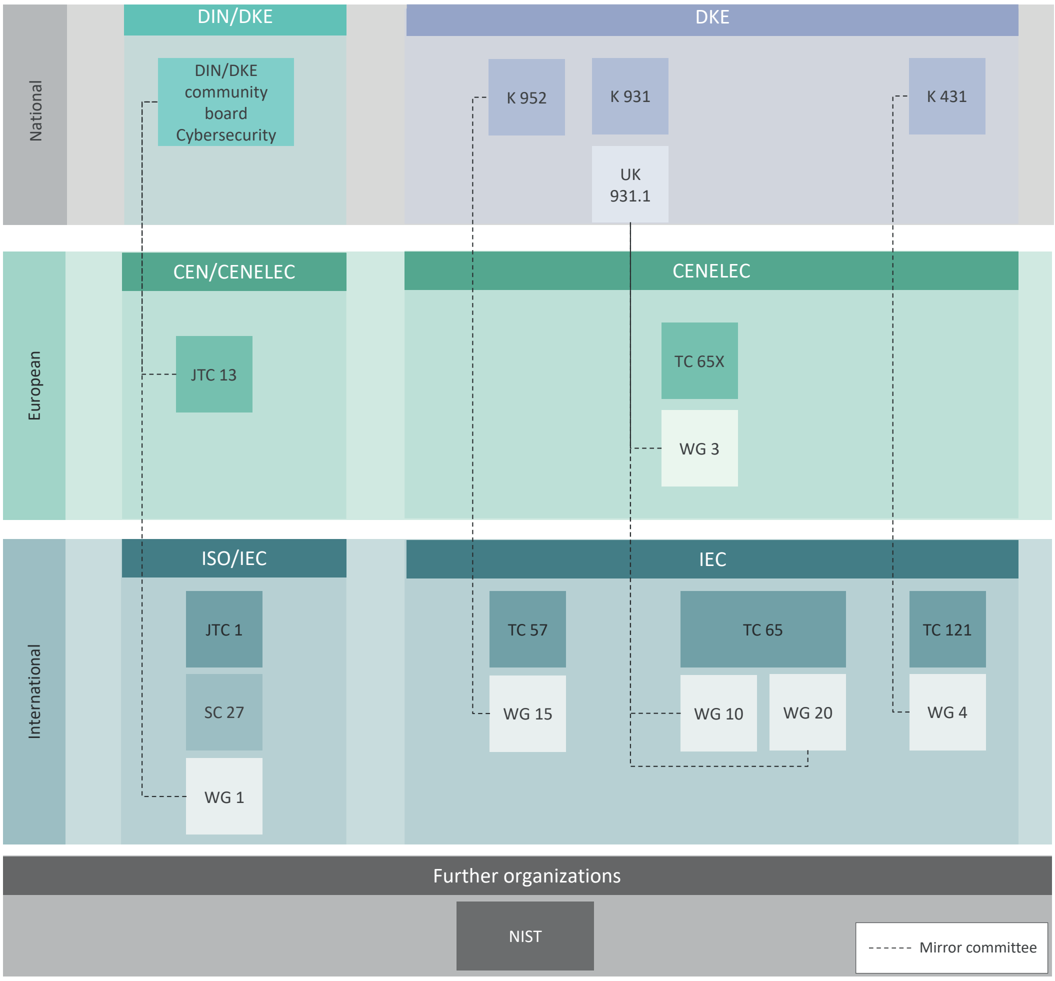

Figure 37: Overview of bodies relevant to technical rule-setting in the area of cyber security (as of 03-2024) (Source: own illustration)

autonomy. This could also be covered by corresponding rules. An initial proposal for this period of time is ten years (see also the cryptography used).

→ **Requirement for minimal complexity:** The hardware, software and operating concept must be designed with minimal complexity. Currently, no standard prescribes the avoidance of unnecessary complexity (e.g. communication functions or AI functions). This could also be covered by corresponding regulations that address the change of operator.

→ **Hardware requirements:** The hardware used must meet established standards in terms of cyber security [399].

→ **Requirements for the cryptography used:** Cryptographic means must be designed to operate for at least ten years. Requirements from DIN EN IEC 62351-9 [400] are seen as applicable guidelines.

A corresponding definition of cybersecurity requirements for the operation of small hydrogen-based appliances in the context of non-industrial applications or for micro-vehicles should be sought.

4.5.2.3 Needs analysis

NEED 4.5.2-01:
Definition of cyber security requirements for the operation of hydrogen-based small appliances in the context of non-industrial applications or for mini-vehicles

CONTENT: Hydrogen-based small appliances; non-industrial applications; mini vehicles

Explosion protection

EXPLANATORY NOTES: In terms of the the energy supply of hydrogen-based small appliances that are operated outside of an industrial context, further measures are required to ensure cyber security. As a rule, they are operated by untrained personnel. The appliance itself must have the necessary technical equipment to ensure cyber security. Monitoring devices that are operated by the manufacturer or authorized representative are a conceivable approach (operator). In principle, all appliances in a decentralized environment (e.g. no permanent connection to the internet or another local network) must be able to perform their nominal task without restrictions. In a critical case, in the event of imminent danger or tampering attempts, such an appliance must take its own steps in this context to bring about a safe state. At present, there are not any known standards or technical rules on this subject (s. Figure 38).

IMPLEMENTATION: The means of implementing this need still needs to be clarified.

4.5.2.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.5.3 Explosion protection

Hydrogen will play a key role in many areas of the future energy system and will come into contact with existing systems such as heating applications, filling stations, industrial applications, electricity production and storage. In the field of explosion protection, there has been experience with hydrogen used in industrial applications for decades. Due to the German and European hydrogen strategies, new and broad applications are being added that come into physical contact with public life and, to a certain extent, are also accessible to non-specialists. Furthermore, the significantly increased

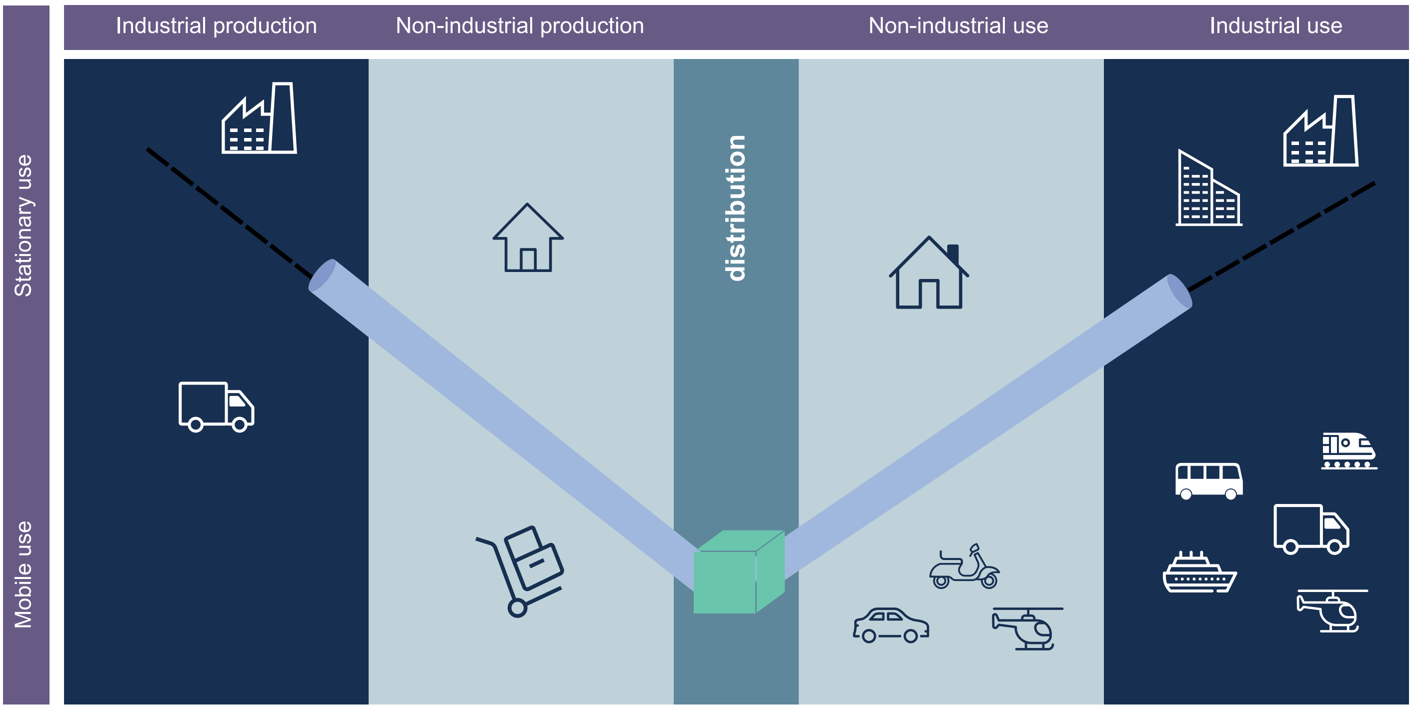

Figure 38: Context cyber security for hydrogen utilization
(Source: Standardization Roadmap Hydrogen Technologies WG Cyber security)

quantities of hydrogen in production and transportation must be taken into account, as well as the fact that many new hydrogen applications take place under special operating conditions. This may result in the need for additions and amendments to the relevant safety standards and technical rules. In order to integrate hydrogen into existing systems in a safe and available manner, it is important to take a special look at the systems and applications against the background of holistic explosion protection. This WG deals with whether there are gaps in standardization and technical rule-setting within the newly added areas of application. There is a close exchange with all relevant WGs of this Roadmap.

It is important that the many national, European and international standards and technical rules are structured and, if necessary, summarized so that users can find the right standards, technical rules and guidelines without time-consuming research. Contradictory statements, overlaps and multiple regulations must be avoided. The focus is on European and non-European standardization and technical rule-setting.

4.5.3.1 Analysis of the status quo

For explosion protection products [10] and potentially explosive atmospheres in commercial operations [11] and in commercial enterprises [12], the standards and technical rules of the relevant international and national bodies also contain requirements relating to the special features of hydrogen. Therefore, these standards and technical rules contain comprehensive and sufficient requirements with regard to the prevention of ignition sources for explosion-protected equipment, even when explosive atmospheres with hydrogen occur. These are very well coordinated from the global to the national level (types of protection, installation, maintenance, principles of zoning). The principles of zoning are described in international standardization. In Germany, the collection of examples, DGUV 113-001 [401], has been in use for many decades. At international level, however, the application of different technical principles in the development and implementation of explosion protection concepts (e.g. tightness of systems) has an influence on the zoning and therefore also on the use of products. At national level, the requirements of TRGS 720 to TRGS 727 [402] apply to commercial operations, which are largely in line with the corresponding European Standards.

According to the current state of knowledge of the WG, the specific international standards and technical rules that deal with general safety concepts of hydrogen plants, including explosion protection [13], refer to the standards dealing with general explosion protection. There are also standards and technical rules for cryogenic hydrogen applications. These are currently undergoing a comprehensive revision and therefore do not yet have the same level of content as the standards and technical rules for gaseous hydrogen. Care should also be taken here to ensure that the content is coordinated with the above-mentioned explosion protection standards.

In summary, there are still gaps in standardization and technical rule-setting. For example, the ATEX Directive 2014/34/EU [237] and the associated standards only refer to atmospheric conditions. There are also gaps in the technical rules, particularly for future applications (e.g. cryogenic hydrogen or high pressures). Various new technologies such as high-temperature electrolysis systems (SOE) are also not yet regulated by standards at present. It should also be noted that some technical rules for specific technologies are not harmonized with the European directives. With the expansion of technologies from the industrial to the public sector (within the scope of the ATEX Directive 2014/34/EU [237] (products) and the German Hazardous Substances Ordinance (operation)), gaps in standards and technical rules may arise. New technologies for areas that are not covered by the regulations (e.g. ATEX), such as domestic areas, must be considered separately.

10 Explosion protection products are appliances, components, and safety, monitoring and control devices and protective systems as defined by Directive 2014/34/EU [237].

11 Commercial operations include, for example, “employing companies” in accordance with Section § 2 of the German Occupational Health and Safety Act (ArbSchG), and companies that fall within the scope of the German Federal Immission Control Act (BImSchG) or that of the German Energy Industry Act (EnWG) [414].

12 Commercial enterprises without their own employees fall within the scope of the German Act on Installations Requiring Monitoring (ÜAnlG) if they operate installations requiring monitoring for commercial purposes [415].

13 For example, standards for electrolysis, filling stations for gaseous hydrogen, fuel cells.

4.5.3.2 Requirements and challenges

The following gaps in standardization and technical rules should be noted:

Harmonized standards for EU Directive 2014/34/EU with an EU request specify the requirements for the products covered by the scope of application. These requirements are binding at national level. At EU level, the EU Directive 1999/92/EC [403] specifies the procedure for a holistic explosion protection concept. The requirements for operation are specified at European level as a minimum and can be supplemented at national level on this basis. Extensive use is made of this adaptation option in the field of explosion protection. There are currently no standardized specifications for the main components of hydrogen systems, such as hydrogen dispensers, compressors, etc., which leads to different product variants and delays the market ramp-up of hydrogen technologies.

For some topics, pre-normative research is still required, such as in the case of:

→ ignition sources, e.g. electrostatic charging due to particles in the gas flow, catalytic surfaces or shock ignition;
→ LH_2, e.g. for ignition processes, during the release or separation of solid, pure oxygen;
→ the design of constructive protective measures such as the installation of flame arresters for hydrogen-oxygen blends, especially for large diameters.

For other topics, there is a specific need to supplement technical rules, such as:

→ requirements for typical non-atmospheric conditions;
→ pressure-resistant design for controlling detonations inside systems;
→ harmonization at international level of requirements for the tightness of hydrogen systems;
→ technical rules on the subject of cryogenic hydrogen are currently still very outdated. For this reason, ISO has launched various standardization projects in which the special requirements of explosion protection are to be taken into account.

In order to ensure the safety of hydrogen plants, there is a fundamental need for a normative and regulatory description of the necessary expertise of all parties involved in the construction and safe operation, including inspection and maintenance, of hydrogen plants.

4.5.3.3 Needs analysis

The WG is currently still working on concrete needs. Due to the complex situation (see 4.5.3.2), it has not yet been possible to convert general needs into specific needs for technical rule-setting. The specific needs will be published in the second version of this Standardization Roadmap Hydrogen Technologies at the end of 2025. The following general needs are currently identified:

→ harmonization at international level of requirements for the tightness of hydrogen systems with the aim of transferring the tried and tested technical rules TRGS 722 [404] into international standardization;
→ adaptation and extensive harmonization of the collections of examples for the design of ex zones to the current development of hydrogen technologies (e.g. upscaling) in international standardization and national technical rule-setting;
→ determination of static equivalent pressures to specify the required compressive strength for detonations in the area of pressure-resistant construction methods for controlling detonations inside systems;
→ consideration of explosion protection requirements right from the start, in the new versions of the standards for cryogenic hydrogen;
→ standardization of various new technologies, such as high-temperature electrolysis plants (SOE).

4.5.3.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.5.4 Safety and integrity management

The topic of safety and integrity management is a classic cross-cutting issue in which, regardless of the various technical implementations in the hydrogen value chain, standards are specified with their subordinate processes and methods in order to ensure the necessary safety throughout the entire life cycle of a hydrogen technology. It thus primarily addresses the management of an organization that manufactures products for the production, transmission, storage or use of hydrogen or is responsible for the ongoing operation of a plant consisting of these components. Due to their structure, these organizations must be able to define the necessary conditions and keep them actively implemented so that their products cannot become the cause of damage or an accident. The WG Safety and integrity management naturally has many points of contact with WG Safety design principles. However, the WG distinguishes itself by not defining any requirements for standards and technical rules with regard to technical safety or the technical implementation of functional safety.

4.5.4.1 Analysis of the status quo

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 [13]. 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 electrolysers, 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. National, European and international standards are listed. Naturally, due to the national initiative of this Standardization Roadmap Hydrogen Technologies and the experts, the focus is primarily on national standards and technical rules.

4.5.4.2 Requirements and challenges

The main activities of WG Safety and integrity management during the first six months included working closely with WG Safety design principles to establish the cross-cutting issues and draw up a list of questions for the other WGs. This list of questions and the answers given are aimed at identifying new applications, their risks and the groups of people affected. This was only possible through knowledge of the actual technical implementation. On the other hand, the WG Safety and integrity management was approached in the same way. The focus here was less on specific questions relating to normative requirements and more on the methodical procedure for carrying out risk analyses. This required an intensive exchange with the experts who formulated the questions.

Another focus was on researching already established incident and event databases. These have been established so that manufacturers or operators can learn from specific incidents and review and improve their systems accordingly. These include the Central Reporting and Evaluation Centre for Incidents and Accidents in Process Engineering Plants (ZEMA) [405] at the German Federal Environment Agency and HIAD 2.1 – The Hydrogen Incident and Accidents Database [406] of the European Commission. However, the solutions available to date are still very limited in their benefits. For example, companies lack the necessary commitment and motivation to report unexpected events. It is also difficult to identify information in the extensive data pools that is relevant for a specific safety-related task. It is seen as the task of industry and politics to ensure a higher level of commitment and to improve the usability of the information for manufacturers and operators.

4.5.4.3 Needs analysis

Due to the complex situation, see Section 4.5.4.2, it has not yet been possible to convert general needs into more specific needs for standardization and technical rule-setting. The following general needs are currently identified:

NEED 4.5.4-01:
Verification of safety

CONTENT: Verification of safety; plants; components

EXPLANATORY NOTES: In order to keep the risk of an accident below a socially accepted threshold risk, uniform procedures and methods for assessing functional safety must be defined. In particular, clear responsibilities of the various stakeholders who are responsible for or come into contact with systems and components in the life cycle of the hydrogen economy must be defined. Standardized verification is a prerequisite for a comparable and efficient assessment by a certification body.

IMPLEMENTATION: The extent to which the existing standards and technical rules are suitable and sufficient cannot yet be answered conclusively.

NEED 4.5.4-02:
Application guide for planning and carrying out hazard and risk analyses on systems and installations with hydrogen

CONTENT: Guide; general hydrogen systems; plants; complexity

EXPLANATORY NOTES: There are basic guidelines and standards for planning and carrying out hazard and risk analyses on systems and installations with hydrogen, as well as concrete application guidelines for specific applications and special methods. However, a guideline that serves as an overarching and generally usable link for hydrogen applications is lacking which, depending on the respective complexity and novelty of a hydrogen application, allows the most economical and target-oriented methods for carrying out hazard and risk analyses to be selected. In addition, many specific areas lack requirements for the qualification of persons involved in the safety life cycle of the system or product.

IMPLEMENTATION: This should be implemented as a new standardization need, preferably at European level. The responsible body still needs to be defined.

NEED 4.5.4-03:
Requirements for persons carrying out risk assessments

CONTENT: Description; role profile; levels of competency

EXPLANATORY NOTES: In standards for the design of hydrogen systems, risk assessments are prescribed with reference to various risk analysis methods. However, a key success factor for risk assessments is not so much the methodology itself, but rather the optimal composition of the assessment team. There should therefore be a technical rule that describes the role profiles, defines the necessary skills profiles, and sets minimum requirements for the necessary professional experience.

IMPLEMENTATION: This should be implemented as a new standardization need, preferably at European level. The responsible body still needs to be defined.

4.5.4.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.5.5 Product certification

WG Product certification deals with the necessary technical rules for the certification of products under the legal provisions. The perspective of the accredited or notified bodies and their requirements and needs for technical rule-setting are considered here.

In accordance with the specifications of the BMWK, the hydrogen medium itself is not the subject of the WG Product certification.

4.5.5.1 Analysis of the status quo

In the European legal system, technical requirements for products that are made available on the market are uniformly regulated by EU regulations and directives. The protection targets of EU legislation can be specified in harmonized standards for the respective products [407]. Although the harmonized standards at EU level do not explicitly deal with hydrogen applications, these applications are also partially covered by the scopes of the respective EU directives. Hydrogen-related system standardization (e.g. for electrolysers) is largely only known at ISO level.

The list of around 135 national, European and international documents identified in this Roadmap (see Standards Database for Hydrogen Technologies [13]) (Database of standards for hydrogen technologies, in German only)) provides the basis for requirements for the certification of products used in the hydrogen value chain. The aforementioned national technical rules, e.g. DIN Standards or DVGW technical rule – codes of practice, fill the gaps in the European collection of technical rules. The WG is currently reviewing the existing standards and technical rules in the areas of the Regulation on Appliances Burning Gaseous Fuels, the Machinery and Pressure Equipment Directives and regulations on explosion protection with regard to their adaptation to hydrogen.

The field of standardization activities at European level is expanding considerably with regard to the production of H_2 as new manufacturing processes are taken up and volumes are scaled up. This results in new assessment criteria for the standards and technical rules with regard to certification. Provisions in national legislation that go beyond European legislation are missing in international standardization, e.g. social, climatic and sustainable aspects according to national climate protection legislation, as well as requirements from additional national fire protection or wastewater legislation. In particular, there are already initial certification schemes for products, e.g. by the DVGW [408]. In a second step, these are being incorporated into national and European standardization and technical rule-setting.

For the operation of plants, there are also EU directives in accordance with Article 153 of the TFEU (minimum social standards) [409] with minimum requirements for the protection of employees at work, which can be supplemented by the member states. There are therefore no uniform operating regulations for trade and industry at European level. In Germany, this is covered for trade and industry by the Ordinance on Industrial Safety and Health and the Ordinance on Hazardous Substances as well as the TRBS and TRGS technical rules issued thereunder.

In the private sector, it must be ensured that the formation of hazardous explosive atmospheres is prevented. It is therefore necessary to check which requirements apply in each individual case, e.g. with regard to tightness. For the private sector, largely uniform building regulations [410] and firing regulations [410] of the German Länder apply. The Länder building regulations refer to correspondingly certified products or construction products. As a rule, this is verified by a corresponding CE certification of the components and appliances. Where harmonized CE provisions do not yet exist, national certification schemes or provisions are also used.

4.5.5.2 Requirements and challenges

The special physical properties of hydrogen, such as higher ignitability [411], a higher combustion temperature [412] and a higher diffusion coefficient [411] compared to conventional energy carriers, require a detailed description of the state of the art, standardization and technical rule-setting for products. This is the only way to ensure safe operation and safe use during a rapid ramp-up of hydrogen technologies. In the area of explosion risks, non-atmospheric conditions (e.g. oxygen enrichment, high pressures and temperatures) are outside the scope of Directive 2014/34/EU [413].

National standardization and technical rule-setting should also provide specific guidance on the installation of systems (interfaces between product safety and operation), taking international standards into account. For the private sector, the use by non-professionals in particular is taken into account as part of product or system certification. Furthermore, the requirements and recognition of qualifications for the specialist companies carrying out the work must be observed. Current standardization and technical rule-setting still have gaps regarding the private application area, the commercial and industrial sectors, the gas infrastructure and safety equipment.

Product standardization does not cover requirements for the maximum permissible leakage rates of systems installed on site or for greenhouse gas emissions over the life cycle of the overall application and proof of compliance. Ongoing prenormative research projects largely cover the subject areas of product standardization. The aspect of sustainability over the product life cycle is currently not always taken into account. Furthermore, future bans on substances such as PFAS in electrolyzer membranes could prevent the market ramp-up, as these would then require an exemption permit.

4.5.5.3 Needs analysis

Legal framework conditions and interfaces between laws and regulations: EU regulations and EU directives generally apply to products throughout Europe, but these do not fully cover the risks associated with hydrogen applications, such as leak tightness or non-atmospheric conditions. In some cases, ISO Standards can be used as a source of information. The extent to which these standards reflect the European requirements for products must be examined at national and European level.

NEED 4.5.5-01:
DIN 30652-1:2021-06, Excess flow valves – Part 1: Excess flow valves for gas installation [373] and DIN 30652-3:2021-06, Excess flow valves – Part 3: Conformity assessment of excess flow valves for gas installation [374]

EXPLANATORY NOTES: This need is also seen by WG Components for application and technologies and will be implemented by them.

NEED 4.5.5-02:
DIN 30652-2:2022-09, Excess flow valves – Part 2: Excess flow valves for service lines [132] and DIN 30652-4:2022-09, Excess flow valves – Part 4: Conformity assessment of excess flow valves for service lines [376]

EXPLANATORY NOTES: This need is also seen by WG Components for application and technologies and will be implemented by them.

NEED 4.5.5-03:
Requirements for sensors for detecting hydrogen

CONTENT: Detection methods; application areas

EXPLANATORY NOTES: The existing standards in the field of gaseous H_2 detection are limited to sensors that make statements about the H_2 content of the measured atmosphere on the basis of the heat tinting of catalytic processes, and therefore require direct exposure to H_2. The processes for hydrogen detection are more advanced, so that new sensor types and new applications are in preparation. The quality requirements and measurement criteria must be expanded for these technologies and cases.

IMPLEMENTATION: The WG is currently working on this specific need. A technical rule-setting body for implementing this need still needs to be identified.

4.5.5.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

4.5.6 Further training

The WG Further training deals with the needs for specialists with different qualifications and tasks along the entire H_2 value chain. Depending on the area of activity, the focus is on acquiring and demonstrating specific specialist skills, which are required in particular by legal regulations.

4.5.6.1 Analysis of the status quo

The qualification of personnel is required by the European legal framework directly, but also indirectly, for both manufacturers [14] and operators [15] of plant or machinery. In Germany, this need is implemented by legislation such as the Product Safety Act, the Occupational Health and Safety Act and the Energy Industry Act, as well as by the Crafts Ordinance and associated ordinances. Manufacturers or installers of systems and other service providers must deploy appropriately trained personnel who are qualified to know the legal requirements

14 Manufacturers can also mean suppliers and service providers. This definition is based on that in EmpfBS 1113 “Procurement of work equipment” No. 2 para. 2 [416].

15 Operators can also mean employers within the meaning of Section 2 of the German Occupational Health and Safety Act (ArbSchG), natural or legal persons within the meaning of Section 2 No. 3 of the Act on Installations Requiring Monitoring (ÜAnlG), persons responsible in companies that fall within the scope of the Federal Immission Control Act (BImSchG) or the Energy Industry Act (EnWG). [414]

and apply them correctly in their area of responsibility. Product requirements are primarily specified in standards. On the operator side, it must be ensured that employees are appropriately qualified to carry out their activities safely. Specialist knowledge is required for certain tasks, e.g. for risk assessment. Occupational health and safety is specified in government technical rules (e.g. TRBS/ TRGS) as well as by regulations and information from the German Social Accident Insurance (DGUV), in which all employers' liability insurance associations and statutory accident insurance funds are represented. The DVGW technical rules apply to the grid-based supply of gas and hydrogen to the general public. The VDE technical rules apply to the grid-based supply of electricity. This legal framework already exists and is generally defined independently of the substances used. The regulations for further training relate primarily to the necessary qualifications of the staff in connection with the respective assigned work tasks and the associated responsibilities.

The analysis of the status quo carried out by the WG focused on national provisions, while international regulations were discussed in some cases. About 40 primarily national documents were identified and are listed in the Standards Database for Hydrogen Technologies (Database of standards for hydrogen technologies, in German only) [13].

4.5.6.2 Requirements and challenges

The properties of hydrogen require specialist expertise from personnel throughout the entire value chain. Among other things, the handling of hazards should be emphasized here, e.g. due to the high diffusivity in solids when compressing hydrogen or the ability to form an explosive atmosphere within very wide limits [394]. H_2 has been used in industry for over 100 years. The historically evolved provisions of the legal framework and the resulting technical rules define qualifications and further training requirements from a wide variety of perspectives. This results in a high lack of transparency. One result of this development is that technical rules and the requirements they contain for qualifications to perform specific tasks were defined at different times and by different bodies for specific topics or tasks and must be complied with. A substance-specific definition is not given as a matter of priority. This leads to a lack of transparency in connection with H_2 technologies, which often results in additional efforts and insufficient knowledge/awareness. Recognizing and deciding on the necessary qualification measures for personnel is particularly challenging for contributors who are considering the topic of H_2 technologies for the first time. As a result, there is a desire among some contributors for H_2-specific qualification requirements, which would, however, lead to existing specifications being taken up again.

Raising awareness of specific qualification requirements affects everyone involved in the H_2 value chain – including manufacturers and operators. Both the manufacture and subsequent operation of H_2-carrying plants require specialist personnel, which is also required by the legal framework. When planning projects, the additional training required must be taken into account. The different perspectives of future participants in the H_2 value chain and the existing lack of transparency lead to uncertainties. As a result, the additional work required for qualifications is not always fully recognized at an early stage or is overestimated. Furthermore, there is an inhomogeneity of terms and their definitions in the legal framework. This applies independently of the topic of hydrogen, but leads to additional challenges.

4.5.6.3 Needs analysis

Overarching needs in the area of training: Qualified personnel must be available for the market ramp-up of hydrogen technologies. Transparency and clarity must therefore be created in the provisions relating to qualification requirements and media-specific knowledge. To this end, an overview of H_2 technology-related requirements for specialist knowledge and skills could be compiled in relation to a specific task or work situation. This would provide all participants with a further concretization of the rather general government requirements and sensitize them to the possible resulting risks.

The existing provisions regulate the qualification requirements for specific topics and tasks. New interest groups in H_2 technologies in particular expect a substance-specific approach. As a result, the desire or demand for H_2-specific specialists for a wide range of tasks should be finally discussed and answered in order to define clear specifications. The assignment of tasks to personnel is associated with the

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respective qualification requirements. This applies to all participants in the field of H_2 technologies. To make it easier for them to get started and thus accelerate the market ramp-up, a clear and practical description of the responsibilities for companies is required. An (H_2-independent) technical rule-setting and harmonization of terms and definitions in the area of training and the associated legal framework should be sought in order to implement clear guidelines.

NEED 4.5.6-01:
DIN/TR – Entry into the H_2 value chain – qualification requirements in accordance with the legal framework

CONTENT: Guidelines; legal framework; qualification requirements

EXPLANATORY NOTES: It is foreseeable that, in the future, H_2 will be used in a new function as an energy carrier and storage medium. New market participants and sectors must have knowledge of the special characteristics of H_2, the legal requirements and the resulting demands on the respective qualifications in order to be able to develop them. At present, the legal and substantive relationships are not transparent due to the historically evolved laws and technical rules.

IMPLEMENTATION: The legal framework with the necessary qualification requirements for those involved in the H_2 value chain will be presented in a comprehensible manner in a guideline. Implementation is expected to take place in a new body of the DIN Standards Committee Gas Technology (NAGas).

4.5.6.4 Implementation projects

To date, no implementation projects have been proposed by the WG for financial support by the BMWK.

5 Looking ahead

The publication of this Standardization Roadmap Hydrogen Technologies lays an important foundation for the further development of the technical rules for hydrogen technologies. A comprehensive network of experts has been established and a diverse German opinion base has been created for future technical rule-setting projects. In the course of the work, it became apparent that the various subject areas are at significantly different stages of development. While the technical rules for grid-bound infrastructures are already almost complete and in some cases are being revised, other areas are in the coordination and initiation phase. For example, there are still many gaps that need to be closed in the areas of aviation and shipping, and alternative types of hydrogen production and derivatives.

The joint project will further specify and consolidate the existing Roadmap in order to further advance the development of the quality infrastructure for hydrogen. Over the next few years, there will also be more results from various research projects and practical experience that will enable the technical rules to be adapted and expanded. Here too, this Roadmap will support and coordinate the implementation of the technical rules with its network of experts. Furthermore, the progress of standardization activities and technical rule-setting activities at national, European and international level will be closely monitored and taken into account accordingly.

These developments and the further elaboration of recommendations for action to close existing gaps, particularly in areas that are currently still at a low level of development, will be presented in the second version of the Standardization Roadmap Hydrogen Technologies. The final version of the Roadmap will be published at the end of 2025.

We would like to thank all the experts involved for their valuable contributions to the successful development of this strategic Roadmap for standardization and technical rule-setting in the field of hydrogen technologies and look forward to further fruitful cooperation.

All interested experts are cordially invited to contribute their needs to the continuation of this Standardization Roadmap and, together with the technical rule makers, to further advance the Roadmap and its corresponding implementation to achieve a congruent and complete set of technical rules.

6
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7

Implementation projects

Below is an overview of all previously approved implementation projects that are financially supported by the BMWK (Federal Ministry for Economic Affairs and Climate Action). A list with further information on the individual projects can also be found on the Roadmap project website

Table 2: Implementation projects of the Standardization Roadmap Hydrogen Technologies

NUMBER	TITLE	TYPE OF PROJECT	TOPIC
DIN 30652 -1, -3	Excess flow valves for gas installations	National project; revision	Quality infrastructure
DIN 30652-2, -4	Excess flow valves for service lines	National project; revision	Quality infrastructure
DIN 35809	Sustainability criteria for hydrogen and hydrogen derivatives as energy carriers	National project; new project	Generation
DIN EN 416	Gas-fired overhead radiant tube heaters and radiant tube heater systems for non-domestic use – Safety and energy efficiency	European project; revision	Application
DIN EN 419	Gas-fired overhead luminous radiant heaters for non-domestic use – Safety and energy efficiency	European project; revision	Application
DIN EN 549	Rubber materials for seals and diaphragms for gas appliances and gas equipment	European project; revision	Quality infrastructure
DIN EN 1359	Gas meters – Diaphragm gas meters	European project; revision	Quality infrastructure
DIN EN 17082	Domestic and non-domestic gas-fired forced convection air heaters for space heating not exceeding a net heat input of 300 kW	European project; revision	Application
DIN SPEC 3456	Industrial valves – Additional requirements for metallic valves for hydrogen applications	National project; new project	Quality infrastructure
DVGW technical rule – code of practice G 441	Shut-off valves for maximum permissible operating pressures of up to 100 bar in the gas supply	National project; revision	Quality infrastructure
DVGW G 110	Stationary gas warning devices	National project; revision	Application

NUMBER	TITLE	TYPE OF PROJECT	TOPIC
DVGW technical information – guideline G 405	Conversion of existing valves for hydrogen	National project; new project	Quality infrastructure
DVGW G 655 (M)	H_2 ready – Gas applications	National project; revision	Application
EN 13385	Transportable gas cylinders – Battery vehicles for permanent and liquefied gases (excluding acetylene) – Inspection at the time of filling	European project; revision	Infrastructure
EN 13445-15	Unfired pressure vessels – Part 15: Specific requirements for hydrogen applications	European project; revision	Infrastructure
EN 13480-11	Metallic industrial piping – Part 11: Additional requirements for piping for hydrogen applications	European project; new project	Infrastructure
EN 13807	Transportable gas cylinders – Battery vehicles and multiple-element gas containers (MEGCs) – Design, manufacture, identification and testing	European project; revision	Infrastructure
ISO 17268-4	Gaseous hydrogen rail vehicle refuelling connection devices	International project; new project	Application
ISO 19887-2	Gaseous hydrogen – Fuel system components for hydrogen fuelled vehicles – Part 2: Railway vehicles	International project; new project	Application
VDE 0100-7XX	Electrical protective measures for hydrogen generators based on the electrolysis of water	National project; new project	Generation
VDE/EN/IEC 63341-4	Railway applications – Rolling stock – Fuel cell systems for propulsion – Part 4: Hydrogen refuelling protocols	National project (with later interna-tional integration); new project	Application
VDI 4635	Power to X; Part 1 – Primary aspects	National project; new project	Application
VDI 4635	Power to X; Part 2.2 Power to Liquids	National project; new project	Application

8
Glossary

TERM GERMAN	TERM ENGLISH	DEFINITION	SOURCE
Norm	standard	Document, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context	DIN EN 45020 [429]
Standard	specification	Result of technical rule-setting without mandatory involvement of all interested parties, without the obligation to involve the public and without a consensus requirement	Own definition
Technische Regelsetzung	technical rule-setting	In the context of the Standardization Roadmap Hydrogen Technologies, this term covers the creation of documents that are developed in technical rule-setting bodies. Among other things, they set out definitions, requirements, tests and/or methods to ensure the protection of health, safety and the environment. They also guarantee compatibility, quality and cost-effectiveness. The application of technical rules is voluntary. They can provide legal certainty for compliance with laws, directives and regulations through the presumption of conformity. Technical rules are an essential part of the self-administration of industry.	Own definition
Richtlinie	regulation	Rules promulgated by a regulatory body in accordance with legal statutes or directives	DIN EN ISO 18229 [430]
Regularien	regulations	Entirety of all rules applicable to a specific action or interaction, a business transaction an official rule or the act of controlling something	[431]
Pränormative Forschung	pre-normative research	Within the meaning of this Standardization Roadmap Hydrogen Technologies, pre-normative research includes research projects for the collection of scientific and technological data or the generally valid answering of normative questions, insofar as these are necessary as a basis for the creation or revision of technical rules.	Own definition

TERM GERMAN	TERM ENGLISH	DEFINITION	SOURCE
Umsetzungsprojekt	implementation project	Project that → is based on a recommendation for action → is recommended for funding by the Roadmap bodies, including the steering committee → is supported by approved funding from the BMWK (Federal Ministry for Economic Affairs and Climate Action) → is to be initiated/implemented by a responsible technical rule-setting body	Own definition
Handlungs-empfehlung an die technische Regelsetzung	standardization recommendation	Recommendation for the development of a technical rule based on a specific need, which has been confirmed by the responsible bodies of this Standardization Roadmap, including the steering committee, and is communicated to technical rule-setting bodies for implementation	Own definition
Konkreter Bedarf der technischen Regelsetzung	specific standardization need	Gap in technical rule-setting identified and formulated by a body of this Standardization Roadmap	Own definition
Bedarf der technischen Regelsetzung	standardization need	Gap in technical rule-setting identified by a body of this Standardization Roadmap and to be discussed there	Own definition
Projekt der technischen Regelsetzung	project for technical rule-setting	Development of a technical rule that can be based on a recommendation for action of this Roadmap or an implementation project of this Roadmap and is initiated/implemented by a responsible technical rule-setting body	Own definition
Wasserstofffähig	H_2-ready	H_2-ready is the term used to describe products or technologies that are able to work safely and efficiently with hydrogen as an energy source due to their features. For example, a gas-powered heat generator/boiler can be considered H_2-ready (hydrogen-capable) if it is technically prepared to be operated with 100 % hydrogen by volume during its service life and with only minimal conversion effort.	bdew – factsheet H_2-ready [432]

TERM GERMAN	TERM ENGLISH	DEFINITION	SOURCE
Brennstoffzelle	fuel cell	A generator of electricity using chemical energy directly by ionisation and oxidation of the fuel	International Electrotechnical Commission (IEV) [433]
Brennstoffzellen-Energiesystem	fuel cell power system	Generator system that uses one or more fuel cell modules to generate electric power and heat	International Electrotechnical Commission (IEV) [434]
Harmonisierte Norm	harmonized standard	European Standard adopted on the basis of a request made by the Commission for the application of Union harmonisation legislation	Regulation (EU) no. 1025/2012, Section 2 para. 1c) [435]

9 Overview of the technical rule-setting bodies named in the figures

Explanatory notes: Below is a list of the full titles of the bodies that are mentioned in the figures in this document to provide an overview of the relevant technical rule-setting bodies of the WGs. Current as of March 2024.

Table 3: Overview of the technical rule-setting bodies for hydrogen technologies named in the figures

ABBREVIATION	NAME OF BODY (GERMAN)	NAME OF BODY (ENGLISH)	LINK
ABS	Ausschuss für Betriebssicherheit	Committee on Work Equipment	Link to web page
AECM		European association for guarantee institutions	Link to web page
AEF		Agricultural Industry Electronics Foundation	Link to web page
AGS	Ausschuss für Gefahrstoffe	Committee on Hazardous Substances	Link to web page
ANSI/ AIAA		American Institute of Aeronautics and Astronautics	Link to web page
ASD-Stan/D 3/ WG 3		Fluid systems and components	Link to web page
ASD-Stan/D 4		Materials	Link to web page
ASTM		American Society for Testing and Materials	Link to web page
CEN/CLC/JTC 1	Kriterien für Konformitätsbegutachtungsstellen	Criteria for conformity assessment bodies	Link to web page
CEN/CLC/JTC 6	Wasserstoff in Energiesystemen	Hydrogen in energy systems	Link to web page
CEN/CLC/JTC 13	Cybersicherheit und Datenschutz	Cybersecurity and Data Protection	Link to web page
CEN/CLC JTC 14	Energiemanagement und Energieeffizienz im Kontext der Energiewende	Energy management and energy efficiency in the framework of energy transition	Link to web page
CEN/CLC JTC 17	Gasgeräte mit Kraft-Wärme-Kopplung	Gas Appliances with Combined Heat and Power	Link to web page
CEN/TC 1	Öl und Gasfernleitungen; Anforderungen an Rohre	Oil and gas pipelines; pipe requirements	Link to web page

ABBREVIATION	NAME OF BODY (GERMAN)	NAME OF BODY (ENGLISH)	LINK
CEN/TC 23	Transportable Gasflaschen	Transportable gas cylinders	Link to web page
CEN/TC 48	Gasbefeuerte Warmwasserbereiter für Haushalte	Domestic gas-fired water heaters	Link to web page
CEN/TC 49	Gaskochgeräte	Gas cooking appliances	Link to web page
CEN/TC 54	Druckbehälter ohne Feuerung	Unfired pressure vessels	Link to web page
CEN/TC 58	Sicherheit von Gasgeräten und Gasverbrauchseinrichtungen	Safety and control devices for burners and appliances burning gaseous or liquid fuels	Link to web page
CEN/TC 69	Industriearmaturen	Industrial valves	Link to web page
CEN/TC 106	Große Küchengeräte, die mit gasförmigen Brennstoffen betrieben werden	Large kitchen appliances using gaseous fuels	Link to web page
CEN/TC 109	Zentralheizungskessel und Kessel für Heizöl	Central heating boilers using gaseous fuels	Link to web page
CEN/TC 121	Schweißen	Welding and allied processes	Link to web page
CEN/TC 131	Gasbrenner	Forced draught burners for gaseous and liquid fuels	Link to web page
CEN/TC 133	Kupfer und Kupferlegierungen	Copper and copper alloys	Link to web page
CEN/TC 138	Zerstörungsfreie Prüfung	Non-destructive testing	Link to web page
CEN/TC 155	Kunststoff-Rohrleitungssysteme und Schutzrohrsysteme	Plastics piping systems and ducting systems	Link to web page
CEN/TC 180	Dezentrale Gasheizung	Decentralized gas heating	Link to web page
CEN/TC 185	Mechanische Verbindungselemente	Fasteners	Link to web page
CEN/TC 197	Pumpen	Pumps	Link to web page
CEN/TC 234	Gasinfrastruktur	Gas infrastructure	Link to web page
CEN/TC 237	Gaszähler	Gas meters	Link to web page

ABBREVIATION	NAME OF BODY (GERMAN)	NAME OF BODY (ENGLISH)	LINK
CEN/TC 238	Prüfgase, Prüfdrücke, Gerätekategorien und Gasgerätearten	Test gases, test pressures, appliance categories and gas appliance types	Link to web page
CEN/TC 267	Industrielle Rohrleitungen und Fernrohrleitungen	Industrial piping and pipelines	Link to web page
CEN/TC 268	Kryo-Behälter und spezielle Einsatzgebiete der Wasserstofftechnologie	Cryogenic vessels and specific hydrogen technologies applications	Link to web page
CEN/TC 269	Großwasserraum- und Wasserrohrkessel	Shell and water-tube boilers	Link to web page
CEN/TC 299	Gasbefeuerte Sorptionsgeräte, indirekt befeuerte Sorptionsgeräte, gasbefeuerte endotherme Motorwärmepumpen und gasbefeuerte Haushaltswasch- und Trockengeräte	Gas-fired sorption appliances, indirect fired sorption appliances, gas-fired endothermic engine heat pumps and domestic gas-fired washing and drying appliances	Link to web page
CEN/TC 305	Explosionsfähige Atmosphären – Explosionsschutz	Potentially explosive atmospheres – Explosion prevention and protection	Link to web page
CEN/TC 393	Ausrüstungen für Lagertanks und für Tankstellen	Equipment for storage tanks and for filling stations	Link to web page
CEN/TC 408	Biomethan zum Einsatz im Transportwesen und zur Einspeisung in Erdgasrohrleitungen	Natural gas and biomethane for use in transport and biomethane for injection in the natural gas grid	Link to web page
CEN/TC 459	ECISS – Europäisches Komitee für Eisen- und Stahlnormung	ECISS – European Committee for Iron and Steel Standardization	Link to web page
CESNI/PT	Europäischer Ausschuss für die Ausarbeitung von Standards im Bereich Binnenschifffahrt	European Committee for drawing up standards in the field of inland navigation	Link to web page
CLC/TC 8x	Systemaspekte der elektrischen Energieversorgung	System aspects of electrical energy supply	Link to web page
CLC/TC 31	Elektrische Betriebsmittel für explosionsgefährdete Bereiche	Electrical apparatus for potentially explosive atmospheres	Link to web page

ABBREVIATION	NAME OF BODY (GERMAN)	NAME OF BODY (ENGLISH)	LINK
CLC/TC 57	Datenmodelle, Schnittstellen und Informationsaustausch für Planung und Betrieb von Energieversorgungs-systemen	Power systems management and associated information exchange	Link to web page
CLC/TC 64	Elektrische Anlagen und Schutz gegen elektrischen Schlag	Electrical installations and protection against electric shock	Link to web page
CLC/TC 65X	Industrielle Prozessleit- und Automatisierungstechnik	Industrial-process measurement, control and automation	Link to web page
CLC/TC 216	Gaswarngeräte	Gas detectors	Link to web page
CSA		Canadian Standards Association	Link to web page
DKE/GK 914	Funktionale Sicherheit elektrischer, elektronischer und programmierbarer elektronischer Systeme (E, E, PES) zum Schutz von Personen und Umwelt		Link to web page
DKE/GUK 384.1	Stationäre Brennstoffzellengeräte		Link to web page
DKE/K 221	Elektrische Anlagen und Schutz gegen elektrischen Schlag		Link to web page
DKE/K 235	Errichten elektrischer Anlagen in explosionsgefährdeten Bereichen		Link to web page
DKE/K 238	Errichten elektrischer Anlagen im Bergbau unter Tage		Link to web page
DKE/K 241	DKE/K 241 Schlagwetter- und explosionsgeschützte elektrische Betriebsmittel		Link to web page
DKE/K 261	Systemaspekte der elektrischen Energieversorgung		Link to web page
DKE/K 384	Brennstoffzellen		Link to web page
DKE/K 431	Niederspannungsschaltgeräte und -kombinationen		Link to web page

ABBREVIATION	NAME OF BODY (GERMAN)	NAME OF BODY (ENGLISH)	LINK
DKE/K 461	Messeinrichtungen und -systeme für Elektrizität		Link to web page
DKE/K 901	System Komitee Smart Energy		Link to web page
DKE/K 931	Systemaspekte der Automatisierung		Link to web page
DKE/K 952	Netzleittechnik		Link to web page
DKE/K 966	Stoffgrößen-Messgeräte für Betrieb und Umwelt		Link to web page
DKE/UK 221.1	Schutz gegen elektrischen Schlag		Link to web page
DKE/UK 261.1	Elektrische Energiespeichersysteme		Link to web page
DKE/UK 931.1	IT-Sicherheit in der Automatisierungs-technik		Link to web page
DKE/UK 966.1	Mess- und Warngeräte für gefährliche Gase		Link to web page
DVGW G-LK-1	Lenkungskomitee Gasversorgung		Link to web page
DVGW G-LK-2	Lenkungskomitee Gasanwendung		Link to web page
DVGW W-LK-2	Lenkungskomitee Wasserver-sorgungssysteme		Link to web page
DWA	Deutsche Vereinigung für Wasser-wirtschaft, Abwasser und Abfall e.V.	German Association for Water, Wastewater and Waste	Link to web page
EIGA		European Industrial Gases Association	Link to web page
EURAMET		European association of national metrology institutes	Link to web page
FCNA (NA 012)	DIN-Normenausschuss Chemischer Apparatebau	DIN Standards Committee for Chemical Apparatus Engineering	Link to web page
FES (NA 021)	DIN-Normenausschuss Eisen und Stahl	DIN Standards Committee Iron and Steel	Link to web page

ABBREVIATION	NAME OF BODY (GERMAN)	NAME OF BODY (ENGLISH)	LINK
FMV (NA 067)	DIN-Normenausschuss Mechanische Verbindungselemente	DIN Standards Committee Mechanical Fasteners	Link to web page
FNH (NA 040)	DIN-Normenausschuss Heiz-, Koch- und Wärmgerät	DIN Standards Committee Heating and Cooking Equipment	Link to web page
FNK (NA 054)	DIN-Normenausschuss Kunststoffe	DIN Standards Committee Plastics	Link to web page
FNKÄ (NA 044)	DIN-Normenausschuss Kältetechnik	DIN Standards Committee Refrigeration Technology	Link to web page
FNNE (NA 066)	DIN-Normenausschuss Nichteisen-metalle	DIN Standards Committee for Nonferrous Metals	Link to web page
IEC/ SyC Smart Energy	Smart Energy	Smart Energy	Link to web page
IEC/SC 65A	Systematische Aspekte	System aspects	Link to web page
IEC/SC 65 B		Measurement and control devices	Link to web page
IEC/TC 121		Switchgear and controlgear and their assemblies for low voltage	Link to web page
IEC/TC 8	Systemaspekte der elektrischen Energieversorgung	System aspects of electrical energy supply	Link to web page
IEC/TC 31	Betriebsmittel für explosions-gefährdete Bereiche	Equipment for explosive atmospheres	Link to web page
IEC/TC 44	Sicherheit von Maschinen – Elektrotechnische Aspekte	Safety of machinery – Electrotechnical aspects	Link to web page
IEC/TC 57	Datenmodelle, Schnittstellen und Informationsaustausch für Planung und Betrieb von Energieversorgungs-systemen	Power systems management and associated information exchange	Link to web page
IEC/TC 64	Elektrische Anlagen und Schutz gegen elektrischen Schlag	Electrical installations and protection against electric shock	Link to web page
IEC/TC 65	Mess-, Regel- und Automatisierungs-technik für Industrieprozesse	Industrial-process measurement, control and automation	Link to web page

ABBREVIATION	NAME OF BODY (GERMAN)	NAME OF BODY (ENGLISH)	LINK
IEC/TC 105	Brennstoffzellentechnologie	Fuel cell technologies	Link to web page
IEC/TC 120	Systeme zur Speicherung elektrischer Energie (EES)	Electrical Energy Storage (EES) systems	Link to web page
IEC/TC 121	Schaltgeräte und Schaltanlagen sowie deren Baugruppen für Nieder-spannung	Switchgear and controlgear and their assemblies for low voltage	Link to web page
IMO	Internationale Seeschifffahrts-Organisation	International Maritime Organization	Link to web page
ISO/IEC/JTC 1	Informationstechnologie	Information technology	Link to web page
ISO/TC 8	Schiffs- und Meerestechnologie	Ships and marine technology	Link to web page
ISO/TC 17	Stahl	Steel	Link to web page
ISO/TC 20	Flugzeuge und Raumfahrzeuge	Aircraft and space vehicles	Link to web page
ISO/TC 22	Straßenfahrzeuge	Road vehicles	Link to web page
ISO/TC 28	Mineralölerzeugnisse und verwandte Produkte, Kraft-, Brenn- und Schmierstoffe mit natürlichem oder synthetischem Ursprung	Petroleum and related products, fuels and lubricants from natural or synthetic sources	Link to web page
ISO/TC 45	Gummi und Gummierzeugnisse	Rubber and rubber products	Link to web page
ISO/TC 47	Chemie	Chemistry	Link to web page
ISO/TC 58	Gasflaschen	Gas cylinders	Link to web page
ISO/TC 61	Kunststoffe	Plastics	Link to web page
ISO/TC 67	Öl- und Gasindustrie einschließlich kohlenstoffarmer Energieträger	Oil and gas industries including lower carbon energy	Link to web page
ISO/TC 71	Beton, Stahlbeton und Spannbeton	Concrete, reinforced concrete and pre-stressed concrete	Link to web page
ISO/TC 138	Kunststoffrohre, Armaturen und Ventile für den Transport von Fluiden	Plastics pipes, fittings and valves for the transport of fluids	Link to web page

ABBREVIATION	NAME OF BODY (GERMAN)	NAME OF BODY (ENGLISH)	LINK
ISO/TC 156	Korrosion von Metallen und Legierungen	Corrosion of metals and alloys	Link to web page
ISO/TC 158	Gasanalyse	Analysis of gases	Link to web page
ISO/TC 161	Regel- und Sicherheitseinrichtungen für Gas und/oder Öl	Controls and protective devices for gaseous and liquid fuels	Link to web page
ISO/TC 164	Mechanische Prüfverfahren für Metalle	Mechanical testing of metals	Link to web page
ISO/TC 172	Optik und Photonik	Optics and photonics	Link to web page
ISO/TC 193	Erdgas	Natural gas	Link to web page
ISO/TC 197	Wasserstofftechnologie	Hydrogen technologies	Link to web page
ISO/TC 199	Sicherheit von Maschinen und Geräten	Safety of machinery	Link to web page
ISO/TC 220	Kryogene Behälter	Cryogenic vessels	Link to web page
ISO/TC 265	Abscheidung, Transport und geologische Speicherung von Kohlendioxid	Carbon dioxide capture, transportation, and geological storage	Link to web page
ITF		International Transport Forum	Link to web page
KRdL (NA 134)	VDI/DIN-Kommission Reinhaltung der Luft	VDI/DIN Commission on Air Pollution Prevention – Standards Committee	Link to web page
NAA (NA 003)	DIN-Normenausschuss Armaturen	DIN Standards Committee Valves	Link to web page
NAAutomobil (NA 052)	DIN-Normenausschuss Auto und Mobilität	DIN Standards Committee Road Vehicles and Mobility	Link to web page
NABau (NA 005)	DIN-Normenausschuss Bauwesen	DIN Standards Committee Building and Civil Engineering	Link to web page
NAFuO (NA 027)	DIN-Normenausschuss Feinmechanik und Optik	DIN standards committee for precision mechanics and optics	Link to web page
NAGas (NA 032)	DIN-Normenausschuss Gastechnik	DIN Standards Committee Gas Technology	Link to web page

ABBREVIATION	NAME OF BODY (GERMAN)	NAME OF BODY (ENGLISH)	LINK
NAGUS (NA 172)	DIN-Normenausschuss Grundlagen des Umweltschutzes	DIN Standards Committee Principles of Environmental Protection	Link to web page
NAM (NA 060)	DIN-Normenausschuss Maschinenbau	DIN Standards Committee Mechanical Engineering	Link to web page
NARD (NA 082)	DIN-Normenausschuss Rohrleitungen und Dampfkesselanlagen	DIN Standards Committee Piping and Boiler Plant	Link to web page
NAS (NA 092)	DIN-Normenausschuss Schweißen und verwandte Verfahren	DIN Standards Committee for Welding and Allied Processes	Link to web page
NASG (NA 095)	DIN-Normenausschuss Sicherheits-technische Grundsätze	DIN Standards Committee on Safety Design Principles	Link to web page
NATank (NA 104)	DIN-Normenausschuss Tankanlagen	DIN Standards Committee Tank Installations	Link to web page
NAW (NA 119)	DIN-Normenausschuss Wasserwesen	DIN Standards Committee Water Practice	Link to web page
NDG (NA 016)	DIN-Normenausschuss Druckgas-anlagen	DIN Standards Committee Pressurized Gas Installations	Link to web page
NHRS (NA 041)	DIN-Normenausschuss Heiz- und Raumlufttechnik sowie deren Sicherheit	DIN Standards Committee for Heating and Ventilation Technology and their Safety	Link to web page
NIA (NA 043)	DIN-Normenausschuss Informations-technik und Anwendungen	DIN Standards Committee for Infor-mation Technology and Applications	Link to web page
NIST		National Institute of Standards and Technology	Link to web page
NL (NA 131)	DIN-Normenausschuss Luft- und Raumfahrt	DIN Standards Committee Aerospace	Link to web page
NMP (NA 062)	Beirat des DIN-Normenausschusses Materialprüfung	DIN Standards Committee Materials Testing	Link to web page
NSMT (NA 132)	DIN-Normenstelle Schiffs- und Meerestechnik	DIN Standards Committee Shipbuilding and Marine Technology	Link to web page

ABBREVIATION	NAME OF BODY (GERMAN)	NAME OF BODY (ENGLISH)	LINK
NoBOMet		NoBoMet is the European Coordination Group of the Conformity Assessment Bodies notified by the European Commission for the Directives 2014/31/EU (NAWID) and 2014/32/EU (MID) as agreed between the Commission and the national coordinators of legal metrology during the Working Group Measuring Instruments (WGMI) meeting on 22 November 2019	Link to web page
NSMT (NA 132)	DIN-Normenstelle Schiffs- und Meerestechnik	DIN Standards Committee Shipbuilding and Marine Technology	Link to web page
NÖG (NA 109)	DIN-Normenausschuss Erdöl- und Erdgasgewinnung	DIN Standards Committee Petroleum and Natural Gas Industries	Link to web page
OIML	Internationale Organisation für das gesetzliche Messwesen	International Organization of Legal Metrology	Link to web page
PTB	Physikalisch-Technische Bundesanstalt	(German national institute of metrology)	Link to web page
SAE		Society of Automotive Engineers	Link to web page
TÜV AD 2000	AD 2000 Regelwerk des TÜV-Verbands	AD 2000 Code of the TÜV Association	Link to web page
US Air Force		Air Force demonstrating hydrogen as alternate fuel source	Link to web page
VDE FNN	Forum Netztechnik/ Netzbetrieb im VDE	Network Technology/Network Operation Forum in the VDE	Link to web page
VDI 4635	VDI-Richtlinie 4635	VDI standard 4635	Link to web page
WELMEC		Legal Metrology in Europe (WELMEC – the European Cooperation in Legal Metrology – is a regional legal metrology organization with membership composed of the representative national authorities responsible for legal metrology in the EU and EFTA countries.)	Link to web page

10 Index of abbreviations

ABBREVIATION	FULL NAME
AD	Arbeitsgemeinschaft Druckbehälter (Working Group for Pressure Vessels)
ADV	Arbeitsgemeinschaft Deutscher Verkehrsflughäfen (Association of German Airports)
AFIR	Alternative Fuels Infrastructure Regulation
API	American Petroleum Institute
ARP	Aerospace Recommended Practice
ASME	American Society of Mechanical
ASTM	American Society for Testing and Materials
ATEX	Atmosphères Explosibles (explosive atmospheres) (see ATEX Equipment Directive 2014/34/EU and ATEX Workplace Directive 1999/92/EC)
BDEW	Bundesverband der Energie- und Wasserwirtschaft (German Association of Energy and Water Industries)
BImSchV (Ordinance on the Nature and the Classification of Fuel Qualities)	Bundes-Immissionsschutzverordnung (German Federal Immission Control Act)
BMDV	Bundesministerium für Digitales und Verkehr (Federal Ministry for Digital and Transport)
BMWK	Bundesministerium für Wirtschaft und Klimaschutz (Federal Ministry for Economic Affairs and Climate Action)
CCU	Carbon Capture and Utilization
CE	Conformité Européenne (European Conformity)
CEN	European Committee for Standardization
CEN TC	CEN Technical Committee
CENELEC	European Committee for Electrotechnical Standardization
CESNI	European Committee for drawing up Standards in Inland Navigation

ABBREVIATION	FULL NAME
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
CSA/ANSI CHMC 2	Canadian Standards Association/American National Standards Institute, Compressed Hydrogen and Methane Containers
DAkkS	Deutsche Akkreditierungsstelle (German Accreditation Body)
DGMK	Deutsche Wissenschaftliche Gesellschaft für nachhaltige Energieträger, Mobilität und Kohlenstoffkreisläufe e. V. (German Scientific Society for Sustainable Energy, Mobility and Carbon Cycles)
DGUV	Deutsche Gesetzliche Unfallversicherung (German Social Accident Insurance)
DIN	Deutsches Institut für Normung e. V. (German Institute for Standardization)
DIN EN Standard	European Standard that has been adopted as a German national standard
DIN EN ISO Standard	International Standard that has been adopted as a European Standard and thus adopted as a German national standard
DIN ISO	International Standard that has been adopted as a German national standard
DIN NA	DIN-Normenausschuss (DIN Standards Committee)
DIN SPEC	DIN Specification
DKE	Deutsche Kommission Elektrotechnik Elektronik Informationstechnik (German Commission for Electrical, Electronic & Information Technologies)
DVGW	Deutscher Verein des Gas- und Wasserfaches e. V. (German Technical and Scientific Association for Gas and Water)
DVGW G LK	DVGW-Lenkungskreis (DVGW Steering Committee)
DVGW G TK	DVGW Technisches Komitee (DVGW Technical Committee)
DVGW G PK	DVGW-Projektkreis (DVGW Project Group)
EclHypse	Energy Cluster H_2-Projects for European Cooperation
EMC	Electromagnetic compatibility

ABBREVIATION	FULL NAME
EN	Europäische Norm (European Standard)
EnWG	Energiewirtschaftsgesetz (German Energy Industry Act)
ERP	Enterprise Resource Planning
ES-TRIN	European Standard for technical Requirements for Inland Navigation Vessels
ETSI	European Telecommunication Standards Institute
EU	European Union
Ex-Schutz	Explosion protection
EX-Zonen	Explosion protection zones
FIPS	Federal Information Processing Standards
FKM	Forschungskuratorium Maschinenbau (Mechanical Engineering Research Board)
FNK	DIN Standards Committee Plastics
GA	Joint Working Committee
GAR	Gas Appliances Regulation
GasHDrLtgV	Gashochdruckleitungsverordnung (German High-Pressure Gas Pipeline Ordinance)
GasNZV	Gasnetzzugangsverordnung (German Gas Network Access Ordinance)
GIS	Geographic Information System
H_2	Hydrogen
HIAD	Hydrogen Incident and Accident Database
HydEKuS	Wasserstoff- und Erdgassicherheit in Kraftwerken und Systemen (hydrogen and natural gas safety in power plants and systems)
IATA	International Air Transport Association
IBC	International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk

ABBREVIATION	FULL NAME
IEC	International Electrotechnical Commission
IGC	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IGF	International Code of Safety for Ships using Gases or other Low-flashpoint Fuels
IMDG	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
IT	Information technology
IT-SIG	Informationstechnik-Sicherheitskatalog (Information Technology Security Catalogue)
ISO	International Organization for Standardization
JIG	Joint Inspection Group
JWG	Joint Working Group
SME	Small- and medium-sized enterprises
KoV	Kooperationsvereinbarung (cooperation agreement)
kWh	Kilowatt hour
KWK	Kraft-Wärme-Kopplung (power-heat coupling)
LH2	Cryogenic liquefied hydrogen
LNG	Liquefied Natural Gas
LOHC	Liquid organic hydrogen carriers
MEGC	Multiple Element Gas Container
MJ	Megajoule
Mol-%	Mol percentage
MPa	Mega Pascal

ABBREVIATION	FULL NAME
MPD	Multiple Product Dispenser
MD	Machinery Directive
MOP	Maximum Operating Pressure
MR	Machinery Regulation (EU Regulation 2023/1230)
NAGas	DIN Standards Committee Gas
NAM	DIN Standards Committee Mechanical Engineering
NARD	DIN Standards Committee Piping and Boiler Plant
NC DC	Network Code Demand Connection
NIS 2	Network and Information System Security Directive
NMP	DIN Standards Committee Materials Testing
NRM	Standardization Roadmap
NRM H2	Standardization Roadmap Hydrogen Technologies
NWB	Verein für die Normung und Weiterentwicklung des Bahnwesens e. V. (Association for Standardization and Development of the Railway System e. V.)
NWS	Nationale Wasserstoffstrategie (German National Hydrogen Strategy)
OIML	Organisation Internationale de Métrologie Légale (International Organization of Legal Metrology)
OEMs	Original Equipment Manufacturers
OT	Operational Technology
PFAS	Per- and polyfluoroalkyl substances
PED	Pressure Equipment Directive (European Directive 2014/68/EU)
PEM	Proton-exchange membrane

ABBREVIATION	FULL NAME
PTB	Physikalisch-Technische Bundesanstalt (Physical-Technical Federal Institute; German National Metrology Institute)
PtJ	Projektträger Jülich
PtX	Power-to-X
ppm	Parts per Million
PWI	Preliminary Work Item
RED II	Renewable Energy Directive II
RL	Richtlinie (directive)
SAE	Society of Automotive Engineers
SAV	Sicherheitsabsperrventil (safety shut-off valve)
SWC	sub-working committee
SGAM	Smart Grid Architecture Model
SSRT	Slow Strain Rate Testing
SOE	Solid Oxide Electrolysis
SOLAS	International Convention for the Safety of Life at Sea
TAR	Technische Anschlussregel (technical connection rule)
TC	Technical Committee
TFEU	Treaty on the Functioning of the European Union
THyGA	Technologische Hybride Gas-Anwendung (Technological Hybride Gas Application)
TPED	Transportable Pressure Equipment Directive (European Directive 2010/35/EU)
TR	Technical Report
TRBS	Technische Regeln für Betriebssicherheit (technical rules for operational safety)

ABBREVIATION	FULL NAME
TRGS	Technische Regeln für Gefahrstoffe (technical rules for hazardous substances)
TRGI	Technische Regel für Gasinstallationen (technical rules for gas installations)
TS	Technical Specification
TRL	Technology Readiness Level
UK	United Kingdom
USA	United States of America
VDA	Verband der Automobilindustrie e. V. (German Association of the Automotive Industry)
VDE	Verband der Elektrotechnik Eletronik Informationstechnik e. V. (Association for Electrical, Electronic & Information Technologies)
VDE FNN	Forum Netztechnik/Netzbetrieb im VDE (Forum Network Technology/Network Operation in the VDE)
VDI	Verein Deutscher Ingenieure e. V. (Association of German Engineers)
VDMA	Verband Deutscher Maschinen- und Anlagenbau e. V. (Machinery and Equipment Manufacturers Association)
WC	Working committee
WG	Working group
WPS	Welding Procedure Specification
ZEMA	Zentrale Melde- und Auswertestelle (central reporting and evaluation body)
ZP	Zertifizierungsprogramme (certification scheme)

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