CEN - CENELEC
Sector Forum Energy Management / Working Group Hydrogen

Final Report

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Executive Summary

Europe's energy system is undergoing profound changes. The EU is planning a decarbonisation path that will see the EU reduce their emissions by up to 95% by 2050. To reach this ambition of a carbon-neutral energy supply, the electricity sector will see an increase in variable renewable energy sources (RES) like wind and solar power in the generation portfolio. As a consequence, the electricity system will not only continue to face varying electricity demand throughout the day, but increasingly experience generation-driven fluctuations. The conversion of excess electricity to hydrogen (and vice versa) can help facilitate the integration of large shares of intermittent renewable sources into the electrical grid. Water electrolysers can produce hydrogen from excess or low-cost electricity, either connected to the grid or in off-grid installations. The conversion of (renewable) electricity to hydrogen, also referred to as power-to-hydrogen (PtH), enables the long-term storage of energy and can reduce the load in electricity grids. The produced hydrogen can either be used directly as a chemical feedstock, as a fuel for transport, be fed into the natural gas grid, or be converted back to electricity during periods of large demands. When hydrogen is injected into the gas grid it will increase the share of renewable energy in the natural gas grid, and from there in the end-use applications of transport, heat and industry, where achieving higher-renewable shares is technologically more difficult and more expensive than for power generation. Moreover, by exploiting the huge storage capacity of the gas system, hydrogen effectively decouples energy supply from demand in time and in location and links the electricity transmission and natural gas grids, thereby enhancing energy security.

The main objective of the SFEM/WG Hydrogen was to perform an analysis of the state of the art of technology and standardization and a gap analysis on the main barriers including challenges and needs. A second objective was to establish contact with key stakeholders from gas sector, grids, electric supply, mobility, the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) to perform the work in the most effective way and to have broad support from the stakeholders for identifying the key challenges. Also the link to EC services, DG JRC, DG RTD, DG ENER, DG GROW was seen as important. The final objective is to set a long term collaborative framework (liaison) with major bodies for strengthening cooperation between regulatory work, standardization work and RDI programs (e.g. European Commission, JRC, FCH2 JU, IEA, ISO, IEC). The scope of the working group covered the production of hydrogen through electrolysis and the transportation, distribution and usage of that hydrogen in pure form or as a natural gas dominant mixture (H2NG). In addition, actions in cross-cutting fields such as safety and training of personnel were identified. These activities will help increase the societal acceptance of hydrogen, key to a successful market uptake.

KEY OUTCOMES of SFEM/WG Hydrogen

Priority challenges have been identified for the various technical areas within the scope of work of the SFEM/WG Hydrogen. Recommendations are given on proposed actions and means of implementation. The actions are visualised in an action roadmap (Figure 6) in which actions are prioritised and with the required timespan indicated. Other outcomes include a clarification of expectations of industry of where and how policy and standardization can contribute to a competitive development of PtH and related issues.

Technical gaps have been identified for new operational modes of **electrolysers**, which call for advances in technology related to performance and safety. Partial load, intermittent operation and fast response will be some of the performance requirements for electrolysers when integrated into a power-to-gas plant or for provision of ancillary services to the electricity grid. For the ancillary service market, PEM and alkaline electrolysers have good ramp rates and respond well to a change in power settings and could therefore, in principle, provide all reserve functions, both negative (absorbing power from the grid) and positive (lowering power demand by decreasing production while being operational). Interconnection standards to allow physical connection and communication between electrolysers and the grid control systems are needed, in addition to a standardization of the key performance indicators of water electrolysers. Performance standards for dynamic operating conditions are currently missing. These conditions occur for electrolysers coupled directly or indirectly to renewable energy sources, such as intermittent renewable energy sources or partial load operation. A clear understanding of electrolyser degradation and subsequent improvement of operating strategies has also been indicated as a major gap.

Key challenges and early topics for standardization related to the **injection of hydrogen into the natural gas grid** have been identified. Establishing a European understanding of an acceptable hydrogen concentration in the natural gas system is seen as an overarching theme, which first requires filling a number of knowledge gaps. Depending on the hydrogen concentration1, different components of the gas system or end-user appliances and processes may be affected. The main issues to be addressed before significant concentrations of hydrogen can be achieved include a study of the behaviour of the operating characteristics of gas turbines with admixture of hydrogen, as here a 1 vol% hydrogen concentration limit applies for some of the turbines operated in the field. A qualification of steel tanks for CNG vehicles and assessment of the long term durability of the steel tanks is a prerequisite for raising the H2 concentration limit above 2 vol% in the gas distribution grid. Other major issues to be considered are an investigation of bacterial growth and compatibility of hydrogen with the used installations for porous rock underground gas storage and the evaluation of impact of hydrogen for industrial processes where natural gas is used as a feedstock. Ensuring safety and performance of compressor stations will need to be addressed in the short term. Performance tests to determine the suitability of odorants for different H2NG mixtures are recommended in the near term. An evaluation of industrial and residential burners performance and safe operation has also been identified as a critical issue.

Pre normative research (PNR) and standardization challenges and needs related to the hydrogen system and the use of pure hydrogen have been analysed. Hydrogen will have the highest value when used in the mobility sector, therefore the technology can be best supported by first focusing on the issued related to the refuelling infrastructure, which is currently being rolled out across Europe. The necessary short term actions include the development of risk assessment methodologies for failure modes of hydrogen refuelling stations to understand the consequences for the on-board hydrogen storage system. Hydrogen metering techniques with accuracy levels between 1% and 2% will have to be available in the near future to fulfil national requirements and

[1] For non-ambient gas pressures, the partial pressure rather than the hydrogen concentration should be considered as the potential degradation of materials depends on the partial pressure and not on the relative hydrogen concentration

regulations. PNR activities are recommended to reduce excessive wear and leakage issues of high pressure nozzles and to further understand the impact of impurities on the performance of the automotive fuel cell system. Another key activity is developing risk assessment methodologies to understand the risk and consequences of exceeding the concentration level of contaminants in hydrogen fuel on the automotive technical systems. It will also be important to have measurement techniques and detection apparatus for online hydrogen quality assurance at refuelling stations.

The **cross-cutting items** were also addressed such as safety (H2NG and hydrogen system), the related technical topics (metrology monitoring and testing), regulation/legislation, certification and societal aspects (public acceptance, awareness and education and training). The key items identified for PNR and standardization actions were safety related topics, certification (Guarantee of Origin), training of personnel. An unambiguous and consistent common set of terms and definitions should also be developed.

In the context of the European strategy related to energy transition, this forum offers a unique platform for sharing needs and for bridging all stakeholders and players of the hydrogen energy chain. This platform gathers all necessary skills for contributing to meeting RDI challenges and to provide input for improving our EU policy framework. The main objective was to identify standardization needs and then propose standardization development to CEN and CENELEC, in a consensus way and with holistic consideration. This platform of experts is a real strength within the European Union to face our EU challenges on energy, environment and competitiveness, as well as to meet our common Energy Union targets. The SFEM/WG Hydrogen has created a momentum for power-to-gas, hydrogen and H2NG, has reached out to a variety of stakeholders and most importantly has created a forum in which experts from the natural gas industry, hydrogen industry and power sector exchange knowledge and expertise and can address common issues.

Recommendations: establish a new CEN/TC for Hydrogen and continue the SFEM/WG Hydrogen

The identified research, pre-normative research and standardization challenges can be addressed in a number of ways, such as funded projects, industrial research or standardization work. The actions proposed by the SFEM/WG Hydrogen range from state-of-the-art analysis to large scale demonstration projects. Pre-normative research is needed in a number of areas to support standardization. A roadmap has been developed, depicting a sequence and timing of actions.

Based on these key challenges, the SFEM/WG Hydrogen has two main recommendations to CEN and CENELEC Technical Boards to:

- Support the establishment of a new CEN/TC for hydrogen to develop the necessary standards since most of the topics identified by the working group fall within the scope of CEN. It is envisaged that this could become a joint CEN/CENELEC Technical Committee in the future.
- Continue the SFEM/WG Hydrogen, which should have a holistic combined approach spanning research, pre-normative research and standardization for Power to Hydrogen and all related technologies including Power to Power. The purpose of the SFEM/WG Hydrogen is to provide a long term – sustainable – platform for strengthening collaboration and thus contribute to boosting the development and subsequent implementation of innovation through consistent and mutually supportive policy, R&D and standardization work.

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1. Introduction

A workshop entitled "Putting Science into Standards" was held at the Institute for Energy and Transport of the JRC in Petten to analyse the current status of pre-normative research and standardization activities in the area of power to hydrogen and hydrogen admixture in the natural gas system and to identify involved stakeholders. This report is the result of work performed in the Sector Forum Energy Management / Working Group Hydrogen, which was set-up as follow up action of the workshop and identifies an action plan for pre-normative research, standardization and other relevant topics in the area of power-to-hydrogen and hydrogen in natural gas.

As stated in the FCH JU 2030 framework for climate and energy policies [1], hydrogen based large-scale energy storage will contribute not only to decarbonisation, but also to Europe's energy independence and security. Finally, successful FCH commercialization will give impetus to several industry sectors in Europe with a direct positive impact on investment and growth. Hydrogen will also have its positive impact on the energy transition with regard to use of renewables and connecting electricity with the gas grid.

1.1 Background

The goal of a resilient Energy Union with ambitious climate policy at its core is to give European consumers secure, sustainable, competitive and affordable energy. Achieving this goal requires a fundamental transformation of Europe's Energy System.

To reach this goal, there is a need to move away from an economy driven by fossil fuels, where energy is based on a centralised, supply-side approach and which relies on old technologies and outdated business models. Energy infrastructure is ageing and not adapted to the increase of renewables. The Energy Union intends to empower consumers through providing them with information, choice and through creating flexibility to manage demand as well as supply. Its strategy has five mutually reinforcing and closely interrelated dimensions designed to bring greater energy security, sustainability and competitiveness. The five guiding dimensions are:

1. Energy security, solidarity and trust
2. A fully integrated internal energy market
3. Energy efficiency first
4. Transition to a low-carbon society
5. Research, innovation, competitiveness

In this context, interaction between the different energy carriers and their grids' management, as well as energy storage capacities are key issues.

Indeed, maintaining stability of the electricity grid with increasing amounts of intermittent renewable energy sources in the generation mix requires capabilities for energy storage throughout the power chain, next to dispatchable power and demand-side management. Thus with the introduction of large amounts of RES into the generation mix, energy storage should play two important roles:

- it will be a source of efficiency, as it allows renewable energy sources to be captured and stored for later use, thus not wasting resources which cannot otherwise be used;
- and it functions as a valuable instrument to provide the needed flexibility.

The increasing needs for high-capacity, long-duration (seasonal) energy storage can only be met through chemical storage of high energy density gases, among which hydrogen can play a powerful role.

In this context, admixture of renewable hydrogen to the natural gas grid (H2NG) presents considerable advantages. H2NG is obtained from injection of hydrogen produced from renewable energy sources (power-to-hydrogen) into the existing NG pipeline network and is subsequently transmitted and distributed to multiple end users: industrial, residential, transportation, power generation. In this way, hydrogen allows increasing the share of renewable energy in the natural gas grid, and from there in the end-use applications of transport, heat and industry, where achieving higher-renewable shares is technologically more difficult and more expensive than for power generation. Moreover, by exploiting the huge storage capacity of the gas system, hydrogen effectively decouples energy supply from demand in time and in location and links the electricity transmission and natural gas grids, thereby enhancing energy security.

As an initial step to address the challenges, the European Commission's Joint Research Centre, the European Standards Organisations and EARTO hosted a workshop on "Power-to-Hydrogen and HCNG", in Petten on October 21-22, 2014.

The workshop confirmed that the Power-to-Hydrogen related topics present a huge potential for Europe in light of denuclearisation, decarbonisation and lower import dependence scenarios and that the European industry can take a leading role in addressing associated challenges.

Hydrogen represents a potentially important factor to enable the storage of energy from renewable sources that are intermittent by definition, be added to compressed natural gas and injected into the gas grid, for use as fuel for transports, heating, gas power stations or as pure fuel in FCEVs (fuel cell electric vehicles).

This technology still needs some further scientific knowledge on key aspects including performance, safety and durability. Close cooperation between the industry, research and standardizers can fill the gap for a successful introduction of this technology.

In addition, there is a significant potential for European stakeholders to lead developments in this field, with relevant European standards providing the basis for future international standards. The European context includes European energy policy and goals including on renewables, research programmes, existing pilot trials run by industry and current European standardization work.

1.2 Need for standardization and pre-normative research

A lack of standardization is recognised as a major barrier for deployment of new and innovative technologies. The Europe 2020 Strategy, in particular its Innovation Union Flagship, recognises

European and international standardization as a major enabler for technology innovation and states that efforts in this area have to be increased. The European standardization policy seeks to promote standards for improving regulation and support competitiveness of the European industry. European standards are effective policy tools for the EU, as they can be used to ensure interoperability, the proper functioning of the single market and a sufficient level of consumer and environmental protection [2]. The Annual Work Programme for European standardization describes the Commission's intentions to use standardization in support of new or existing legislation and policies, which could lead to formal standardization requests (mandates). The obligation to identify strategic priorities for European Standardization for the upcoming year derives from Regulation (EU) No 1025/2012 [3], which aims to improve both the speed and science-base of EU standards. The Commission objective is to reduce the average time to develop European standards or European standardization deliverables requested by the Commission by 50% by 2020. The Commission can issue "requests for standardization" to support EU legislation. It should be noted that only references to European standards are allowed in EU Directives and Regulations. Energy is currently one of the European policy priorities, as set out in the Energy Union strategy and forthcoming legislation on internal electricity market.

Pre-normative research enables the gathering of relevant **data** for the development of standards. It may also cover the development of **testing procedures and methodologies**. It provides a link to the potential synergies between research, innovation and standardization. Standards can also be seen as a means of knowledge transfer, as the results of (publicly funded) pre-normative research are made available in a structured manner. Scientific results relevant to standardization from EU funded research projects and other sources are complemented by the input of the Joint Research Centre of the European Commission in its area of expertise.

Council Regulation 1291/2013 establishing Horizon 2020 states that activities involving all relevant stakeholders in support of standardization activities will be promoted. Funding for PNR and research topics related to NG blends (H2NG) could be found for energy applications under calls of the Horizon 2020 Energy Societal Challenge. The Energy Societal Challenge follows SET-Plan priorities, which include integration aspects between different energy sectors. Input to Energy Societal Challenge is given by Member States through comitology. Another player relevant for PNR is the EMPIR metrology programme.

The European level legislation and regulation is initiated and drafted by the policy DG's in the European Commission in charge of the specific policy. Especially the DG's ENER, RTD and MOVE are involved in the development of legislative initiatives relevant to the FCH sector and also finance the FCH2 JU in support to the technology projects. In this context, the FCH2 JU is expected to actively contribute to standardization in the area of pure hydrogen technologies. Council Regulation 559/2014 establishing the Joint Undertaking states that it shall carry out tasks that encourage the development of new regulations and standards and review existing ones to eliminate artificial barriers to market and to support inter-changeability, inter-operability, cross-border trading, and export markets. Suggestions for inclusion of PNR topics in future Annual Work Programmes can be made through members of the Industry Grouping and Research Grouping. To help meet this objective, an industry-led RCS co-ordination activity has been set up, "to identify and address PNR needs in conjunction with the research community with the results being fed back into standardization activities. (...) As part of the JRC support activities to FCH JU, the JRC will assist the RCS Group and the PO in their RCS tasks" [4].

Additional EU initiatives that may provide financial support are the Connecting Europe Facility (CEF) for trans-European Energy Networks (TEN-E) and the Smart Specialisation Initiative on Energy for financial support to European Regions which have identified energy as priority for further development.

1.3 CEN/CENELEC SFEM/Working Group Hydrogen

In order to perform the gap analyses for standards and for research and to bring partners from the different sectors closer together, a workshop on PtH and Hydrogen Compressed Natural Gas (H2NG) in a series entitled “Putting Science into Standards" was held in at the Institute for Energy and Transport of the JRC in Petten in October 2014. The workshop offered a platform to exchange ideas on technologies, policy and standardization issues. The participation of a wide group of stakeholders from both industry and research enabled the formation of a pre-consensus on the relevant technical issues involved and on a common way forward to increase the maturity and market visibility of PtH components and systems.

In consideration of the strong interest and real needs from industry that were expressed at the workshop, a CEN/CENELEC Working Group (WG) on Hydrogen under the Sector Forum Energy Management (SFEM) was approved by the CEN/CENELEC technical board in December 2014 with the aim to provide the technical board of CEN and CENELEC with concrete proposals on the way forward to address research and standardization needs in this emerging field. The scope of work includes a mapping of hydrogen-energy related issues and challenges as well as of existing standardization initiatives, needs and gaps in a holistic manner. The objectives of the WG on Hydrogen is an analysis of the state of the art of technology and standardization and a gap analysis on the main barriers including the identification of challenges and needs for PNR and standardization. In addition recommended actions were identified to address these challenges, along with the means of implementation.

The WG is chaired by the SFEM chair of CEN/CENELEC, co-chaired by the JRC of the European Commission and the secretariat is provided by NEN, the Dutch standardization organisation. In total more than 50 European companies, organisations, institutes and authorities have been participating in the WG. Five Task Forces have been formed mainly around the interfaces of the power-to-hydrogen related technologies (electricity grid, natural gas grid, hydrogen infrastructure). An ad-hoc working group was established to define and visualise the scope of work. Each Task Force consists of a Task Force leader and Task Force members. The Task Forces address the objectives of the WG within their scope of work. Four plenary meetings of the WG were organised in February, April, June and September 2015 where progress of the Task Forces was presented and discussed and way forward identified.

1.4 Structure of the report

This report by the Sector Forum Energy Management / Working Group Hydrogen is written in a chronological sequence. Chapter 1 describes the background and the motivation for organizing the SFEM/WG Hydrogen forum. The exact scope of work of the SFEM/WG Hydrogen has been redefined during the workshop and is shown with the objectives in chapter 2. The first objective was to map the current activities in the field of standardization and relevant (pre normative) research and demonstration projects, these are introduced in chapter 3. Within the WG, 5 taskforces identified challenges of new pre-normative research and standardization. These challenges are presented in chapter 4. Based on the individual assessment of each taskforce priority actions have been identified and prioritised in in a road map. In chapter 5 the identified actions are assessed on synergies, areas of common interest and visualised in a combined road map. Chapter 5 gives also an overview of short and near term standardization actions. In chapter 6 recommendations are made and next steps are proposed.

In Annex A the methodology used by the SFEM/WG Hydrogen and process is described. A short overview of the standardization process is given in Annex B. The list of referred standards can be found in Annex C and other references in Annex D. The terms and abbreviations are presented in annex E.

2. Scope of work, objectives and expected outcomes

2.1 Scope of work

The scope of work of the SFEM/WG Hydrogen has been refined from the Petten workshop organised jointly by JRC, CEN/CENELEC and EARTO. It has been organised around the three interfaces of the electrolyser system as the means of producing hydrogen: the interface with the electricity grid, with the natural gas system and with the hydrogen system. Central was the issue of integrating power to gas into the energy system. The hydrogen produced by the electrolysis can be used in a variety of end applications. The injection of hydrogen into the natural gas grid and the associated challenges were covered as well as the use of pure hydrogen, for which the focus was placed on the most economically relevant markets.

The following Task Forces have been established within the WG:

- **Task Force 1** concerns the **electricity grid** that is connected to the electrolyser. The electricity grid is a supplier of surplus/excess electricity from renewable energy sources and power plants to the electrolyser and is a user of services from the electrolyser to stabilise the grid ("ancillary services").
- **Task Force 2** concerns the **electrolyser** itself as a means to convert the electricity received from the grid into hydrogen.
- **Task Force 3** concerns the **natural gas system (gas infrastructure, components and storage)** into which the hydrogen produced by the electrolyser is injected. The Task Force has decided to consider concentrations of up to 20 vol% of hydrogen to natural gas to be within the scope of work. Besides the natural gas grid and the components itself, the **end-users** connected to the natural gas grid are considered. These include end-users connected to the transmission grid, like industrial end-users and large underground storage facilities as well as end-users connected to the distribution grid, like industrial end-users, small scale stationary storage systems, refuelling stations, transportation (vehicles, trucks), residential appliances and dispatchable power equipment (re-electrification). Also the storage of the mixture of hydrogen and natural gas was covered under this Task Force.
- **Task Force 4** concerns the **hydrogen system (hydrogen infrastructure, components and storage)** and **end-users** of pure hydrogen. The Task Force has decided that hydrogen pipelines fall outside the scope of work as the near term deployment potential is limited. However, distribution means like trailers and cylinder bundles are included as well as industrial end-users, large scale underground storage in salt caverns, small scale stationary storage systems, hydrogen refuelling stations, transportation (vehicles, trucks), residential appliances and dispatchable power (re-electrification, e.g. fuel cells) are within the scope of the WG.
- **Task Force 5** deals with **cross-cutting items**. Cross cutting items are topics that are relevant for the full scope and therefore related to all other Task Forces. The cross cutting approach was agreed on for safety (H2NG and hydrogen system), the related technical topics (metrology monitoring and testing), regulation/legislation, certification and societal aspects (public acceptance, awareness and education and training). This is also in line with the scope of FCH JU with regard to cross cutting items. They defined it as

'Cross-cutting activities will support and enable the Energy and Transport Pillars and facilitate the transition to market for fuel cell and hydrogen technologies'

In the FCH JU European consultation on “A 2030 framework for climate and energy policies” it was stated that more attention should be paid to activities accompanying and facilitating the establishment of new technologies, such as socio-economic, environmental and energy systems analysis; regulations; codes and standards; manufacturing methods; public awareness and acceptance, as is the case in the FCH JU, with the supportive pillar on “cross-cutting issues” as part of its structure.

The scope of the WG and of the five Task Forces is depicted in Figure 1. Production of hydrogen by other means than electrolysers is excluded from the scope. However, a short outlook is provided on major needs and challenges of the main types of green hydrogen production as well as on methanation in section 4.6.

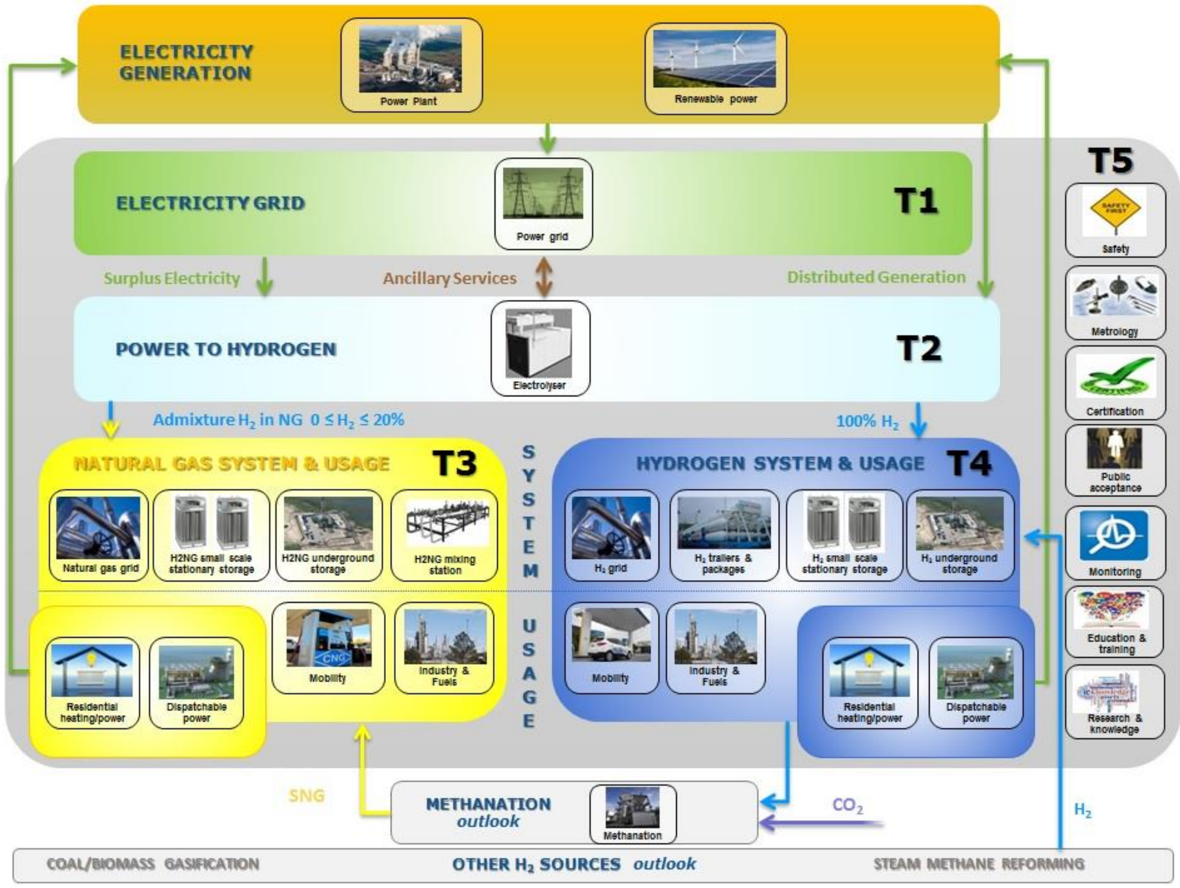


Figure 1: Scope of work of the CEN/CENELEC SFEM/WG on Hydrogen Energy

2.2 Objectives and expected outcomes

The objectives and main expected outcomes of the WG on Hydrogen is an analysis on the state of the art of technology and standardization and a gap analysis on the main barriers including challenges and needs.

- Identify and prioritize main research and PNR needs and standardization gaps;
- Map relevant current standardization activities and links with European standardization work and programs (e.g CEN/TC 234 “gas infrastructure”, CEN/TC 268 “Cryogenic vessels and specific hydrogen technologies applications”) and international ones (e.g. ISO/TC 197 "Hydrogen technologies");
- Map relevant current research and PNR;
- Establish contact with key stakeholders from the gas sector, grids, electric supply, mobility, link with the Fuel Cells and Hydrogen Joint Undertaking (FCH2 JU);
- Link to EC services, DG JRC, DG RTD, DG ENER, DG GROW, to cover regulatory and policy development and links to standardization policy.
- Set a long term framework (liaison) with major bodies for strengthening cooperation between regulatory work, standardization work and RDI programs (e.g. European Commission, JRC, FCH JU, IEA, ISO, IEC)
- Identify recommended actions, means and timeline of implementation
- Disseminate results

3. Mapping of research and standardization activities

The first part of the work of the working group was to map the current activities in the field of standardization and relevant (pre normative) research and demonstration projects. This chapter shows the current standardization activities (section 3.1) and the latest research and demonstration projects (section 3.2).

3.1 Mapping of standardization activities

The scope of the working group includes the production of hydrogen through electrolysis and the transportation, distribution and usage of that hydrogen in pure form or as a natural gas dominant mixture. As such, standardization activities dealing with infrastructure and end-users will probably become affected by changes in gas composition due to admixing hydrogen in natural gas. To provide an as comprehensive overview of standardization committees as possible, an inventory of relevant technical committees at international (ISO and IEC) and European (CEN/CENELEC) level has been made. This overview is shown in Figure 2 below.

Some of these technical committees have developed hydrogen or H2NG related standards, while others do not have H2NG (yet) in their scope. Technical committees that have developed standards are e.g. ISO/TC 197, which is the international standardization platform on hydrogen technologies and CEN/TC 234, which is the European standardization platform on natural gas infrastructure and has included in the EN 16726 " Gas infrastructure - Quality of gas - Group H" an informative annex on the admissible concentrations of hydrogen in natural gas systems. Besides the implications of using increased hydrogen concentrations in natural gas in burning systems at end-user sites (engines, turbines), also components for measurement and analysis, gas storage in transport systems and refuelling stations, cylinders/tube trailers as well as components for safety including ATEX standards, safety and detection systems will need to be (re)considered.

In the chart below, the relevant standardization activities are clustered to represent the areas of application. Within the areas of application, the relative distance from the centre is used as a measure to reflect how the standardization activities will be influenced by the increasing use of PtH technologies or the higher availability of hydrogen for natural gas/hydrogen systems and its end-users. It can therefore be understood as a means to reflect the impact on existing standardization activities. The distance measure used is a rough and indicative means as the mentioned standardization platforms have not been directly consulted. Also, although a thorough effort is made, it cannot be said with full certainty that all standardization activities are included. With the latter comments kept in mind, a standardization impact chart shown in Figure 2 has been created. The colour coding reflects to which SFEM/WG Task Force the standardization activity belongs. The format applied covers the standardization body, the technical committee number and title, the most important standards produced and the topics covered in the scope of the technical committee. Space limitation prevents an exhaustive listing of topics.

The most important standardization activities in view of the scope of the SFEM/WG on hydrogen are:

- ISO/TC 197 on Hydrogen Technologies
- CEN/TC 234 on Gas Infrastructure

- ISO/TC 193 on Natural Gas
- ISO/TC 158 on Analysis of Gases
- ISO/TC 58 on Gas Cylinders
- ISO/TC 22 on Road Vehicles
- CEN/TC 408 on Biomethane and CNG
- CEN/TC 238 on Test Gases
- CEN/TC 268 on Cryogenic Vessels and Hydrogen Technologies
- CEN/TC 58 on Safety and Control Devices of Burners and Appliances
- ISO/TC 192 on Gas Turbines
- IEC/TC 105 on Fuel Cell Technologies
- ISO/PC 252 on Natural Gas Fuelling Stations

In chapter 4, pre-normative and standardization needs and challenges per SFEM/WG Task Force are being identified and links will be made to standardization activities in Figure 2.

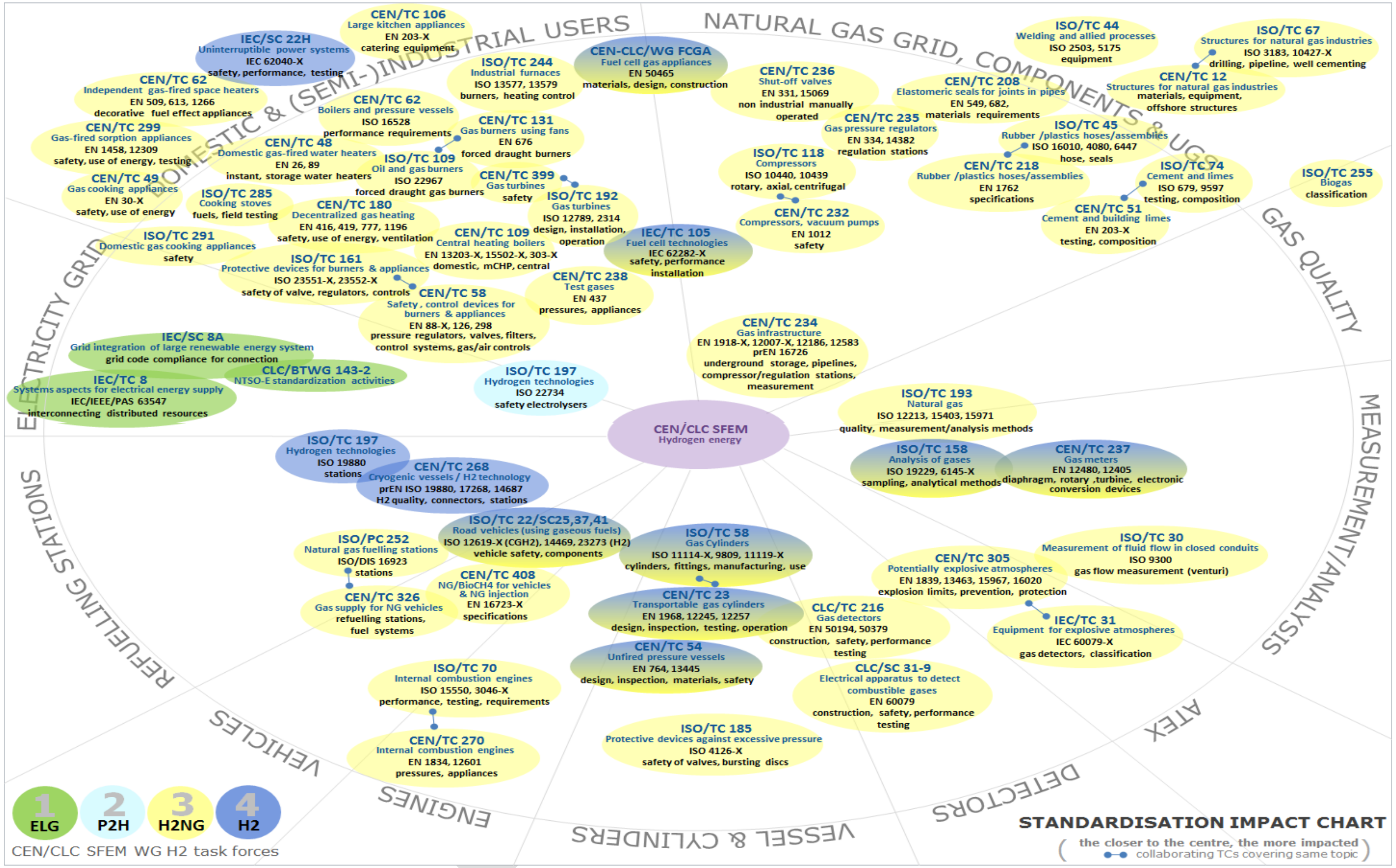


Figure 2 Mapping of international and European standardization activities in the area of hydrogen and H2NG.

3.2 Mapping of relevant research, PNR and demonstration projects

The most relevant research, PNR and demonstration projects are reported on in this section The aims and outcomes of selected projects are highlighted. Relevant RCS and PNR outcomes of these projects for the identification of PNR and standardization challenges will be highlighted in chapter 4.

3.2.1 Task Force 2 – Electrolysers

For Task Force 2, the EU FCH2 JU and FP7 research framework is funding projects in the area of electrolysis, but also electrolyser projects on EU Member State level are taking place (e.g. as part of the National Innovation Programme Hydrogen and Fuel Cell Technology (NIP) and the lighthouse project Clean Energy Partnership (CEP)).

Among the most important FCH2 JU/FP7 projects are ELYGRID, INGRID and Don Quichote. In order to improve and adapt alkaline electrolysers when coupled to intermittent renewable energies (wind energy), the ELYGRID (FCHJU, 2011-2014) project develops a high pressure and high capacity alkaline electrolyser with reduced costs and higher efficiencies. A new cell topology has established a stack efficiency of 70% has been reached, thereby decreasing the total cost of the hydrogen produced. Also new and efficient power electronics have been designed for operating to work well when coupled to renewable energy sources. New BOP has been designed which allow to include all components of a MW electrolyser in the same container.

To demonstrate an alkaline electrolyser with a solid-state hydrogen storage system and fuel cells for energy supply and demand balancing within active power distribution grids, the **INGRID** (2012-2016) project is set-up. Smart Grid cutting-edge ICT-based active network control technologies for balancing highly variable power supply and demand in a scenario of high penetration of renewable energy sources is applied. The project aims to increase round-trip efficiency (50%-60%), energy density (600 kWh/m3), modularity and dispatchability.

The **Don Quichote** (2012-2017) project demonstrates PEM electrolyser technology, electrochemical compression and fuel cell technology as an expansion of an existing hydrogen refuelling station consisting of alkaline electrolysis and mechanical compression. The demonstrated technologies enable the production of hydrogen from cheap electricity and the production of electricity when electricity prices are high. The technological, economic and environmental performance of the demonstrated equipment is benchmarked against existing infrastructure in order to determine the progress against the state of the art.

The INSIDE project was focused on mapping of performance for different electrolyser technologies (PEM, Alkaline and AEM). Projects as MEGASTACK or NOVEL are focused on PEM electrolysers, the first is working in the upscaling of PEM stack in the range of MW, meanwhile NOVEL is developing new materials to increase durability and efficiency and to reduce costs. RELHY project is also related to the development of new materials that will improve durability, efficiency and costs, but based on the SOEL technology. Regarding the same technology, but at system level, we can find HELMETH, where Power-to-gas technology, SOEL and methanation are integrated, and SOPHIA where the integration of SOEL with a concentrated solar energy source is studied.

3.2.2 Task Force 3 – Natural gas system and usage (H2NG)

For Task Force 3, comprehensive testing on the effect of hydrogen on the gas grid infrastructure has been performed within several past and on-going projects. Most notable among those is "NaturalHy", which focussed on pipelines, end use and safety. A major outcome of the project was that the maximum percentage of H2 in a homogeneous H2NG mixture is limited by (in order of increasing stringency) pipeline materials (at least 50 vol% H2), safety (30 vol% H2) and end user appliances (0-20 vol% H2). The findings did not reveal any major showstoppers for the pipeline system, but not all elements had been investigated in the frame of the project.

The "Ameland" demonstration project supplied natural gas with added sustainably produced hydrogen to fourteen houses for four years. During the pilot, the percentage of hydrogen was increased in stages to 20 vol%. The results indicated the used materials and installations and concluded that the admixture of hydrogen does not have "a noticeable influence" on the different pipe materials and gas devices. The GRHYD Demonstration project (GRid Management by HYDrogen Injection for Reducing Carbon Energies) is a more recent project to inject hydrogen in a natural gas distribution network in France. Renewable electricity is used to generate hydrogen (when production exceeds demand of electricity), so as to make a valuable use of it through natural gas uses (heating, hot water, fuel, ….). 200 dwellings will be supplied by a mixture of hydrogen and natural gas, with hydrogen concentration up to 20 vol%. The project will measure the performance of "green" hydrogen production and storage and perform an assessment of social acceptability, economic and environmental results.

In Germany quite a large number of power-to-gas demonstration projects have been launched. An overview of the power-to-gas pilot plants that have been realized or are being planned can be found in [5]. Among the notable projects are the Hybrid Power Plant Enertrag, the demonstration Plant EON, Falkenhagen, the Thüga PtG plant, the soon to be operational Energiepark Mainz, and the project Power-to-Gas for Hamburg. In terms of total installed power, these plant range from 325 kW to 2 MW of the electrolyser. Valuable information has been gained from running these plants on aspects of permitting, installation and integration with the gas grid. Several of the PtG plant have qualified for provision of ancillary services in the form of secondary reserve. Synthetic methane for mobility is produced in the Solar Fuel Beta-Plant Audi, Werlte through electrolysers of 6.3 MW capacity. Currently activities are also underway to determine the effect of hydrogen in porous rock underground storage in the RAG sun storage project.

Recently a project called HYREADY has been launched, with participation from natural gas value chain participants and technology providers, in order to develop standards for hydrogen injection based on already existing knowledge. It also aims to provide engineering practice and guidance to operators. To establish a common European understanding of the H2 tolerance of the existing natural gas grid, the admissible hydrogen concentrations in natural gas systems was studied within the Hydrogen in Pipeline Systems (HIPS) project from the European gas research group (GERG). The project concluded that for hydrogen up to 10% uncertainties exist over the behaviour in long term tests and for different (lower) Wobbe ranges. In addition, further information is needed on the behaviour of older pre-GAD appliances (test gas G222 is 23% Hydrogen). The GERG Domhydo project is focusing on extreme conditions and longer term testing of outlying appliances.

3.2.3 Task Force 4 – Hydrogen system and usage

The Fuel Cells and Hydrogen Joint Undertaking is the main funding organisation for hydrogen and fuel cell projects in the 7th framework programme. In nearly 9 years, over 150 projects on hydrogen and fuel cells have been funded. However, also on national level funding has been provided for hydrogen and fuel cell technologies. For example, the German National Innovation Programme Hydrogen and Fuel Cell Technology has co-funded more than 200 projects in nearly 8 years. As part of the NIP/CEP, projects have been funded to demonstrate hydrogen distribution trailers and hydrogen refuelling stations. PNR has been performed in the area of hydrogen metering and quality assurance. The NIP also funded research projects in the area of on-board storage and distributed generation.

For the areas relevant to Task Force 4, the most important EU projects regarding underground hydrogen storage, hydrogen distribution by trailers, hydrogen refuelling stations, on-board hydrogen storage and fuel cells and distributed generation are highlighted below.

Underground hydrogen storage

A highly relevant project in the area of underground hydrogen storage is the **HyUnder** project (2012-2014) that assessed, the techno-economic feasibility of underground hydrogen storage as a means for large-scale electricity storage. It was concluded that underground hydrogen storage in salt caverns is a technically feasible option for large-scale storage of electricity for weeks and months and makes economic sense in places with (i) suitable geology, (ii) electricity generation from intermittent renewables and surplus in the order of tens of TWhs over extended periods, (iii) low electricity prices during a significant part of the year and (iv) a favourable policy framework. However, the underlying economic assessment of all case studies has shown that the development of potential business cases will be challenging.

Hydrogen distribution by trailers

The **DeliverHy** project (2012-2013) focuses directly on hydrogen distribution by trailers, and especially on advanced hydrogen delivery trailer concepts. State-of-the-art hydrogen delivery trailers store between 350 and 550 kg hydrogen at 20 MPa in metallic tubes or cylinders. An increase in payload of trailers up to 1400 kg would limit the number of trailer exchanges at the refuelling station. Therefore, lighter composite materials, higher pressure (well beyond 20 MPa) and bigger volumes (> 3000 litres per tube) of tubes and cylinders must be introduced in advanced trailer concepts. The increased payload of the high-capacity composite trailers reduces the delivery frequency by a factor of three and transport emissions by more than a factor of four, but shifts the costs from OPEX dominated to CAPEX dominated. There is a specific distance window (150-400 km) and HRS size (> 300 kg/day) in which the overall costs for advanced trailer concepts will be lower than the state of the art GH2 and LH2 trailers.

Hydrogen refuelling stations

There have been several projects funded to deploy hydrogen refuelling infrastructure and address specific issues related to hydrogen refuelling stations. In the area of *hydrogen metering*, the **HyAC** project (2014) assesses the accuracy of hydrogen mass flow meters and concludes that for the tested equipment the accuracy deviation ranges from approximately -5,4% to +0,7%. The majority of the tests resulted in a negative deviation, which means that a refuelling customer would get more hydrogen than charged for on the basis of the mass flow meter reading. Higher accuracy flow meters are required.

For *hydrogen quality* and *hydrogen quality assurance*, the HyQ and HyCORA projects are state of the art projects. The **HyQ** project (2011-2014) performed PNR to improve understanding of the impact of impurities on the performance of automotive PEMFC systems and to define the most cost effective and most accurate ways to assess hydrogen impurities. The project showed that on/off cycles are beneficial to mitigate the impact of impurities. The **HyCORA** project (2014-2017) builds on the PNR performed in the HyQ project on hydrogen contaminant research in automotive PEMFC systems and includes start-stop cycling. It especially focuses on developing cost effective means for hydrogen quality assurance based on a hydrogen quality risk assessment methodology that defines the needs for hydrogen impurity gas analysis.

To advance the development of *hydrogen refuelling protocols*, the **HyTransfer** project (2013-2015) aims to develop and experimentally validate a practical approach for optimizing means of temperature control during fast transfers of compressed hydrogen to meet the specified temperature limit (gas or material), taking into account the system's thermal properties. Whereas existing approaches focus on gas temperature and specify gas pre-cooling temperature, this project is based on the implementation of a simple model predicting gas and wall temperature to determine the amount of cooling required to avoid exceeding the limit temperature, and on the specification of cooling energy, rather than a fixed pre-cooling temperature. In this way, it is envisaged that a refuelling protocol takes due account of initial conditions will decrease refuelling times while requiring less pre-cooling requirements, and hence increase refuelling flexibility.

In the area of *stationary hydrogen storage* in refuelling stations, the **MATHRYCE** project (2012–2015) developed a methodology for the design of high pressure metallic vessels and for the assessment of their lifetime that takes into account hydrogen-enhanced fatigue. The metallic vessels are exposed to operational conditions that hydrogen storage buffers at 90 MPa in a hydrogen refuelling station will experience. Since full scale component testing is considered impractical because of the expected cycle life and equipment size, an approach is adopted where the assessment of lifetime stems from combining hydraulic cycling performance of the component with the appropriate knowledge of the performance of the metallic material in hydrogen under cyclic loading. Results are validated by comparing the lifetime prediction of the component calculated from lab-scale tests to that obtained from large scale component tests. The analysis of the results, based on numerical simulations as well as on scientific understanding of the prevailing hydrogen embrittlement mechanisms, feeds into the proposed design methodology.

Safety issues related to e.g. containerised refuelling stations are addressed in the **HyIndoor** (2012-2015) project which deals with the issue of safe indoor use of hydrogen and fuel cells systems for early markets (forklift refuelling and operation, back-up power supply, portable power generation, etc.). It provides scientific and engineering knowledge for the specification of cost-effective means to control hazards specific to the use of hydrogen indoors or in confined space and develops state-of-the-art guidelines for European stakeholders. The guidelines include contemporary engineering tools and recommendations for safety.

On-board hydrogen storage

Relevant projects that improve composite tanks for on-board hydrogen storage in terms of structural integrity, mechanical impacts and fire resistance are HyComp, HyPactor and FireComp. The **HyComp** (2011-2014) project develops enhanced design requirements and testing procedures for composite cylinders to improve existing requirements for ensuring structural integrity throughout their service life. These requirements relate to cylinder design, but also to testing procedures for type approval, manufacturing quality assurance and in-service inspection. RCS recommendations are provided for all these requirements.

The **HyPactor** (2014-2017) project addresses the knowledge gap on composite overwrapped pressure vessels' (COPV) behaviour when submitted to mechanical impacts. Existing standards are not well-appropriate to composite materials and therefore the project aims to provide RCS recommendations regarding the qualification of new designs of COPV and the procedures for periodic inspection in service of COPV subjected to mechanical impacts.

The **FireComp** (2013-2016) project provides experimental and modelling results to better characterize the conditions that need to be achieved to avoid the burst of hydrogen pressure vessels. Experimental work is done to improve the understanding of heat transfer mechanisms and the loss of strength of composite high-pressure vessels in fire conditions. The modelling work will address the thermo-mechanical behaviour of these vessels. Different applications are considered and include automotive applications, stationary applications, transportable cylinders, bundles and tube trailers. A risk analysis will be conducted for each application leading to the definition of optimised safety strategies.

Fuel cells and distributed generation

A significant number of projects in the area of fuel cells have been funded and one of these is the **Flumaback** (2014-2016) project. The project aims to improve the performance, life time and cost of balance of plant (BOP) components of back up fuel cell systems specifically developed to face black-out periods. The improvement of system components addressed in this project will benefit both back-up and CHP applications.

3.2.4 Task Force 5 – Cross cutting issues

Among the European projects dedicated to **safety** of hydrogen technologies, the FP6 Network of Excellence **HySafe** (2004-2009) deserves special mention as the biggest project focussing holistically on all fundamental and applications-related aspects of hydrogen behaviour. The Network generated a huge amount of knowledge and the developed methods and tools are still used now in the safety assessment of hydrogen technologies. The support to Standardization achieved in the following years has also been considerable. Internal projects of HySafe were dedicated to specific issues and applications: for example the **INSHYDE** project investigated indoor leaks and provided recommendations for the safe use of indoor hydrogen systems. Similarly, an internal project **HyTunnel** focussed on safety issues in hydrogen vehicles inside tunnels.

Building on these results, more recent pre-normative research efforts are taking place in the frame of the Fuel Cell and Hydrogen Joint Undertaking (FCH JU), such as the above mentioned project **HyIndoor** focussing on indoor safety, and a similar project **HySEA** (2015-2018) dedicated to safe installation of hydrogen technology in containers.

In terms of effort towards practical guidelines for development/assessment/installation of specific technologies, two additional FP6 projects deserve mention. Project **HyApproval** (2005-2007) produced a handbook for laying out, installing, approving and operating hydrogen refuelling stations (HRS) while project **HyPer** (2006-2009) developed guidance for permitting of small stationary hydrogen and fuel cell systems.

More recently, in the frame of the FCH JU, project **H2Sense** (2013-14) has investigated the market for hydrogen safety sensors, mapped their performance criteria and issued a gap analysis and development needs. In the field of hydrogen releases and their consequences, project **SUSANA** (2013-16) is developing an evaluation protocol for computational fluid-dynamics (CFD) tools applied to safety analysis of hydrogen and fuel cell technologies. This will allow for a quantitative control of the quality of CFD results in a similar way to what is available for liquid natural gas.

Regarding development and harmonisation of testing protocols for components such as fuel cells stacks and electrolysers, a considerable amount of work is being performed within EU supported projects aiming at the development of these components for specific applications. The only project exclusively dedicated to validate harmonized and industrially relevant test procedures for PEFC stacks is **STACK-TEST** (2012-15). Based on this, further harmonisation efforts for automobile, stationary and electrolyser applications are being considered .

In the frame of the **training, educational and dissemination activities** of the FCH JU, the EU supported project **HyProfessionals** (2011-12) focussed on training of technicians, students and end users and designers, while **HyFacts** (2011-13) aimed at Regulators and Public Safety Officials and **TrainHy-Prof** (2010-12) developed a vocational education and training programme at a Masters or PhD studies level. The on-going project **KnowHy** (2014-17), aims to provide technicians and workers practical training modules to facilitate the installation, maintenance and operation of hydrogen and fuel cell applications. Finally **HyResponse (2013-2016)**, still on-going, aims at a training programme for first responders, including training facilities, and an official curriculum.

Also on EU Member State level, projects on cross-cutting issues have been, and are being, carried out. For example, within the Programme Area Transportation of the German NIP, demonstration projects on hydrogen storage on board of fuel cells electric vehicles, and in high-pressure trailers, have been funded, with analysis encompassing safety aspects. A comprehensive study on hydrogen infrastructure safety (Sichere Wasserstoffinfrastruktur) was completed, scanning and evaluating the regulatory environment of hydrogen infrastructure for road transport. A follow-up study is planned, furnishing an up-to-date picture of relevant RCS and need for further development, embedded in a strategic perspective. Guidelines for investors and public authorities regarding permission procedures for hydrogen retail stations in Germany were developed and published as well.

4. Pre-normative research and standardization challenges

During the Petten workshop each Task Force identified pre-normative research and standardization challenges. This chapter describes per Task Force the standardizations actions, pre-normative research actions and gives a roadmap.

4.1 Task Force 1 – Electricity grid connection

In order to keep the electricity grid stable within the required frequency boundaries, grid stabilisation measures are required. Grid stabilisation services for frequency control are typically distinguished on response time: frequency containment (or primary reserve), frequency restoration (or secondary reserve) and frequency replacement reserves (or tertiary reserves). In the current electricity system, primary balancing energy is mainly provided by conventional power plants that are connected to the grid. Qualified power plants change their output setting depending on the need. In case of falling grid frequency, the plant needs to increase power while in case of rising grid frequency, the plant needs to decrease power. Fast response times are required to stop frequencies trespassing the operating boundaries. Restoration or secondary reserves are required to bring the frequency back to its set point and power plants with typically slower response times will need to provide more or less power depending on the action required. Tertiary reserve is utilised to provide/absorb power and allow the plants providing secondary reserve to return to the original set point.

The integration of significant amounts of intermittent renewable energy sources will increase the need for balancing services to the electricity grid. A Germany study performed by DENA "Ancillary services study 2030" assessed the needs for balancing energy for a Germany electricity market in 2030, where the installed capacity of renewable energies (wind, photovoltaics) is 150 GW, triple the amount compared to the 2013 situation. The study reveals that there is a significant increase in the secondary balancing energy and tertiary reserve to be provided. In particular, the effect of generation forecasting errors which grows with the installed renewable energy capacity affects the demand for balancing energy. Assuming a constant forecast precision for RE feed-in, the demand for negative minute reserve capacity will increase approximately 70 percent and the demand for positive minute reserve capacity will increase by approximately 90 percent. The demand for secondary balancing energy will increase to a lesser extent (approx. 10 percent for negative and 40 percent for positive secondary balancing energy), however the increased occurrence of major wind flanks leads to the assumption of more frequent activation of the secondary balancing energy. There are several ways to accommodate this need for additional balancing services. Using electrolysers as a form of demand side management, could be one of the options for providing primary and/or secondary reserves.

Electrolysers are primarily used to produce hydrogen from (renewable) electricity in function of demand (hydrogen consumption) or supply (e.g. low electricity prices) characteristics. However, due to their fast response capabilities to changes in power settings, it is being considered to utilise electrolyser technologies (as well) for electricity grid balancing purposes. The electricity grid operates in narrow frequency and voltage regimes and any deviations from their mean value (50 Hz, 230 V) should be countered by appropriate actions from the grid operators to return to the set value. The electricity grid operator has several options of countermeasures by utilising services from generator/load capacities that are connected to the grid. The procurement of these services by grid operators generates additional revenue for operators of these capacities. If electrolysers can be operated to comply with the requirements of ancillary service providers (e.g. by meeting capacity and operational requirements), offering these services can positively affect the business case. Other services that electrolysers could provide, but not considered as a grid ancillary service, are facilitation of renewable energy integration, prevention of wind curtailment and production of hydrogen for energy storage.

For the ancillary service market, PEM and alkaline electrolysers have good ramp rates and respond well to a change in power settings and could therefore, in principle, provide all reserve functions, both negative (absorbing power from the grid) and positive (lowering power demand by decreasing production while being operational). As PEM electrolysers respond faster to changes in power settings than alkaline electrolysers, PEM electrolysers are more suited for the primary reserve market. Alkaline electrolysers could provide services to the secondary reserve market. Using electrolysers for grid balancing is in a sense demand response management. Additionally, especially PEM electrolysers may have overload capabilities up to 300%. This would allow electrolyser to temporarily absorb larger amount of energy from the grid when negative reserve power is required. This demand side management function of electrolyser could enable less reactive power plants when coupled or pooled with the electrolyser to play a role on the reserve market. The Energy Efficiency Directive requires that Member States promote the use of demand response for balancing services. So far only few Member States have created regulatory and contractual structures that support aggregated demand response. Another area where electrolysers could play a role is for voltage regulation as an ancillary service as the electrolyser contains AC/DC converters and as such can absorb reactive power.

As a main outcome of the work within TF1, it was identified a need to properly consider, as a priority, the installation/interconnectivity issues, then all ancillary services needs and opportunities.

Pre-normative research topics:

- Development of measurement methods and test procedures for electrolyser performance dedicated to the needs of ancillary service requirements

Standardization topics:

- Standards for electrolysers (e.g. initial response time, total response time, ramp rate) coupled to the transmission and distribution grid to enabling them to allow grid operators or third parties to assess capabilities as ancillary service provider, covering, among others, frequency and voltage control requirements of grid operators
- Interconnection standards to allow physical connection (also considering overload capability) of and communication between the electrolyser and the grid control systems

Other topics:

- Identification of main needs for grid operators regarding assessment criteria for ancillary services providers (also in view of the capabilities of electrolyser connected to the distribution grid)

- Investigation among grid operators to understand nearby and future trends in the field of ancillary services, e.g. in bid blocks, quality remuneration, service stacking

There is still a need to strengthen relation and cooperation with electricity grid Transmission System Operators and Distribution System Operators. Indeed, moving from a centralised energy supply system to decentralised ones, consistent with the energy transition and the development of Renewables, means considering local grid management as a key issue for contributing to making our energy system sustainable and efficient.

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Urgent, start right now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
TSOs and DSOs actors, electrolyser manufacturers and operators, research organisations, standardization bodies and policy makers

4.2 Task Force 2 – Electrolysers

Introduction

This Task Force focuses on the needs and challenges related to PtH technologies and more especially alkaline (AEL), proton exchange membrane (PEMEL) and solid oxide electrolysers (SOEL).

Electrolysis of water has been used industrially for more than 100 years, but despite the maturity of this technology, much progress has been made in recent years. Electrolyser technologies are differentiated according to their configurations of electrodes and electrolyte:

- Alkaline: where two electrodes operate in a liquid alkaline electrolyte solution of potassium hydroxide or sodium hydroxide.

- PEM: In this technology, the electrolyte is a solid polymer (SPE). This electrolyte allows the conduction of protons, the separation of product gases, and the electrical insulation of the electrodes

- SOEC: The Solid Oxide electrolyser uses an ceramic electrolyte and operates at high temperatures (500-1000°C)

Power-to-hydrogen has specific challenges as the electrolyser may be operated for only part of the year (when surplus electricity is available) but should be able to start up at short notice (in the order of minutes). These new operational modes call for advances in electrolysis technology related to performance and safety. Partial load, intermittent operation and fast response are new operating conditions that electrolysers will have to face when they are integrated into a power-to-gas plant or when providing ancillary services. New Key Performance Indicators (KPI) should be defined to cover these new operating conditions, outlining the appropriate testing methods and protocols (see Specification of new key performance indicators). Stationary hydrogen storage is usually included in the electrolyser system, and therefore affected by the performance of the electrolyser. However, actions to be performed on this technology, regarding R&D, PNR and standards will be addressed in **Error! Reference source not found.**.

The current standards for electrolysers, ISO 22734-1: 2008 for industrial applications and ISO 22734-2: 2011 for residential applications, address mainly safety and certification aspects, and are currently being merged into one standard (ISO 22734). This update will allow the standard to include MW sized systems, new electrolyser technology (e.g. AEM: Anion exchange membrane) and design, and test requirements.

Standardization gaps however still remain. For example, solid oxide electrolysis (SOEL) is a novel technology for which test methodologies and procedures for performance characterisation of cells, stacks and systems could be helpful and are currently not part of the scope. Also dedicated testing procedures and associated load profiles to simulate dynamic operating conditions for electrolysers coupled directly or indirectly to renewable energy sources, such as intermittent renewable energy sources or subject to partial load operation are currently missing. In order to compare efficiencies among electrolysers, performance standards are required that define operating conditions (see standardization action **Installation and operational standards)**, calculation methods (see standardization action **Specification of new key performance indicators**) and the system boundaries (see standardization action **Definition of boundaries)**. Furthermore, the performance requirements for the electrolyser for connecting to fluctuating power sources (e.g. wind or solar) and to the gas grid (to deliver the hydrogen produced) in power-to-gas applications are needed. In addition, there are still some major challenges to overcome in terms of cost, efficiency and performance spanning from R&D to pre-normative research (PNR). These research topics to be addressed can be defined at cell, stack and system level.

4.2.1 Standardization actions

- Harmonisation of existing terminology and definitions

One of the main issues to be addressed by an updated or new standard is the harmonisation of existing terminology and definitions for all different electrolyser technologies.

- Definition of boundaries

Electrolyser system boundaries have to be defined in order to calculate efficiency and other key performance indicators. Components that could be included in such a system boundary definition are stack(s), gas separation, pumps, sensors, heat exchangers, water and gas purification, rectifiers, transformers and control systems.

- Specification of new key performance indicators (KPIs)

Among the topics to be included in a standard is the specification of new key performance indicators (KPIs) related to dynamic operating conditions. The definition of characteristic efficiencies (at rated power and in an intermittent profile) and the specification of a commonly agreed output pressure level are first steps in order to make technologies comparable. For power-to-gas applications the pressure required for injection of hydrogen is determined by the pressure of the gas grid into which the hydrogen is injected. Gas grid pressures are different both within countries and across Europe. Also regulations governing whether the hydrogen can be added to the gas transmission network (typically 80 bar) or the gas distribution network (<30 bar for example) differ across Europe.

U-I characteristics at defined run-in time, stack temperature and voltage ramp rate are others KPIs to be included or redefined in a standard.

- Oxygen quality specifications

The requirement for oxygen quality specification is another standardization gap that needs to be addressed for cases in which the oxygen stream can be utilised.

- Installation and operational standards– partly PNR

Besides the need for performance requirements, e.g. to determine efficiency at the system level, installation, operational and maintenance guidelines should be included in the standards. This is especially needed in a European context when connecting to and providing services to the electricity grid and when feeding (part of) the hydrogen into the natural gas grid.

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Electrolyser cell, stack and system developers, standardization bodies and research organisations

4.2.2 Pre-normative Research Actions

Some of the standardization topics described above requires PNR actions. These actions will be focused on the evaluation of parameters related with safety (validation of pressure resistant membranes and electrodes, see standardization action **Safety and performance**) and durability (validation of new materials, see standardization action **Test procedures degradation and gas purity**), specifically in the definition of the tests that will evaluate the mentioned parameters. Also the definition of tests to evaluate performance of the systems in new operating conditions, as intermittent or partial load, is another issue to be addressed by the PNR actions (see standardization action **Safety and performance)**. In the case of solid oxide electrolysis, the tests for long term operation should be combined with advanced electrochemical characterisation in order to identify critical operating conditions and to define a performance map. Also, the determination of degradation rates depending of operating conditions is another topic to be addressed by the PNR actions.

- **Test procedures degradation and gas purity**
New test procedures have to be defined to identify key parameters such as degradation and gas purity. Degradation and purity tests should be performed at rated current density and with an intermittent load profile. In addition, tests with and without gas purification should also be performed in order to identify the purity of the gas that the electrolyser system is able to reach.

- Safety and performance
For closely related technologies, like fuel cells, testing methodologies and procedures for safety and performance requirements are developed for single cells, stack modules and systems. This approach has improved communication among technology providers. A similar approach should be considered for electrolyser technology. Additional testing procedures to determine response characteristics (e.g.

response time, ramp rate) for ancillary services for the grid, will be required in performance standards.

Hydrogen storage could be considered as part of the electrolyser system. Small to medium scale size is related to topic see section **Error! Reference source not found.**.

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Electrolyser cell, stack and system developers, Research organisations, FCH JU

4.2.3 Research and development actions

Research should focus on bringing down the cost of electrodes and membranes, through reduction of precious metals content (as outlined in the Materials Roadmap Enabling Low Carbon Energy Technologies (SEC 2011/1609)). Upscaling of electrolyser systems (reaching MW sizes, especially for PEM electrolysers) and development of new materials to reduce degradation and, therefore, to increase lifetime are further priority topics. Also the improvement of efficiency through the adaptation and optimization of peripheral components or through the optimisation of heat flows and heat recovery is another priority topic.

In case of SOEL, the integration with renewable sources (as a heat supplier) is another topic that deserves further research activities.

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Electrolyser cell, stack and system developers, Research organisations, FCH JU

4.2.4 Roadmap and conclusions

The proposed R&D, PNR and standardization actions have been visualised in the Task Force 2 roadmap and include timelines, prioritisation and urgency. In order to further develop electrolyser technologies, especially in view of the dynamic operating conditions, all topics have a high priority and should start immediately. The most important standardization action required is the definition of Key Performance Indicators (KPI), as it enables characterisation and thus comparison of technologies.

As alkaline electrolyser technology is the most mature and established technology, the high priority topics for pre-normative research (PNR) and R&D are related to PEM and solid oxide electrolyser technologies. Regarding PNR, the development of performance characterisation and validation of materials that will increase lifetime is a critical challenge that should be tackled in short notice. Performance characterisation of solid oxide electrolyser technologies by means of performance maps in which performance and operating conditions are correlated as well as electrochemical performance characterisation to identify critical operating conditions are considered as most important PNR topics.

Regarding R&D actions, degradation is the most critical topic, so actions should be focused on the development of new materials and improvement of operating conditions.

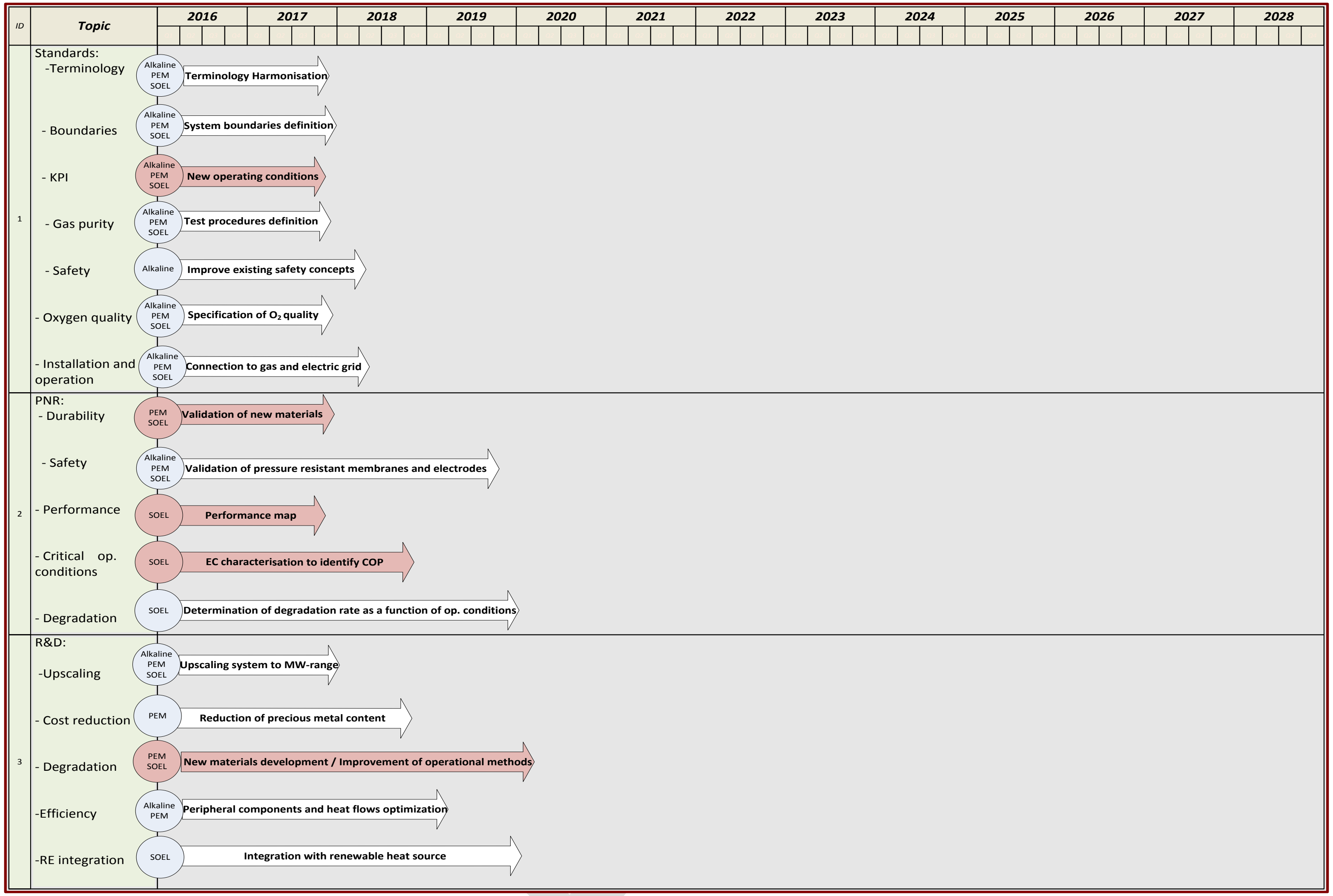
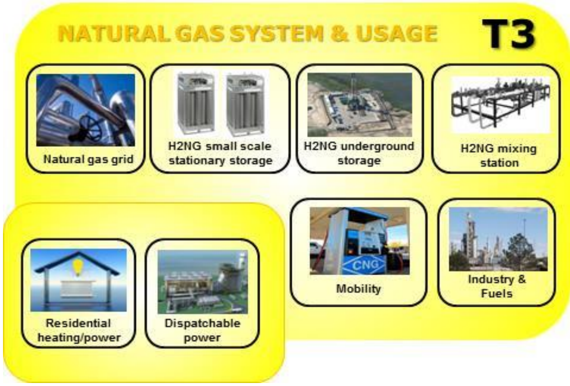


Figure 3 Roadmap Task Force 2

4.3 Task Force 3: Natural gas system and usage

Introduction

Task Force 3 focuses on the PNR and standardization challenges and needs related to the natural gas system and the use of the H2NG mixture.



Injecting hydrogen into the natural gas network can contribute significantly to solving the problem of transporting and storing surplus electricity generated from renewable resources. However, some major challenges related to the injection of hydrogen into the natural gas grid have been identified, taking into account the results of past and on-going initiatives, such as the projects NaturalHy, HyReady, Ameland and HIPS (see Chapter 3. Mapping of research and standardization activities). Generally the addition of hydrogen to natural gas may influence gas properties and therefore operational aspects, functionality of devices and appliances, degradation of materials and requirements to stations and installations (safety and functionality). Depending on the hydrogen concentration, different components of the gas system or end-user appliances and processes may be affected. The installations and components present in the gas transmission grid vary from those in the distribution grid. The distribution grid also uses a greater variety of materials such as plastic pipelines, therefore a differentiation was made between the grids where necessary. An assessment was performed to identify the key issues related to different hydrogen concentration limits of 2 vol%, 5 vol% and 10 vol%, taking into account the results of prior research. These hydrogen concentration limits also affect the timing of the proposed actions, as higher hydrogen levels are not expected in the short term.

In terms of standardization, the major relevant standards can be grouped into ‘functional’ standards, such as those developed by CEN/TC 234 - Gas infrastructure and ‘product’ standards. Functional standards specify the function of technically complex systems, with function referring to "the work or activity something is designed to do" [6]. The functional standards for gas infrastructure therefore cover the many activities related to the creation of gas infrastructure systems, and to their proper operation and maintenance. Therefore, the term functional refers in broad terms to all of the technical and operational activities necessary to ensure that gas infrastructure systems fulfil their purpose, i.e. to provide a safe, continuous and reliable supply of gas to different consumers. Product standards are covered by CEN/TC 69 Industrial valves, CEN/TC 74 Flanges and their joints, CEN/TC 155 Plastic piping systems and ducting systems, CEN/TC 235 Gas pressure regulators and associated safety devices, CEN/TC 236 Non industrial manually operated shut-off valves and CEN/TC 237 Gas meters.

Gas Quality

Different gas qualities are used throughout Europe, as the composition of natural gas varies depending on the source and further on the mixing within the networks themselves. Important parameters describing gas quality are the calorific value, the Wobbe index[2], the methane number[3] and the flame velocity which determines the flame stability. Gas quality standards are important to limit the variability in composition and hence in properties of the gas. In an integrated European gas market, suppliers could have their gas rejected by transmission system operators of another country if it does not meet the respective quality specifications. Moreover, different gas compositions may have consequences for the safe operation of domestic and industrial appliances [7].

Natural gas quality is regulated in almost all countries, where acceptable ranges of variation in quality are given in national standards, regulations or network codes. Differences in gas quality specifications impede free trade; therefore a harmonisation is in the interest of the European citizen. The question on how broad or narrow the acceptable quality range should be defined is subject to much controversy. The varied developments of the gas industry in different EU member states led to different gas supplies, technical regulations, standards and practises. This shaped quite different national views on the safely acceptable range of variations. The increasingly tough requirements on operational as well as environmental performance of appliances and applications make the issue even more difficult to tackle by manufacturers. Narrow specifications could exclude some of the potential sources, which limits the diversification of gas sources and act as a technical barrier to trade or to integrate biomethane or hydrogen. However, a broad range of composition may cause problems for at least some end-users. In addition gas quality is currently often seen as country specific: it starts on the transmission grid and ends up at the final customer where all the appliances are set up for the specific quality they are receiving. Another aspect is that not only the quality range itself but fluctuations in composition may affect the end-use appliances. The EU is working on harmonising the quality of gas in Europe, for which a mandate (M400) has been issued to the European Committee for Standardization (CEN) to draw up standards. This EC mandate has two phases:

1. Testing of gas appliances, where research is being performed by the GASQUAL consortium under supervision of CEN/BT/WG 197 Gas Quality. The final report was published in March 2013 (see section 4.3.5.2 Residential appliances).

2. Development of an EN standard by CEN/TC 234/WG 11, EN 16726 Gas infrastructure — Quality of gas — Group H. The standard shall define the acceptable range of gas quality parameters for H-gas, that are the broadest possible within reasonable costs. The definition of acceptable gas quality should also account for the effects of the injection of renewable gases (biogas, hydrogen) into the gas grids. The expected date of publication for standard EN 16726 is mid of December 2015, however, hydrogen is still excluded. "*For hydrogen, at present it is not possible to specify a limiting value which would generally be valid for all parts of the European gas infrastructure (see Annex E).*" One reason for this situation is that for the time being there is no common understanding for an admissible hydrogen concentration due to a lack of knowledge. At present the results of a GERG study on the effect of hydrogen on natural gas systems are described in an informative Annex of the

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[2] The Wobbe index refers to the calorific value of the gaseous fuel divided by the square root of its specific density (relative to air)

[3] The methane number indicates the knocking resistance of a fuel

draft standard. It should also be noted that no reference to a Wobbe index range is made in the standard, as it was not possible to reach consensus on this topic. It is planned to revise the standard in the near future to include further specifications.

Currently member states and even regions specify different concentration limits for hydrogen in the natural gas grid. For example, in Germany no maximum H2 is set and the German Technical and Scientific Association for Gas and Water (DVGW) states that the maximum H2 concentration to 9.9 vol% may be possible if there are no sensitive components, such as gas turbines, underground gas storage or CNG refilling stations, installed downstream of the injection point[4], whereas in the Netherlands the hydrogen limit is proposed to set to <0.5 vol% in regional gas grid for G-gas. As another example, the UK limit under the Gas Safety (Management) Regulations is 0.1 vol%. A comprehensive overview of all existing regulations regarding hydrogen throughout the EU should be undertaken as soon as possible.

A European-wide understanding on the acceptable hydrogen content in natural gas is needed as a basis for a future gas quality harmonization. The hydrogen tolerance of infrastructure components, end-user appliances and the effect on the system as a whole (e.g. effects on capacity) needs to be identified and agreed upon, as described in the following sections. The impact of hydrogen natural gas mixtures on the operation of the network has also been considered. Clearly identifying the research needed to be able to specify a limiting hydrogen value valid for particular parts of the European gas infrastructure is an important prerequisite for all further actions. Links to the results of networks/projects such as HIPS-NET and HYREADY should be explored and as far as possible used in the standardization process.

4.3.1 Gas system

Gas transmission by pipeline is the transportation of gas over large distances under pressure (typically over 80 bars). The transmission pipeline system in Europe extends to around 200,000 km. The gas system consists of various components such as pipelines, compressors, gas stations, analysers and storage facilities. The flow within the pipelines is maintained through compressor stations located along the pipeline. The addition of hydrogen leads to a lower energy content of the gas. Provided that the same amount of energy needs to be transported, the volume flow needs to be increased. There are measurement and pressure reduction stations to regulate and monitor flow and gas characteristics especially when handed over to lower pressure tiers. There is at least one Transmission System Operator (TSO) in each member state responsible for the safe and reliable operation of the gas grid including supervision and maintenance.

The considerable experience in delivering blends of hydrogen and methane by pipeline dates back to the gaslight era when manufactured gas was used for streetlamps and households. The so-called town gas typically contained 30 vol% – 50 vol% hydrogen and was distributed at low pressures.

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[4]It should be noted that the allowed Wobbe fluctuation in Germany is smaller than 2MJ/m3, which implies that often <<10 vol% hydrogen can be added. Moreover many appliances are restricted to lower concentrations than 10 vol%.

Although no major problems were encountered, adding hydrogen to natural gas changes the chemical composition of the gas and moreover today new materials and technologies have been introduced for which no “town-gas-experience” is available. Furthermore not all transmission systems have been operated with town gas. Therefore the effect of hydrogen on all components of the gas grid infrastructure and the gas system including underground storage needs to be assessed, also considering already available experience. The gas distribution system, as operated by the Distribution System Operators (DSOs) will be affected as well. The distribution grid shows a higher complexity of the infrastructure itself and a higher variety of materials compared to the transmission system.

Gas grid operators, when receiving a request to connect a PtG plant should analyse the current status and any potential effect in their grid to determine the maximum volume of hydrogen the network is capable of accommodating. As part of this assessment, the network operator must determine the limiting factors in its network and any upstream or downstream networks and consider the end-users requirements.

4.3.1.1 Gas infrastructure equipment and devices

4.3.1.1.1 Gas analysis methods and instruments

The addition of hydrogen to the gas grid influences the properties of the gas, such as compressibility, viscosity, density and heat capacity. The effect on volume measurement, gas composition analysis, metering and measurement of calorific value, especially for billing purposes should be assessed. In order to quantify the delivered amount of energy, the calorific value and other properties of the gas have to be measured. Currently this is performed with process gas chromatographs (PGC). The current generation of PGC use helium as carrier gas, which has a very similar thermal conductivity to hydrogen (helium = 151 W/m*K; hydrogen = 180 W/m*K). The detection method is based on the differences in thermal conductivity of gases. Therefore the PGCs, which are certified for metering, may have to be adapted or replaced [8]. In addition, calibration gases with different hydrogen concentrations may have to be used. Another issue is that some gas detection devices are not sensitive to hydrogen. The effect of hydrogen on existing gas analysis methods needs to be quantified and mitigation actions should be recommended in the short term.

Boundary conditions for existing devices concerning hydrogen concentration should be defined. This activity requires further investigation, testing and subsequent certification. As a first step, a gap analysis should be performed, followed by an evaluation if the results are transferable to all types of PGCs. This activity may be complemented by spot tests.

Based on the results of previous investigations, such as DVGW study "Energiemessung" [9], some preliminary standardization recommendations are available. Further recommendations should be developed and discussed within ISO/TC 193. Key performance requirements, such as accuracy, reliability and durability should be defined and also harmonized, preferably on a European level in order to achieve comparability and the opportunity to use the same products across Europe.

The standardization committee ISO/TC 193 Natural Gas develops international standards for natural gas and natural gas substitutes (gaseous fuels) in all its facets from production to delivery to all possible end users across national boundaries. These standards include terminology, quality specifications, methods of measurement, sampling, analysis and calculation and tests. At present most analytical methods are validated only for low levels of H2. For example in the ISO 6974 series, *Natural gas — Determination of composition with defined uncertainty by gas chromatography*, the applicable range is below 0,5 vol% H2. However, a resolution dating back to 10/2013 for the adaptation of ISO/TC 193 standards for analysis, noted the expected change in natural gas composition including oxygen content up to 1 vol% and hydrogen content up to 10 vol%.

Adaptation of gas analysis instruments and methods

Research actions:

- Perform gap analysis
- Quantify effect of hydrogen on existing gas analysis methods
- Recommend mitigation actions
- Define boundary conditions for existing devices
- Evaluation if the results are transferable to all types of PGCs
- Perform complementary spot tests

Certification actions:

- Certification of devices following the proposed investigations

Standardization actions:

- Develop adaptation of standard within ISO/TC 193
- Define and harmonize key performance requirements, such as accuracy, reliability and durability

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Manufacturers, DSOs, TSOs, standardization bodies, research institutes and certification bodies

Development and qualification of new gas analysis devices

Gas analysis devices - general

Measuring devices for hydrogen concentration above 5 vol% should be developed and put into the market, preferably by several manufacturers. First devices able to measure up to 5 vol% H2 are available and currently undergoing (national) certification processes. A variety of products (PGCs or other analytic devices) will be needed in the future for higher concentration levels. The newly developed products or technologies should be certified.

Research & development / certification actions:

- Develop measuring devices for hydrogen concentration above 5 vol%
- Certification of newly developed products or technologies

Impact of proposed actions on technology deployment:

Medium

Urgency to start the proposed actions:

Start now

Estimated time required to finalise the proposed actions:

Less than 5 years

Actors needed to fulfil the proposed actions:

Manufacturers, TSOs, DSOs, certification bodies, regulators and research institutes.

Sensors for concentration monitoring and process control

Increasing fluctuations in gas composition could necessitate further monitoring of gas for process control. As gas chromatographs are expensive, sensors could be an option for measurements of gross calorific value or Wobbe index. Sensors are needed for process control purposes, validation and further development of gas composition measurements, in particular for enabling continuous monitoring. Sensors could also be used for hydrogen concentration monitoring. Although there are many commercially available sensors able to specifically detect hydrogen, many sensing platforms are not suitable to analyse the concentration of hydrogen in methane. The presence of another combustible gas (methane) and a lack of oxygen precludes the use of common sensor types. Therefore a validation of sensor suitability should be performed and guidelines for proper usage need to be developed. The availability of dedicated gas composition measurement devices of H2NG could facilitate the introduction of hydrogen for metering, billing and modelling.

Sensors for detection of leaks

The development of sensors enabling the detection of potential leaks specifically of H2NG is also needed. As this is a safety issue, the topic is described in the cross cutting section 4.5.2 Gas detection systems.

Research actions:

- Validation of suitable sensor systems

Certification actions

- Certification of sensors
- Proof of the technical concept and acceptance by authorities

Standardization actions:

- Definition of requirements (including regulatory requirements)
- Development of guidelines

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Manufacturers, TSOs, DSOs, standardization bodies, certification bodies, regulators and research institutes.

4.3.1.1.2 Pressure regulators and valves

The suitability of components of gas pressure regulation stations with regard to higher concentrations of hydrogen still needs to be proved. At present the available knowledge does not indicate difficulties for low hydrogen concentration (below 10 vol%), however further investigation is needed. The soft sealing used in pressure regulators, valves and slam shut valves (SSV) should be considered. These devices have a major influence on safety, therefore the effect of hydrogen, also at concentrations above 10 vol% H2 has to be determined. An inventory of the state-of-the-art of the devices, including certification status, is needed in consultation with manufacturers. An investigation of materials that have not been tested so far should be performed. This data is needed to establish the necessary knowledge base to ensure the suitability of these infrastructure components. In addition spot tests should be carried out, for example of valves to determine their tightness for hydrogen.

The standards PN-EN 15848-1 and PN-EN 15848-2 should be analysed in detail, as they describe methods to investigate tightness of industrial valves using helium as a medium due to similarities of hydrogen and helium molecules. An acceptable hydrogen leakage/permeation rate, depending on hydrogen concentrations in the mixture (H2/NG) should be agreed upon and set out in an appropriate standard.

Inventory and testing actions:

- Inventory of the state-of-the-art of the devices, including certification status
- Investigation of materials
- Spot tests should be carried out

Certification action:

- Certification of components for H2NG

Standardization actions:

- Definition of requirements (including regulatory requirements)
- Development of guidelines

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start within 5 years

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Actors are manufacturers, TSOs, DSOs, standardization bodies and testing laboratories.

4.3.1.1.3 Seals and connections

Seals and connections are crucial for safety and to prevent losses. Hydrogen is more mobile than methane in many polymer materials, including elastomeric seals used in transmission lines and plastic pipes in distribution systems, leading to increased gas losses. Soft rubber seals are also used in pressure regulators and in safety shut-off devices. The suitability of seals and connections for H2NG needs to be ascertained. An evaluation of performance (tightness) of the connection techniques should be performed in the short term, following the selection of connection types that should be investigated.

PNR actions:

- Selection of connection types
- Evaluation of performance (tightness) of the connection techniques

Standardization action:

- Definition of acceptable performance should be a standardization activity

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
TSOs, DSOs, standardization bodies and testing laboratories

4.3.1.1.4 Excess flow valves

In some systems excess flow valves are installed to ensure that the gas flow rate does not exceed specifications. The valve can prevent leakage by automatically shutting down the volume flow when gas flow is above a predetermined rate. The valves should be gas tight and made of materials suitable for use with hydrogen. The effect of hydrogen on closing the volume flow should be determined for different hydrogen concentrations and the various available products. This activity addresses a safety issue and is needed in the medium term. It calls for testing and certification of products for natural gas/hydrogen mixtures.

PNR action:

- Determine closing volume for different hydrogen concentrations and products

Certification action:

- Certification of products

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Grid operators, industry

4.3.1.2 Gas infrastructure installations and other components

4.3.1.2.1 Compressor stations

To transport the gas through the transmission grid, compressor stations are needed to build up the required pressure. Compressor stations are typically placed every 250km on the pipeline network. Gas turbines, fuelled with gas from the pipeline, are often used to power these compressors (see section 4.3.5.3 Gas turbines for issues identified for gas turbines in general). The effect of H2NG on these and other components such as reciprocating compressors and gas motors should be assessed. For low concentrations of hydrogen (below 5 vol%) the effects are expected to be minor, but further investigations should be performed. In particular for hydrogen concentrations above 5 vol%, the effects on both materials compatibility and influence on functionality should be considered. An assessment of higher concentrations of hydrogen in terms of impact on performance and lifetime of compressors, considering in particular the higher flow rates needed for the delivery of the same energy contents, has not been performed to date.

Studies are needed to understand the behaviour of the operating characteristics of the compressors (efficiency, pressure, leak rate) with admixture of hydrogen. This includes analysing material compatibility with hydrogen (see section 4.5.3 Hydrogen compatibility of materials) following an analysis of the state-of-the-art. The effect of hydrogen can be observed through demonstrations and field tests. It needs to be investigated if in medium and long term the same amount of energy needs to be delivered and if so, which measures could be taken to ensure the delivery of the same amount of energy with increasing hydrogen concentration. The main aim is to provide reliable recommendations to operators.

Research actions:

- Evaluate operating characteristics
- Analyse material compatibility
- Investigate energy efficiency

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start within 5 years

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
TSOs and compressor manufacturers

4.3.1.2.2 Underground Storage

Large quantities of natural gas are being sorted in underground reservoirs as an integral part of the natural gas system, amounting to more than 108BNm^3 for Europe. Currently salt caverns, aquifers and depleted gas fields are the important geologic structures that are used for underground gas storage (UGS). The addition of hydrogen to natural gas may have consequences for UGS. Due to the high reactivity and diffusivity of hydrogen, some challenges may need to be overcome to ensure leak tightness, to prevent hydrogen embrittlement especially of subsurface steel installations but also surface installations similar to those named in other chapters (compressors stations, piping, valves,…) and microbiological interactions and deterioration of stored gases. In addition, there may be loss of hydrogen through microorganisms, as some microbes can metabolise hydrogen and carbon dioxide which will consume hydrogen. Microbial activity or the reaction of sulphides of the reservoir material with hydrogen could lead to the formation of hydrogen sulphide. Therefore specifically the suitability of porous rock UGS should be carefully assessed for hydrogen concentrations above 2 vol%.

4.3.1.2.2.1 Underground storage in porous rocks

The main UGS options in porous rocks are aquifers and depleted gas/oil fields. The standards *EN 1918-1:1998 Gas supply systems - Underground gas storage - Part 1: Functional recommendations for storage in aquifers* and *EN 1918-2:1998 - Part 2: Functional recommendations for storage in oil and gas fields* specify procedures and practices which are safe and environmentally acceptable. It covers the functional recommendations for design, construction, testing, commissioning, operation and maintenance of underground gas storage facilities aquifers and in oil and gas fields up to and including the wing valve of the wellhead. The necessary surface facilities for underground gas storage are described in prEN 1918-5.

Depleted gas/oil fields are typically well characterized, since they were analysed and operated during hydrocarbon extraction. Experiences with the storage of town gas within aquifers have revealed changes in composition caused by microbial activity have been reported in addition to losses [10]. However, research effort is still required in order to use a depleted gas field for underground H2NG storage. Especially as previous experience in storage of gas mixtures (town-gas) in aquifers have highlighted the fact that significant amounts of hydrogen are trapped, lost or contaminated in these reservoirs. Therefore, R&D actions have to take place in order to reduce these losses of hydrogen and to identify and understand the potential issues. The impact of hydrogen microbiology of the storage should be assessed, to evaluate potential safety and integrity issues for gas mixtures. Further research should focus on the investigation of bacterial growth and simulation of microbiological hydrogen sulphide (H2S)-formation and corrosion in wet environment of different rock formations. The reactions of anaerobic sulphate/sulphur- reducing bacteria in the presence of hydrogen should be clarified. Also possible reactions between hydrogen and rocks that could affect the structure integrity of the reservoir should be studied.

Investigations about the tightness of the cap rock have to be performed, in order to avoid any hydrogen leak from the storage. Displacement of the brine present in the storage by the hydrogen injected has to be studied to be able to determine the available storage volume (sweep efficiency).

This will require flow experiments to identify hydrogen and brine permeability as well as hydrogen capillary entry pressures in cap rocks. In addition the compatibility of hydrogen with the used installations, especially the subsurface installations has to be ensured considering the applied high pressures. This research has to focus mainly on the integrity and tightness of the cemented connection between the equipment and the rock as well as the specifications for the utilised equipment.

In UGS withdrawn gas requires gas treatment for dehydration and for removal of hydrocarbons in some cases also removal of sulphur compounds. In some facilities gas treatment processes are applied based on the Joule Thomson expansion gas cooling to provide gas quality according to specifications. It has to be investigated if the envisaged hydrogen concentrations have relevant effects on this type of treatment facilities.

Furthermore the addition of hydrogen leads to a lower energy content of the stored gas. Thus storage capacities are reduced.

The results of projects such as "RAG underground sun storage" and HyUnder need to be analysed, and in the following step a decision made on future actions, which may consist of mitigation measures or standardization.

Research actions:

- Evaluate operating characteristics
- Assessment of impact of hydrogen microbiology of the storage
- Flow experiments to identify hydrogen and brine permeability
- Ensure compatibility of hydrogen with the used installations and analyse materials compatibility
- Investigate tightness of the cap rock
- Study displacement of brine
- Investigate integrity and tightness of the cemented connection between the equipment and the rock

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Storage operators, TSOs and qualified laboratories

4.3.1.2.2.2 Underground storage in salt and rock caverns

Due to the very limited use of rock caverns, salt caverns are more relevant. Although the storage of H2NG in salt caverns is not seen as particularly challenging, safety and integrity issues should still be evaluated. The standard EN 1918-3:1998 gives functional recommendations for gas storage in solution-mined salt cavities. Safety requirements may need to be adapted based on the outcome of research on the integrity and tightness of the cemented connection between the equipment and the rock as well as the specifications for the utilised equipment. Details of the specific challenges of hydrogen storage in caverns are given in TF4 (see section **Error! Reference source not found.**). The storage of H2NG in (lined) hard rock caverns is an option for regions where depleted reservoirs, aquifers, and salt deposits are not available. This gas storage option is covered by EN 1918-4:1998. The compatibility with hydrogen can be ensured by lining the rock caverns with appropriated steel liners. In the case of salt caverns, as mentioned above, only limited R&D needs be performed before the storage facility can be operated according to European safety standards. This research has to focus mainly on the integrity and tightness of the cemented connection between the equipment and the rock as well as the specifications for the utilised equipment. Materials as steel and plastics should be also analysed to identify their compatibility with hydrogen. However, rock caverns require greater R&D efforts. The impact of hydrogen microbiology of caverns should be assessed, to evaluate potential safety and integrity issues for gas mixtures.

Furthermore the addition of hydrogen leads to a lower energy content of the stored gas. Thus storage capacities are reduced.

Research actions:

- Evaluate operating characteristics
- Investigate integrity and tightness of the cemented connection between the equipment and the rock
- Assessment of impact of hydrogen on microbiology of the storage
- Analyse materials compatibility

For rock caverns the following activities are recommended:

- Screening in order to determine the number and relevance of this UGS type before further R&D is recommended.
- Long-term stability of the storage facility
- Corrosion and leak tightness against hydrogen of materials for the sealing structure and for the production wells
- Specific exploration and testing to get information about the permeability of lime stone
- Evaluation of water curtain technology determine the maximum pressure differences at which storage can still be considered to be leak tight
- Investigation of reactivity of the rock
- Development of new testing techniques to confirm the integrity of these gas storages

Impact of proposed actions on technology deployment:

Salt caverns: medium
Rock caverns: low (due to limited use)

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Storage operators, TSOs, research institutes and testing laboratories

4.3.1.2.3 Pre-mixing stations

Depending on the location of the power-to-gas plant, hydrogen could be injected either into the transmission or distribution grid, which have very different gas flow rates. Low flow rates can limit the maximum injection rate to not to exceed a concentration limit. In transmission lines experience has shown that a minimum flow rate of 10000 m^3/h is needed to achieve homogeneous mixing at a distance of 10 – 20 meter downstream from the injection point. In the distribution network proper mixing may only be achieved after 2.5 km, assuming flow rates of 1000 m^3/h [11]. In order not to exceed concentration limits, premixing units may be required. This calls for identification of the technical requirements for the mixing of hydrogen and natural gas and for further investigation of the conditions for proper mixing with an as simple as possible configuration of the mixing unit. A first step would be the definition of requirements about mixing the H2 with natural gas, i.e. the degree of mixing needed. These requirements should be used for standardization.

Following the identification of requirements, the assessment of performance of the mixing process and equipment is necessary. This requires the development of a test bench and sensors to measure the hydrogen concentration delivered by premixing units. Once test results are available, clear conclusions may be drawn regarding how the technical requirements can be met through premixing devices. The actions required are R&D, modelling of mixing behaviour and definition of requirements.

Although this issue is not perceived as a show-stopper, delayed standardization could lead to a high variety of technical solutions.

PNR action:

- Modelling of mixing behaviour

Standardization action:

- Definition of requirements

Impact of proposed actions on technology deployment:

Medium

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
TSOs, DSOs, standardization bodies and research institutes

4.3.2 Grid integrity

The durability of pipeline materials is key for maintaining integrity within the pipeline system. Hydrogen can cause degradation of steel pipelines, especially when present for long periods and at high concentrations and pressures (>20 vol% H2). Gaseous hydrogen dissociates to atomic hydrogen when in contact with unoxidised, smooth steel surfaces. The atomic hydrogen dissolves into the material and can alter its structural properties, making it more brittle and/or susceptible to hydrogen assisted fatigue and fracture. Depending on the steel alloy composition, this could be the case when large amounts of hydrogen are injected into the steel high- pressure natural gas transmission lines resulting in high concentrations of hydrogen. The effect of hydrogen on the distribution network also needs to be evaluated, in particular in terms of potential degradation of plastic pipelines and rubber seals. In the short to medium term, hydrogen concentrations above 10 vol% are not expected, therefore the proposed activities have been divided into two sections, those needed in the short term to safely inject hydrogen up to 10 vol% and further actions in order to raise the limit above 10 vol%.

Previous studies, such as those performed within the NaturalHy project have concluded that concentrations of hydrogen up to 20 vol% do no cause any issues for the currently used pipelines materials. The EDGaR/ NaturalHy studies have shown that adding 25% H2 to the Dutch grid does not change the fatigue crack growth rate compared to 100% natural gas [12]. The integrity of the natural gas transport pipelines (at 67 bar) are not affected when blends up to 75% natural gas and 25% H2 are co-transported, for the materials range X42 up to X70, including the welds.

4.3.2.1 Grid integrity issues to hydrogen concentrations up to 10 vol%

Experimental proof is needed that embrittlement and fatigue effects do not occur below 10 vol% hydrogen in natural gas for all materials used in the grid especially if further imperfections are present. The assessment of the potential for grid degradation should commence with a comprehensive mapping of the materials used in both transmission and distribution networks to document their sensitivity to hydrogen. The effect of hydrogen embrittlement is highly dependent on the type of steel, therefore an overview of the used materials is necessary. An analysis of impact of hydrogen on plastic and rubber components should also be undertaken.

Other necessary actions include an evaluation of the susceptibility to hydrogen damage in pipelines in use, as there are concerns about possible (accelerated) crack growth due to hydrogen injection into older and damaged pipelines. These activities should include quantification of the expected degradation/embrittlement effects through additional investigations on aged ex-service pipeline materials. It should also be defined how the acceptance criteria for existing damage to pipelines must be modified with H2 addition.

On a standardization level, the Pipeline Integrity Management System (PIMS) standards, for example ASME B31.8 and EN 16348 have to be updated based on the outcome of the research conducted. Evaluation methods for assessing pre-damage should be established as a basis for implementation into the PIMS of TSOs and the necessary material property data should be made available. It is proposed to further analyse standards/codes for evaluation of anomalies of steel pipeline wall thickness in order to assess hydrogen impact on the pipelines (i.e. DNV-RP-F101 Corroded pipelines and ASME B31.G Manual for determining the Remaining Strength of Corroded Pipelines).

PNR actions:

- Analysis of impact of hydrogen on plastic and rubber components
- Evaluation of the status regarding imperfections and damage of the pipelines and determining the possible effects of hydrogen on these materials
- Determining the expected degradation/embrittlement effects
- Define acceptance criteria for existing degradation must be modified with H2 addition.
- Validation of test methods for crack initiation under hydrogen environment
- Development and validation of accelerated test methods for characterising crack growth under hydrogen-assisted fatigue
- Clarification of role of hydrogen impurity levels on embrittlement and enhanced fatigue susceptibility

Standardization actions:

- Update of PIMS standards (EN 16348), Pipelines for maximum operating pressure over 16 bar (EN 1594) and Pipelines for maximum operating pressure up to and including 16 bar (EN 12007 series)

Impact of proposed actions on technology deployment:

High

Urgency to start the proposed actions:

Start now

Estimated time required to finalise the proposed actions:

Less than 5 years

Actors needed to fulfil the proposed actions:

TSOs, DSOs, testing laboratories, standardization bodies, companies offering inline inspection technology for transportation pipelines and research institutes

4.3.2.2 Grid integrity issues for hydrogen concentrations above 10 vol%

In the medium term an investigation on the expected effects of hydrogen additions above 10 vol% on fatigue should be undertaken. Research should be performed to generate the needed material property data, followed by establishing evaluation methods as a basis for implementation into the PIMS of TSOs. The available standards may not be prepared for hydrogen at these concentration levels concerning materials, operational conditions and acceptable pre-existing damage. As safety and integrity issues are concerned, this is a high priority activity, but concentrations of hydrogen at these levels are not expected in the short term.

PNR/Standardization actions:

- Generate material property data
- Establish evaluation methods

Impact of proposed actions on technology deployment:

High

Urgency to start the proposed actions:

Start within 5 years

Estimated time required to finalise the proposed actions:

Less than 5 years

Actors needed to fulfil the proposed actions:

TSOs, DSOs, testing laboratories, standardization bodies and research institutes.

4.3.3 Grid operation

4.3.3.1 Flow behaviour

A pipeline system operator needs to have information of the system's pressures and flows for ensuring a continuous supply of gas to the end users and for billing purposes. As gas analysis devices are only installed at a few locations, the complete current system state of transmission grids and the amount of energy delivered is computed by simulation using a hydraulic model using heating values for predefined regions. Simulation software is crucial for the operation especially for the transmission grid but is gaining increasing importance for distribution to enable accurate billing when injecting decentralised green gas. Simulations can either evaluate steady-state flow scenarios with constant hydraulic quantities or dynamic scenarios. The modelling considers factors such as pressure drop, flow rate, flow patterns and pipe characteristics. Variables include thermodynamic properties of all components of the gas mixture and their interactions.

The thermodynamic properties of hydrogen–natural mixtures gas significantly differ from those of natural gas. It has been demonstrated that assuming isothermal and steady-state flow may not be sufficiently accurate to describe gas mixtures [13]. For an equal volume flow, the addition of hydrogen significantly lowers the amount of energy transported. The effect of the addition of hydrogen can be described as a decrease in pressure and temperature gradient in the pipeline for an unchanged gas demand. Compressors may have to compensate for increased pressure losses.

Improved modelling of the mixing behaviour is needed to better understand the flow behaviour of gas mixtures and to identify areas where due to imperfect mixing higher H2-concentrations can occur. Low cost and low consumption sensors for grid and gas meter monitoring should be developed. Further development of hydraulic software for modelling gas flows/pressures is required, in order to meet billing requirements. As a first step the ability of the available software to deal with mixtures of hydrogen and natural gas will have to be verified in the field. The development of software for hydraulic analysis purposes is difficult and expensive. Companies offering software for hydraulic analysis have the necessary experience and know-how, therefore cooperation with these companies as well as research bodies should be sought and strengthened.

Although this activity should be started immediately, the results will prove most important in the medium term, as in the short term hydrogen concentrations significantly affecting flow are not expected.

Research actions:

- Modelling the mixing behaviour
- Development of hydraulic software

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
TSOs, DSOs, software manufacturer and research bodies

4.3.3.2 Condition monitoring, maintenance and repair procedures and related equipment

An evaluation of the effects of hydrogen on maintenance and repair procedures and equipment should be performed. Existing procedures need to be evaluated and adapted for natural gas/hydrogen mixtures in the medium term. The effect on the maintenance and repair procedures is connected to the hydrogen concentration, which is not expected to increase significantly in short term. Furthermore results from other investigations (e.g. elements as valves) first need to be available as input for the method adopted. The aim is to give recommendations for adaptation of the existing methods or for equipment replacement. The results of past projects such as NaturalHy should be analysed and links to on-going initiatives (HIPS-NET/HYREADY) established.

PNR actions:

- State of art analysis, evaluation of the expected effects
- evaluate existing procedures

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start immediately

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
TSOs and DSOs, research institutes

4.3.3.3 Effect of H2NG on odorization

The odorization of natural gas is an important safety measure to enable the detection of leaks without resorting to sensors or other devices. Odorization is mostly carried out using sulphur based odorants. Throughout Europe the requirements for odorization vary (e.g., specific network level where the gas is odorized, minimum concentration and olfactory degree), which causes problems for the transmission of natural gas across borders. Therefore in general European harmonization of odorization of natural gas would be beneficial. Recently sulphur free odorants have been developed for which there is no experience regarding their performance, stability and possible reaction with hydrogen. The impact on odorants should be assessed for all types of odorants. ISO TR 16922:2013 specifies the principles for the odorization technique and the control of odorization of natural gas. General requirements for odorants, and the physical and chemical properties of commonly used odorants are specified in ISO 13734:2013.

Performance tests to determine the suitability of odorants for different H2NG mixtures should be performed and recommendations given for odorant concentrations in order to achieve the necessary smell intensity.

Standardization is recommended in order to harmonise the performance indicators for odorants used for H2NG. It should be noted that there is no European aligned method for odorization of natural gas.

PNR action:

- Performance tests on the propagation of smell

Standardization action:

- Harmonise the performance indicators

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Gas suppliers, research institutes and standardization bodies.

4.3.3.4 Losses due to permeation

Losses due to the permeation of hydrogen need to be determined and evaluated. In particular there is a need for determining the acceptable hydrogen permeation rates through polymer pipelines. The existing knowledge does not identify critical permeation rates, however some materials (especially new plastic types) have not been investigated. All types plastic pipes, such as PE63, PE80, PE100, PA6, PA11, PA12,… have to be investigated. Pipeline producers indicate permeation coefficients for different media, i.e. gas, which are used in equations to calculate permeation of a specific medium. The permeation coefficient for mixtures as well as for pure H2 should be determined. A standardization of permeation limits would be beneficial. In the medium term testing of these materials is recommended, following a thorough inventory of the state-of-the-art. Results from past research e.g. NaturalHy should be incorporated.

Pre-normative research actions:

- Determine loss rate
- Determine permeation coefficient

Standardization action:

- Set limit of acceptable hydrogen permeation

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start within 5 years

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Research institutes, standardization bodies and testing laboratories

4.3.4 Separation

Hydrogen has the highest value as a commodity in its pure form, to be used either for H2 mobility or as a feedstock for the chemical industry. Furthermore, as described in this report, hydrogen can have a negative impact on some components of the gas infrastructure (e.g. underground storage or equipment) and applications (industrial or domestic), in particular at high concentrations. Research should be conducted on separation of hydrogen from H2NG from transportation or distribution networks. The goal is to guarantee that:

- the overall costs of a H2NG path is lower than a pure hydrogen path which requires a dedicated hydrogen grid,
- hydrogen can be valorised as such and not only as H2NG,
- it can be stored at specific points to provide hydrogen for specific industrial processes.

A first step would be the definition of requirements for separating H2 from H2NG, i.e. the degree of separation needed (speed of separation depending of flow /pressure, temperature and resulting hydrogen purity). These requirements should be used for standardization.

Following the definition, an assessment of the requirements depending on the expected situation is necessary. Then clear conclusions may be drawn regarding how the technical requirements can be met, for example through separation devices. The actions required are R&D, modelling of separation behaviour and definition of requirements. Although this issue is not perceived as a show-stopper, late standardization could lead to a high variety of technical solutions or even an implementation of unfavourable solutions.

Research action:

- Benchmark and field test of existing separation techniques in transportation and distribution grid

Standardization action:

- Definition of requirements

Impact of proposed actions on technology deployment:

Medium

Urgency to start the proposed actions:
Start within 5 years

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
TSOs, DSOSs, standardization bodies and research institutes

4.3.5 H2NG End-users

The injection of hydrogen in the natural gas grid will affect all gas users. Therefore the use of hydrogen mixed with compressed natural gas should be carefully assessed in terms of safety and performance of end user installations, such as the 200 million residential gas appliances in Europe. Other major gas end-users include gas power stations, the mobility sector as fuel for vehicles and the industrial sector, where gas is used for a great variety of purposes, for example heating, thermochemical processes and as a process gas. All end-use appliances should be certified specifically for H2NG, with the key issues being flame stability and hydrogen embrittlement. The project NaturalHy has evaluated the potential impacts of the addition of hydrogen for the end users. In general, no major safety concerns were found for residential appliances, but long-term experience of material compatibility with hydrogen and natural gas mixtures is missing. For industrial end-users problems may occur if there are major changes in gas quality. Due to regulations for emissions and efficiency, most appliances function within a limited fuel composition range. Changes in gas composition may require the adaptation of combustion systems (turbines or engines) or the evaluation of the impact on chemical process stability, as also the quality of the product may be affected. The Hyready project is currently making an inventory and determining the knowledge gaps. Moreover guidelines for mitigating the negative effects of hydrogens addition will be developed.

4.3.5.1 CNG vehicles

4.3.5.1.1 CNG vehicles - on-board storage

The storage of hydrogen-natural gas mixtures in steel cylinders type 1, fitted to natural gas vehicles, has been identified as one of the key limiting factors regarding the allowable concentration of hydrogen especially in the gas distribution grid. It also limits the use of biomethane produced from gasification, where hydrogen will be introduced into the gas grid. About 1.1 million natural gas vehicles are deployed in Europe, primarily in Italy, corresponding to a share of 0.41% of all passenger vehicles [14]. According to a recently published study by the DVGW [15], 95% of all currently deployed CNG passenger vehicles are fitted with steel tanks. In Europe all of these tanks are made of chrome molybdenum steel which would in principle be suited for gases containing hydrogen. It is in fact the same material used for transport of hydrogen at 200 bar on trailers [16].The suitability of these tanks for the storage of hydrogen-natural gas mixtures is primarily dependent on the tensile strength of the steel and the quality of the inner surface of the tank. The steel should not be too hard, as it could otherwise be susceptible to fatigue crack growth when hydrogen is present. In addition, the inner surface should be monitored for defects, as these have been found to seriously compromise the product life in case of hydrogen gas cylinders [17].

The regulation UNECE R110 [18] sets out minimum requirements for light-weight refillable gas cylinders in Annex 3a. The regulation refers to several ISO standards (e.g. ISO 9809 and ISO 1114-1) setting out the requirement for the on-board gas storage system. The regulation defines a maximum limit of 2 vol% hydrogen in CNG as a fuel for tank cylinders that are manufactured from steel with an ultimate tensile strength exceeding 950 MPa. In case of a high humidity content of the CNG (>32mg/m3) the limit is set even lower at 0.1 vol%. The reason for these strict limits is the expected susceptibility of steel tanks to hydrogen embrittlement, which can cause crack propagation in steel, a serious safety issue.

To reduce the weight of the on-board storage system car manufacturers typically use high strength steel so that the wall thickness of CNG tanks can be decreased. Therefore the material may have a tensile strength surpassing the limit of 950 MPa, rendering the tanks unsuitable for hydrogen concentrations above 2 vol%. The inner surfaces of the cylinder are currently not inspected for defects as this step is not needed for storing CNG.

In the short term, tests are needed to qualify steel tanks for H2NG with hydrogen concentrations above 2 vol%. As a first step, the in-depths analysis on the effect of hydrogen on steel tanks commonly used in the NG-vehicles is recommended, to experimentally determine the technically acceptable hydrogen concentration for CNG steel tanks. Pre-normative research should be performed to determine the durability of the steel tanks including the maximum number of cycles.

The results of the study could be used to update the ISO standards referred to in the R 110 regulation. Work should specifically focus on standards ISO 11439 „Gas cylinders - High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles" and standard ISO 15869:2009 "Gaseous hydrogen and hydrogen blends -- Land vehicle fuel tanks".

Incentives to encourage the use of more advanced type 3 or 4 tanks for on-board storage could be explored. Such tanks are technologically mature and used in fuel cell hydrogen electric vehicles, as well as in some models of CNG vehicles. The more costly composite tanks have several advantages, such as a higher gravimetric density of the storage system. For these tanks no hydrogen limitation applies. This topic should be taken up by the United Nations Economic Commission for Europe UN ECE WP 29 "World Forum for Harmonization of Vehicle Regulations" which is responsible for the regulations on the homologation of vehicles (ECE R110).

PNR actions:

- Qualification methods for steel tanks for H2NG with hydrogen concentrations above 2 vol%
- Establishment of test methodologies for characterising the durability (including under cycling conditions) of steel tanks

Standardization action:

- Update the ISO standards referred to in the R 110 regulation

Regulatory action:

- Incentives for type 3 or 4 tanks

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
TSOs, DSOs, tank manufacturers, OEMs, material experts/testing laboratories and standardization bodies.

4.3.5.1.2 CNG vehicles - adaptation of combustion system

The addition of hydrogen influences the combustion behaviour in the IC engines of natural gas vehicles. Positive effects occur due to the high reactivity of hydrogen, which extends the flammability limits and enhances flame propagation. The main effect is an increase in laminar burning speed, which plays a major role in determining the combustion process characteristics as well as the engine performance and emissions [19]. This can result in more efficient combustion, lowering harmful emissions. However, higher peak pressures and temperatures will occur, which can reduce the life time of the engine and the increase in temperature result in an increase in NOx emission. Issues may also arise related to abnormal combustion including knock, engine wear and backfiring. Therefore the effect of hydrogen on combustion in different types of engines should be assessed, as a function of hydrogen concentration and the natural gas composition. While low hydrogen concentrations (< 10 vol% H2) have only minor effects on engines, limits should be established and mitigation measures identified for overcoming problems. In the medium term, car manufactures should undertake further research and development, for example on smarter engine management control systems to avoid some of these issues (knock and emission of NOx).

Pre-normative research action:

- Effect of hydrogen on the combustion on different engines types

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start within 5 years

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Research institutes, engine manufacturers

4.3.5.1.3 CNG filling stations - metering

The meters are typically calibrated for a particular gas quality, such as H or L type gas. Depending on the type of meter used in the filling station, the influence of hydrogen may need to be accounted for to ensure accurate billing. The often used Coriolis type meters are in principle able to measure up to 100 vol% H2, but further demonstration of accurate performance of the metering devices is needed.

Pre-normative research action:

- Proof of accurate performance (measuring)

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start within 5 years

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Testing institutes, meter manufacturers, metrology institutes

4.3.5.2 Residential appliances

4.3.5.2.1 Residential appliances - Certification of appliances for H2NG

Existing and new appliances need to be evaluated regarding their performance and operational safety for (intermittent) use with various hydrogen concentrations. The necessary activities include first establishing an inventory and state-of-the-art analysis for residential appliances followed by subsequent testing and certification to guarantee the safe use of H2NG mixtures. Certification is very important point, it is therefore crucial to timely start with this certification action, in parallel to the market development.

A thorough review should be performed of the underlying tests and assumptions included in existing studies made by the affected appliance sectors. Manufacturers should be closely involved, as they have the expertise on assessing the safety and reliability of their products, especially for long term operation. The appliance sectors with their related standardization groups should be consulted on the likely levels and impact of hydrogen being discussed. It should also be noted that the output of a number of hydrogen studies may not yet be widely known within these appliance sectors - either through CEN/TCs or through Trade Associations.

In the future liaisons should be set up with CEN/TC 48, CEN/TC 49, CEN/TC 58, CEN/TC 62, CEN/TC 106, CEN/TC 109, CEN/TC 131, CEN/TC 180, CEN/TC 237, CEN/TC 299, ISO/TC 291, CEN Sector Forum Gas – Utilisation (SFG-U) and the Association of the European Heating Industry.

Research action:

- State-of-the-art analysis in close consultation with appliance manufacturers and potential liaisons as mentioned above

Certification actions:

- Evaluation of performance
- Certification of appliances for H2NG

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
This action should involve manufacturers, end-users, safety regulators, certification bodies, heating sector and DSOs

4.3.5.2.2 Residential appliances – definition of an appliance category and test gases

The Gas Appliances Directive 2009/142/EC (GAD) constitutes the legal framework for gas appliances in the EU Member States. It aims to provide access to the EU market for appliances and fittings concerning gas safety of these products. The GAD contains the essential requirements that an appliance or a fitting must meet when it is placed on the EU market. Appliances covered by the GAD may only be brought to the market for a specific appliance category. If no appliance category is defined, it will not be possible to bring products that use H2NG to the market.

To demonstrate the suitability of appliances for the use of H2NG, three separate steps are necessary. First of all, a range of distribution gas parameters should be defined, including the Wobbe index range and hydrogen content range. Secondly, suitable test gases have to be determined for this distribution range. Lastly an EU-gas category should be established. The corresponding label is to be attached to appliances indicating their suitability for H2NG.

CEN/TC 238 deals with test gases, test pressures, appliance categories and is in charge of EN 437 Test gases - test pressures - appliance categories. This standard constitutes the reference document for appliances that fall within the scope of the Gas Appliance Directive (GAD). It classifies distributed gases into families and groups, depending on Wobbe index range and specifies test gases, test pressures and appliances categories for gas families and groups. These are declared by Member states and published in the OJEU. Currently, for H gas group, one of the test gases (light back limit gas) G222 (CH_4 = 77 % + H_2 = 23 %) is used. EN 437 is under revision at this moment.

Standardization actions:

- Inclusion of H2NG and the gas appliance category in the standard for test gases (EN 437).
- Standardization work should consider gas composition, gas pressures and conditions for 1) normal use of the gas appliances; 2) testing of gas appliances.

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start within the next 5 years

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
H2NG suppliers, appliance manufacturers, standardization bodies, notified bodies and testing facilities for the GAD

4.3.5.2.3 Residential appliances – adaptive combustion control

Residential appliances include burners and space heaters. They will need to be able to adapt to gas composition changes resulting from the addition of hydrogen to natural gas. This is actually a more general issue as gas quality fluctuations are more likely to occur in the future, even without any addition of hydrogen to natural gas, due to the security of gas supply requiring a broadening of the supply base. Therefore more flexible devices should be developed, standardised and brought to the market. In some countries it is mandatory to provide evidence to the authorities that safety hazards due to the injection of hydrogen are avoided for the installed base of appliances. Immediate action is needed, involving appliance manufacturers, authorities on gas safety and appliance experts. It should be noted that the GRHYD project is addressing a number of these challenges, with results expected by the end of 2016 with first laboratory tests and at the end of the project in 2017 for a real demonstration.

Standardization action:

- Develop, standardise and bring more flexible devices in the market

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
H2NG suppliers, appliance manufacturers, standardization bodies, notified bodies and testing facilities for the GAD

4.3.5.2.4 Gas pipework for buildings

The connections and other infrastructure components needed for the in-house infrastructure which includes pipelines, tubes, valves, meters and other components should firstly evaluated based on the available knowledge (e.g. by using results from NaturalHy). Subsequently a gap analysis of the materials used in Europe should give an indication if further testing is needed in the medium term. The relevant standard is EN 1775 for a maximum operating pressure less than or equal to 5 bar.

Testing action:

- Gap analysis of materials

Standardization action:

- Revision of EN 1775 based on research results with regard to pipeline integrity.

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Medium

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Manufacturer, DSOS, testing laboratories (optional).

4.3.5.3 Gas turbines

Gas turbines can run on various fuels, but currently the common fuel is natural gas. The stringent regulations on emission of gases nitrogen oxides (NOx) and carbon monoxide influence the way gas turbines are designed and operated. The commonly used lean premixed combustion of natural gas is able to achieve low NOx emissions at high efficiency. However, operating conditions are restricted to a narrow window as the gas turbine combustion system is tuned for optimum operation. This entails strict limits on changes in gas composition [20]. The addition of hydrogen will influence the heating value as well as the combustion characteristics (i.e. air/fuel ratio). Current fuel specifications often place an upper limit on hydrogen volume fraction in natural gas of 1- 5 vol% [6]. Hydrogen could cause flame instabilities such as flash back, flame out and pulsations. A raised flame temperature could also increase NOx emissions. A thorough assessment of the effects of hydrogen admixture in natural gas for already installed gas turbines has not been performed yet. Relevant standards are being developed by ISO/TC 192 and CEN/TC 399, for example ISO 3977-4:2002 Gas turbines -- Procurement -- Part 4: Fuels and environment.

To determine the acceptable hydrogen concentration of gas turbines in the field, a study of the behaviour of the operating characteristics (efficiency, flame speed, air/fuel ratio, impact on combustion chamber, emission) with admixture of hydrogen is needed. If possible a comparison should be made with the experience for gas turbines already operating with 100% of H2, for example those developed under the Advanced Hydrogen Turbine Development Project [21]. In addition, the material compatibility and leak rate should be assessed. This action is best performed by investigating some representative installed gas turbine types. The aim of this activity is to provide reliable recommendations for acceptable hydrogen concentrations to the transmission system operators. Immediate action is needed, as gas turbines are not only end using devices, but are also important element of the gas transmission system (see section 4.3.1.2.1 Compressor stations).

Research actions:

- Study of the behaviour of the operating characteristics
- Assess materials compatibility and leak rate

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Manufacturers of gas turbines, in addition to research institutes and grid operators.

4.3.5.4 Industry

4.3.5.4.1 Industry - Certification of burners for H2NG

Existing and new industrial burners need to be evaluated regarding their performance and operational safety for (intermittent) use with various hydrogen concentrations. The necessary activities include first establishing an inventory and state-of-the art analysis for industrial burners with subsequent testing and certification, in parallel to market development.

Certification action:

- Certification of burners for H2NG

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
This action should involve manufacturers, end-users, safety regulators, certification bodies, and TSOs

4.3.5.4.2 Industry - effect of H2NG on industrial applications

Industrial process applications include the chemical and petrochemical industries, various kinds of thermal treatments, glass, ceramics and melting furnaces. For these not only the impact on burners (see section 4.3.5.4.1 Industry - Certification of burners for H2NG) but also on the industrial processes themselves needs to be considered (furnaces, boilers, flame working, e.g.).

The chemical industry consumes large quantities of natural gas, including the use as a feedstock. The effects of hydrogen on chemical processes are currently not well known. Immediate action is needed in order to identify sensitive processes and mitigation measures. Further activities include developing cost efficient strategies for adapting the infrastructure for H2NG. A transition roadmap could be useful.

PNR actions:

- o Evaluate impact of hydrogen industrial processes, based on hydrogen concentration between 2 and 10 vol% hydrogen in the H2NG mixture
- o Identify sensitive processes
- o Adapt infrastructure if needed

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
The actors should be industry, associations, R&D institutes, TSOs, DSOs.

4.3.5.4.3 Industry - effect of H2NG on industrial gas installation pipework

When H2NG is used in industry, the industrial gas installation pipework needs to be designed to make sure that pipeline integrity is assured. For industrial gas installation pipework with an operating pressure greater than 0,5 bar and greater than 5 bar for industrial and non-industrial installations EN 15001-1 is applicable. The standard does not cover H2NG yet and should therefore be assessed and possibly revised. Revision of EN 15001 is at this moment ongoing.

PNR actions:
The connections and other infrastructure components needed for the industrial infrastructure should firstly evaluated based on the available knowledge. Subsequently a gap analysis of the materials used in Europe should indicate if further testing is needed in the medium term.

Standardization action:
Revision of EN 15001-1 based on research results with regard to pipeline integrity.

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Medium

Estimated time required to finalise the proposed actions:
5 - 10 years

Actors needed to fulfil the proposed actions:
Industry, manufacturer, DSOs, testing laboratories (optional)

4.3.6 Roadmap and conclusions

PNR and standardization actions have been identified for the natural gas system and for the use of H2NG. The actions proposed for the key items have been visualised in the Task Force 3 roadmap below which includes timelines, prioritisation and urgency.

The first priorities identified for the gas grid infrastructure are actions to enabling an increase of the acceptable concentration of hydrogen in natural gas. Establishing a European understanding on this issue can be seen as an overarching theme for the gas system. This requires filling in a number of knowledge gaps. Depending on the hydrogen concentration, different components of the gas system or end-user appliances and processes may be affected. More sensitive elements are present in the gas transmission grid than in the distribution grid therefore a differentiation was made between the transmission and distribution gas grid infrastructure and related applications with their the impacts. An assessment was performed to identify the key issues related to different hydrogen concentration limits of 2 vol%, 5 vol% and up to 10 vol%. Prior research has identified these limits as possible hurdles. The 10 vol% limit is also set as an outlook for the future with a strong role of hydrogen in the energy transition. However, in order to proceed with the admixture of hydrogen in the gas grid, it was decided to focus on lower concentrations 2-5 vol% in the mid-term. The identified critical issues and activities that are needed in order to achieve certain tolerances over hydrogen are based on current knowledge and account for the majority of components and situations that occur across Europe. Nevertheless some individual situations may need to be carefully analysed to identify specific situations that have to be considered. Adequate measures to inform the customer are mandatory before hydrogen is injected in the natural gas grid. In the following the sensitive topics that need to be addressed as well as accompanying activities are summarised. Further information is given in the road maps, see Figure 4 Figure 6.

The main topics as identified for a **hydrogen limit of 2 vol%** are aspects related to gas quality (common understanding of acceptable hydrogen concentrations in the gas grid), gas turbines, porous underground gas storages and the possible impact on industrial processes when using H2NG as feedstock.

Further topics of a legislative/standardization nature need be addressed as they can support the technical transition but are not linked directly to the 2 vol% limit. A key item concerning gas quality are the related equipment and devices. Research and standardization actions have been identified for the adaptation of the gas analysis instruments and methods. Aspects of importance are the accuracy, reliability and durability requirements. Also actions with regard to the validation of suitable sensors and guidelines for their proper usage have been prioritized. Seals and connections are crucial for safety and to prevent losses therefore also considered of high importance. This also regards the excess flow valves, the valves should be gas tight and made of materials suitable for use with hydrogen.

Gas turbines have been identified as a sensitive component. As the gas turbine can typically only tolerate limited changes in gas composition current fuel specifications often place a limit on hydrogen volume fraction in natural gas in a limited range of 1-5 vol%. In order to determine the acceptable hydrogen concentration of gas turbines in the field and with admixture of hydrogen (focus on gas turbines in the natural gas grid) a study is needed.

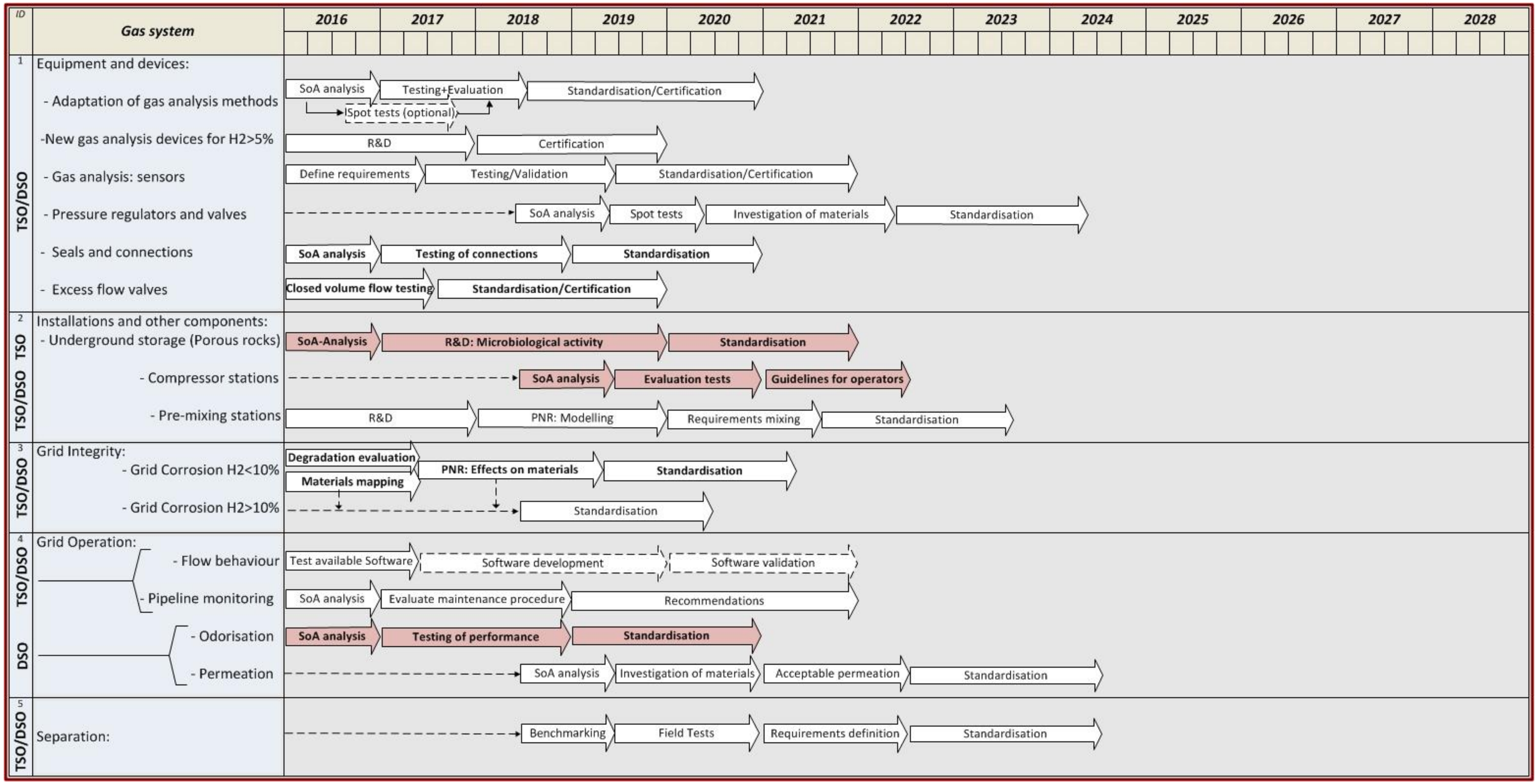
The effects of hydrogen on chemical processes are currently not well known. Immediate action is therefore needed in order to identify sensitive processes and mitigation measures.

With regard to the **hydrogen limit of 5 vol%** all of the identified actions as with the 2vol% limit are needed. For the 5 vol% limit additionally the tests are needed to qualify steel tanks for on-board storage with hydrogen concentrations above 2 vol%.

When applying **hydrogen concentrations up to 10 vol%** of course the same priorities remain as identified with the 2 and 5 vol% limit. Measuring devices for hydrogen concentration above 5 vol% still have to be developed and put into the market, preferably by several manufacturers. Before the hydrogen concentration surpasses 5 vol%, the safety and performance of compressor stations has to be ensured. In addition the safety and performance of industrial and residential burners will also need to be addressed. Another major issue to be considered is an investigation e.g. of bacterial growth and compatibility of hydrogen with the used installations for cavern underground gas storage. Other important issues are related to safety and grid integrity (grid corrosion by choice of materials). Also performance tests on the propagation of smell depending on hydrogen concentration for new odorants are recommended in the near term and should be addressed before 10 vol% H2 is injected into the natural gas grid.

Not connected directly for achieving hydrogen concentration above 5 vol% but also important in order to ensure an efficient hydrogen admixture in the gas grid are:

- The determination of acceptable hydrogen permeation through polymer pipelines.
- Standardization of performance of premixing stations.
- Flow behaviour and condition monitoring.
- Maintenance, repair procedures and related equipment.


ID
Gas system
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
1
TSO/DSO
Equipment and devices:
- Adaptation of gas analysis methods
SoA analysis
Testing+Evaluation
Standardisation/Certification
Spot tests (optional)
-New gas analysis devices for H2>5%
R&D
Certification
- Gas analysis: sensors
Define requirements
Testing/Validation
Standardisation/Certification
- Pressure regulators and valves
SoA analysis
Spot tests
Investigation of materials
Standardisation
- Seals and connections
SoA analysis
Testing of connections
Standardisation
- Excess flow valves
Closed volume flow testing
Standardisation/Certification
2
TSO
TSO/DSO
Installations and other components:
- Underground storage (Porous rocks)
SoA-Analysis
R&D: Microbiological activity
Standardisation
- Compressor stations
SoA analysis
Evaluation tests
Guidelines for operators
- Pre-mixing stations
R&D
PNR: Modelling
Requirements mixing
Standardisation
3
TSO/DSO
Grid Integrity:
- Grid Corrosion H2<10%
Degradation evaluation
Materials mapping
PNR: Effects on materials
Standardisation
- Grid Corrosion H2>10%
Standardisation
4
TSO/DSO
DSO
Grid Operation:
- Flow behaviour
Test available Software
Software development
Software validation
- Pipeline monitoring
SoA analysis
Evaluate maintenance procedure
Recommendations
- Odorisation
SoA analysis
Testing of performance
Standardisation
- Permeation
SoA analysis
Investigation of materials
Acceptable permeation
Standardisation
5
TSO/DSO
Separation:
Benchmarking
Field Tests
Requirements definition
Standardisation

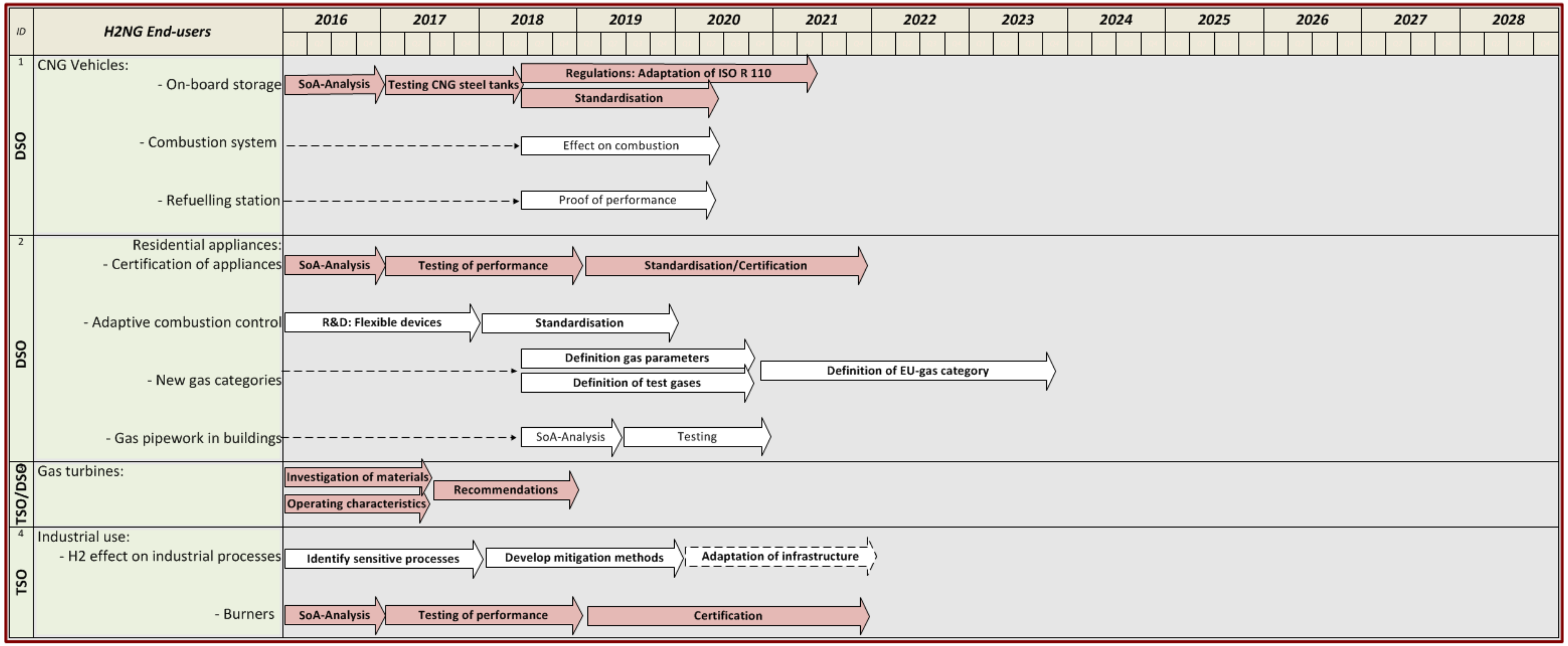
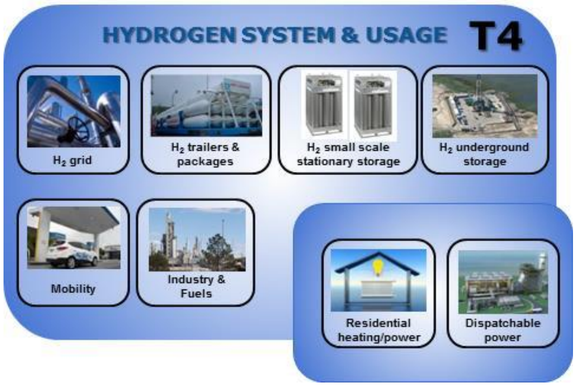


Figure 4 Roadmap Task Force 3

4.4 Task Force 4: Hydrogen system and usage



Task Force 4 focuses on the PNR and standardization challenges and needs related to hydrogen systems and the use of pure hydrogen. The hydrogen system includes means to store hydrogen in stationary storage cylinders and underground salt caverns and to transport hydrogen to the end-user via packages and trailers. End-users are vehicles and industrial users but also residential applications and dispatchable power that provides electricity back to the grid. Hydrogen pipeline infrastructure and the connected industrial end-users have been given less priority in this section as it concerns private pipeline systems. Therefore, the following sections address storage in salt caverns, distribution through trailers, refuelling stations (including stationary storage), on-board hydrogen storage in vehicles and distributed power and fuel cells.

4.4.1 Hydrogen infrastructure – Underground hydrogen storage in salt caverns

Salt caverns are well suited for hydrogen gas storage and are therefore addressed in this chapter. The utilisation of porous rocks for storing H2NG might be more likely in the near term and is therefore dealt with in 4.3.1.2.2.1 Underground storage in porous rocks.

Current situation – observed gaps:
Using hydrogen as a means to storage renewable energy is receiving increased attention in assessment studies. The German study "Integration of Wind-Hydrogen-Systems in the Energy System" for example has looked into salt caverns and analysed the storage potential, permitting processes and R&D needs. There is nearly half a decade of practical experience with natural gas storage in salt caverns worldwide. The operation of salt caverns dedicated to hydrogen storage in Europe (since 1972, Teesside) and the US (since 1983, Texas) has been successful and has shown that hydrogen can safely be stored for long periods of time. The storage of natural gas and hydrogen in salt caverns has similarities; therefore any progress made in technology, safety, maintenance and operations in natural gas storage is at the benefit of hydrogen storage. The European standard EN 1918-3 developed within CEN/TC 234 provides functional recommendations for the design, construction, testing, commissioning, operation and maintenance for gas storage in salt caverns in general and for CNG and LPG storage in particular. To facilitate hydrogen storage, the standard would need to be updated to include hydrogen, taking stock of the experiences gained in existing caverns used for hydrogen storage. The EU supported HyUnder project has investigated the potential of underground storage in Europe and has identified some PNR work for hydrogen storage in salt caverns. PNR is considered to be minor due to advanced state-of-the-art of natural gas storage. The activities are needed in the area of cement integrity and the specifications for the equipment utilised. The cemented connection between the casing and the rock salt in the cavern neck has been identified the most sensitive point in the cavern and tightness of cement mixtures

should be proven for hydrogen. The ample experience available on susceptibility to hydrogen embrittlement of steels and non-metallic materials should enable the selection and use of appropriate and approved materials. The mechanical integrity test, which is used to confirm gas tightness of rock salts for sealing, might need to be modified for salt caverns for hydrogen storage.

PNR action:

- Pre-normative research into materials compatibility and durability of especially cement mixtures, but also steels and non-metallic materials for use in hydrogen storage facilities.

Standardization action:

- Consider the update of the European standard EN 1918-3 for functional recommendations for underground gas storage in solution-mined salt cavities, developed within CEN/TC 234, to include hydrogen specific sections e.g. for first gas fills (including monitoring of in- and outflows) as well as specifications for mechanical integrity testing.

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start within 5 years

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Standardization bodies, industrial and research organisations

4.4.2 Hydrogen infrastructure – Distribution by tube/cylinder trailers

Current situation – observed gaps:
End-users of hydrogen either produce hydrogen onsite or buy in hydrogen from hydrogen production plants. In the latter case, hydrogen needs to be transported to the end-user e.g. by pipelines but typically by cylinder tubes and trailers. The transport of hydrogen by cylinders and tubes and trailers is subjected to the UN Model Regulations on the Transport of Dangerous Goods, the UNECE European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) and the Transportable Pressure Equipment Directive (TPED). The TPED is one of a series of measures implementing the ADR. Currently, high safety factors in these regulations have restricted the increase of payload of hydrogen trailers (the safety factor is defined as the ratio between the burst pressure and the nominal fill pressure) and restricted the cylinder/tube volume (450 l for cylinders and 3,000 l for tubes). The availability of low-weight, high volume composite vessels makes it possible to increase payload which would result in lower delivery costs to end-users (industrial users, hydrogen refuelling stations). The EU supported DeliverHy project has developed a strategic

plan towards facilitating regulations, codes and standards (RCS) which basically urges industry to start the development of high pressure type IV cylinders within the current limits of the ADR. The ADR does not restrict pressure limits and would allow for a European approach to high pressure hydrogen trailers instead of the currently applied route by using national regulations and standards. Executing this strategic plan would prove operational safety and associated benefits which provide a basis for initiating discussions with the UNECE to prepare the necessary regulatory changes. An amendment to allow high pressure hydrogen trailers on the road has been introduced to the ADR and accepted by a number of countries to arrive at a permanent solution, a two-step approach is suggested.

As a first step, the most relevant standards developed in ISO/TC 58/SC3 on gas cylinders/tubes with composite materials need to be adapted. The ISO 11119-X standards (for pressure vessels designated as cylinders in the standard but having a water capacity greater than 150 l but lower than 450 l) and ISO 11515 (for tubes in composite material (Types 2, 3, and 4)) could include an informative annex which describes a new approach to calculate safety factors for a composite pressure vessel using probabilistic methods. Adopting a probabilistic approach towards risk and safety factors over the current deterministic approach requires industrial agreement and confidence and is something for the longer term. A classification towards subdividing gases to dedicated gases (like hydrogen) and other gases is being implemented in the standards. In that way, safety factors can become more specific for the gas considered. For hydrogen, the current pre-consensus seems to be between 2.25 and 2.4, which is considerably lower than the safety factor of 3 currently applied. Additionally, the working pressure needs to be increased from 20 MPa to higher pressures (e.g. 70/100 MPa) and the water capacity needs to be increased to 10,000 l in ISO 17519 (for frame mounted tubes having a water capacity from 450 l up to 10,000 l). The current European standard EN 12245 developed by CEN/TC 23 limits the volume to 3,000 l but does not limit pressure. In ISO/TC 58/SC3, an intermediate compromise is being found to restrict the combined product of volume times pressure to 300,000 (MPa-L) allowing the use of 3,000 l tubes at 100 MPa and of 10,000 l tubes at 30 MPa, or any other combination thereof.

Once these standards have successfully been adapted, the second step would be to update the ADR and have it refer to these revised versions of the standards. That update would need to come along with a request for a new volume category in the ADR (tubes from 3,000 – 10,000 l), introduce a value for the safety factor that depends on the applied probabilistic methods (so not a fixed value) and develop and qualify a method for cylinder testing and requalification. In order to do that, it is necessary to develop an argumentation based on a risk and consequence analysis (for volume category) and performance of qualification tests (for safety factor). Besides that, periodic inspection requirements for composite vessels determined from requirements specified in the ADR are needed.

PNR work in projects (DeliverHy, HyComp, FireComp, HyPactor, HyTransfer) focuses on specific topics but a bundling and review of findings, filling gaps (e.g. strengthening the probabilistic approach to determine safety factors, pressures going to 100 MPa) in an overarching PNR effort is considered necessary.

Besides at EU level, relevant PNR activities are also being executed at EU Member State level, so alignment and consideration of results of these activities are necessary.

PNR actions:

- Further develop probabilistic methodology to determine safety factors for composite vessels.
- Develop methods for cylinder testing and requalification.
- Develop equipment interfaces for high pressure trailers and end-users (e.g. refuelling stations), filling procedures and component requirements.
- Develop an overarching PNR activity that combines results from individual projects (e.g. DeliverHy, HyComp, FireComp, HyPactor, HyTransfer, EU Member State projects), fills gaps (e.g. go to 100 MPa) and provides recommendations for standards and regulations and probabilistic risk approach.

Standardization actions:

- Continue to establish industrial consensus to further improve pressure/volume limitations currently considered within ISO/TC 58/SC3 on gas cylinders/tubes with composite materials in view of the revision of ISO 17519.
- Development of an informative annex for ISO 11119-X standards and ISO 11515 which introduces the concept of probabilistic risk approach to determine safety factors.
- Consider to update EN 12245 to reflect the latest developments in ISO/TC 58/SC3 regarding cylinder/tube volume and pressure.

Regulatory actions:

- Once the relevant ISO standards for gas cylinders with composite materials are updated, consider updating the ADR to include references to these ISO standards and to accommodate new tube size categories.
- Consider using the UN model regulations as a platform to establish a global consensus on the transportation of hydrogen in high pressure, high volume trailers.

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Standardization bodies, regulatory bodies, industrial and research organisations, research funding organisations

4.4.3 Hydrogen infrastructure – Refuelling infrastructure (components)

Current situation and observed gaps:

Hydrogen refuelling infrastructure is slowly being rolled out across Europe. The recently adopted European Directive (2014/94/EU) on the deployment of alternative fuels infrastructure (AFID) ensures the interoperability between hydrogen refuelling stations and vehicles. The AFID addresses 4 interoperability requirements to which hydrogen refuelling stations accessible to the public need to comply with as of end 2017: general requirements for refuelling stations, hydrogen quality levels, refuelling algorithms and equipment and connectors. European standards need to be developed for each of these areas, for which mandate M/533 has been issued by the Commission. The mandate requests the ESOs (and in particular CEN/TC 268/WG 5) to develop harmonised European standards by end 2016 for hydrogen connectors and by end 2017 for refuelling stations, hydrogen quality levels and refuelling algorithms and equipment.

The ISO standards currently referred to in the Directive are ISO/TS 20100 for refuelling stations and refuelling algorithms and equipment, ISO 14687-2:2012 for hydrogen quality levels and ISO 17268:2012 for connectors. These standards are currently being revised within ISO/TC 197 with foreseen finalisation dates close to or possibly after the date requested in the mandate. The current timeline is that the forthcoming ISO 19880-1 (currently a technical report), that is replacing the ISO/TS 20100, is expected to be finalised in December 2016, the updated ISO 17268 (currently in preparatory stage) has a foreseen end date for the IS in fall 2015 and the updated ISO 14687 (currently in preliminary stage) has a target date for the IS in fall 2018.

Hydrogen refuelling stations, station components and interoperability issues are addressed specifically below.

4.4.3.1 Hydrogen refuelling stations (general)

A technical specification ISO TS 20100 was published in 2008 that specifies requirements for outdoor public and non-public hydrogen refuelling stations. The technical specification represents a compromise and never made it to IS because it proved impossible to reach consensus between P-members on the draft standard. This technical specification is referenced in the AFID as one of the three hydrogen standards ensuring interoperability. Technical progress and operational experiences in the deployment of hydrogen refuelling stations worldwide since 2008 have triggered the establishment of WG24 of ISO/TC 197 aimed at updating ISO TS 20100:2008 to the current state of the art. A new IS 19880-1 is expected to be published at the end of 2016. At present a technical report ISO TR 19880-1 is available. CEN/TC 268 on cryogenic vessels and hydrogen technologies has been identified as the European standardization platform to monitor the progress and ensure that the international standard will be adopted as European standard before the end of 2017.

At present, performance requirements for refuelling protocols are not within the scope of ISO/TC 197 and are only covered in SAE standard J2601. This standard is applied in the vast majority of the hydrogen refuelling stations. ISO/TC 197/WG24 has adopted an approach stating that fuelling should be conducted within the operational limits of the on-board hydrogen storage system (e.g. temperature, pressure, state of charge, flow rate). However a risk assessment exercise is ongoing to understand the consequence of over-pressurising or overheating of hydrogen on-board storage systems due to different failure modes of the hydrogen refuelling station. This work has revealed that the consequences of different exposure and frequency levels in terms of temperature and pressure for the on-board storage tank are currently unclear. PNR is performed within the EU supported HyTransfer project to refine existing and new refuelling protocols.

Within ISO 19880-1 a hydrogen station testing apparatus is to be used to verify the compliance with the applied refuelling protocol. Within the German Clean Energy Partnership (CEP), a Fuelling Test Device has been developed to test compliance of hydrogen refuelling stations to SAE J2601.
Based on the experiences from station operators, it would be beneficial to have a single solution for a complete qualification process for a hydrogen refuelling station that would include: assurance of fuel quality, appropriate particle retention, legally compliant metering, compliance with refuelling protocol, legally compliant payment process, verification methods for HRS availability, etc. Standards addressing the need for qualification and inspection of refuelling assemblies are being developed.

PNR actions:

- Secure continuation of PNR work in EU projects on hydrogen refuelling station concepts and protocols, and facilitate information exchange with relevant activities undertaken by EU Member States.
- Further develop risk assessment methodologies for failure modes of hydrogen refuelling stations to understand the consequences for on-board hydrogen storage systems.

Standardization actions:

- Development of European standards required by AFID.
- Development of performance based standards for refuelling protocols outside the SAE standardization platform.
- Develop a single solution for a complete qualification process for European hydrogen refuelling stations.

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Standardization bodies, industrial and research organisations, research funding organisations

4.4.3.2 Hydrogen refuelling station components

ISO/TC 197 is developing a series of standards for refuelling station ("19880" series) in which standards are being developed for dispensers, compressors, valves, hoses and fittings. The growing number of European manufacturers of station components enables the development of a European perspective on the requirements needed for those components. Currently observed but not yet addressed standardization gaps such as relevant safety and performance standards of hydrogen cooling devices would fit within the scope of ISO/TC 197. European stakeholders have considerable experience with the deployment and operations of hydrogen refuelling stations and are well able to provide feedback on component operations to fine-tune existing standards and identify further needs for standardization.

PNR action:
- Continuation of PNR work in EU projects on components development.

Standardization actions:
- Identify and address gaps in standards for hydrogen refuelling components.
- Development of a European standardization platform in which feedback is systematically collected on the operation of station components and on which a European perspective on component requirements can be developed (e.g. a dedicated technical committee on hydrogen).

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Standardization bodies, industrial and research organisations, research funding organisations

4.4.3.3 Stationary hydrogen storage in hydrogen refuelling stations

Hydrogen storage buffers in refuelling stations experience shallow cycles and are expected to resist many of them, but state of health results of vessels that have reached end-of-service life are limited. Lifetime assessment is performed in the EU supported project MATHRYCE, but conclusions have been drafted on the basis of results from full (deep) cycles, because testing till leak before break with shallow cycles is time-prohibitive. Currently, an accelerated lifetime testing methodology to characterise and predict performance under small amplitude cycling at high average pressure is not available. In addition, there is a lack of publically available results from accidents/incidents due to hydrogen enhanced fatigue. In the MATHRYCE project, a comparison of fatigue crack propagation using a fracture mechanics and a strain life approach resulted in very different numbers of cycles to failure. The reasons for the discrepancies are to be clarified by further by PNR to deepen the understanding of causes for fatigue under shallow cycles and to develop appropriate testing procedures and methodologies for accelerated lifetime testing.

PNR action:
- Develop PNR activities to deepen the understanding of causes for fatigue under shallow cycles.

Standardization action:

- Develop appropriate testing procedures and methodologies for accelerated lifetime testing based on profiles that reflect user patterns of storage means in hydrogen refuelling stations.

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Standardization bodies, industrial and research organisations, research funding organisations

4.4.3.4 Hydrogen metering

Direct mass flow measurement techniques are considered the technology of choice to quantify the amount of dispensed hydrogen at refuelling stations. Although generally applied at hydrogen refuelling stations, hydrogen flow meters have shown inaccuracies beyond the regulated error margin of 2% due to large variations in flow rates, pressure and temperature ranges. The EU supported project HyAC attempted to determine the accuracy of state-of-the-art hydrogen mass flow meters during refuelling. Comparing data obtained by Coriolis flow meters at the HRS with results using the Pressure-Temperature calculation method at the car at a station in Germany revealed that 38% of refuellings had tolerances above ± 9%. In Germany, a dedicated working group within the CEP on metering has made progress in developing a dialogue between stakeholders to improve the performance of metering equipment. As part of the National Innovation Programme Hydrogen and Fuel Cell Technology (NIP), a research project geared towards improving metering accuracy is carried out. Because these results do not comply with the requirements of the Measuring Instruments Directive (MID, 2009/137/EC) which prescribes an accuracy level between 1% and 3% for gas meters depending on the flow rate and the meter class, It has been suggested to review the currently mandated measurement accuracy of hydrogen meters of 2% and determine whether a temporary lift to ± 5%, at least in the short term, can be considered. Even though current metering technology is considered to offer a level of metering accuracy of circa 5%, PNR is required to further develop the technology to achieve consistent accuracy levels of between 1% and 2%.
The hydrogen flow meter is an integral part of the dispenser but accuracy verification of fill content for vehicle hydrogen tanks does not fall within the scope of ISO/TC 197/WG 19 that is developing a hydrogen dispenser standard (ISO 19880-2).

PNR action:

- Development of hydrogen metering techniques to achieve consistent accuracy levels between 1% and 2%.

Standardization action:

- Development of standardised test and measurements methods to determine accuracy levels of meters (currently not in scope of ISO 19880-2).

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Standardization bodies, regulatory bodies, industrial and research organisations, research funding organisations

4.4.3.5 Hydrogen connectors

The first international standard on refuelling connection devices was published in 2006 as ISO 17268. The standard includes design, safety and operational features of the nozzle (station) and the receptacle (vehicle) at working pressures of 11, 25, 35 and 70 MPa. This standard has been based on early standardization work performed for the publication of SAE J2600 in 2002. Continuous development and harmonisation between ISO/TC 197 and SAE has led to two standards: SAE J2600:2012 and ISO 17268:2012. ISO 17268:2012 is referenced in the AFID as one of the three hydrogen standards ensuring interoperability. CEN/TC 268 has included the standard in its work programme to adopt it as a European standard. The M/533 mandate requires the European standard for hydrogen connectors to be published at the end of 2016. ISO and SAE are currently revising the standards produced in 2012 to, among others, include freeze/icing and abuse test methods and harmonise the high flow connector system. Besides PNR to assist specifying nozzle requirements for operation at low temperatures as to prevent freezing of nozzles to cars, PNR is also needed to further understand excessive wear and leakage issues.
European stakeholders are well positioned in the development and deployment of nozzle and receptacle equipment as well as dispenser components (e.g. break-away couplings, check-valves, filters). The majority of these products use SAE J2600 as relevant standard and bear CE certification according to the Pressure Equipment Directive (PED). It should be seen whether a European standardization platform could facilitate connection devices to confirm to the requirements in ISO 17268 instead of the commonly applied SAE J2600.

PNR action:

- Develop PNR activities to reduce excessive wear and leakage issues of high pressure nozzles.

Standardization actions:

- o Development of standardised test methods and preventive measures to overcome nozzle freezing.
- o Consider to (further) develop a European standardization platform that could facilitate connection devices to confirm to the requirements in EN ISO 17268.

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Standardization bodies, industrial and research organisations, research funding organisations

4.4.3.6 Hydrogen quality

Purity requirements for hydrogen as a fuel for fuel cells used in vehicles are specified in ISO 14687-2:2012. New standardization work has started to update impurity levels currently included in the standard, based on recent PNR work and on feedback from hydrogen refuelling stations, and to consider impurities currently not yet covered by the standard. The development time for the new standard is considered to be 3 years. The new standard can take advantage of the work performed within the European Industrial Gases Association, in which a risk assessment approach is being developed for a number of hydrogen supply pathways to understand the risks and consequences associated to exceeding impurity levels specified in ISO 14687-2.

Currently the hydrogen quality standard has 13 gaseous impurities levels specified. The acceptable concentration limits have been obtained by extrapolation of results from fuel cell degradation tests using higher fractions of impurities. It is unclear how the resulting allowed impurity levels (in the ppm and ppb ranges) influence the durability of the fuel cell/fuel cell system. Moreover, for some impurities the resolution of commercially available analysis techniques is insufficient (therefore requiring more expensive analysers to be used) whereas for the level required for total halogenated compounds no measurement method exists. To decrease costs and to open up the market for analysis and thus quality assurance, methods to concentrate impurities (e.g. by means of enrichment/concentration by taking out only hydrogen of the fuel sample or increase impurities levels of the fuel sample with known quantities of impurities) are being considered.

A project proposal for the EMPIR metrology programme is being prepared in which, once approved, co-normative research will be performed to strengthen arguments to revise some impurity levels and to further develop offline methods for hydrogen purity analysis.

From a European hydrogen supply perspective, there is an interest to be at the forefront of the international discussion and European initiatives, whether being PNR or in industrial consortia, are established. The international standardization community has stressed the need for internationally agreed specifications in order to not create segregated markets for fuel cell vehicles. PNR remains necessary to assess the impact of hydrogen impurities on fuel cell system performance under automotive conditions and to develop risk assessment methodologies to understand the risk and consequences of exceeding impurity level limits.

PNR actions:
- Development of improved metrological methods and measurement techniques for hydrogen purity analysis (e.g. by using means for concentrating and/or enriching hydrogen gas).
- Continue PNR activities to further understand the impact of impurities on fuel cell system performance under automotive conditions.
- Develop risk assessment methodologies to understand the risk and consequences of trespassing impurity level limits.

Standardization actions:
- Harmonise (pre-)standardization work performed at EIGA, ISO/TC 197 and SAE.
- Reassess PNR results to feed into revision work of hydrogen quality standards.

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Standardization bodies, industrial and research organisations, research funding organisations

4.4.3.7 Hydrogen quality assurance

Besides specifying hydrogen purity requirements, the assurance of having hydrogen delivered at distribution centres and at refuelling stations meeting these requirements is equally important. The CEP, though its working group on hydrogen quality, has looked at hydrogen quality issues at operating hydrogen refuelling stations. Typically, online quality assurance of hydrogen is performed through process control parameters (usually through measurement of canary species, such as carbon monoxide). Analysis equipment to perform online analysis is available but expensive and it is essential that the limit of detection of these instruments can be robustly assessed using fully traceable standards. Therefore, within ISO/TC 197, new standardization work (ISO 19880-8) is being initiated to develop a practical implementing method for hydrogen quality control in which minimum analysis requirements of impurities are specified per hydrogen supply chain, as well as the frequency at which the analyses should be performed. This would include both online and offline analyses as well as a specific spectrum of impurities per hydrogen supply and delivery chain, as some impurities are only associated with a particular component in the chain. The EU supported HyCORA project performs PNR by developing a risk assessment approach which assesses the harmful effects that impurities in hydrogen fuel, introduced along the hydrogen supply chain, may induce on automotive fuel cell systems as well as methods and measures used for fuel production and purification and quality assurance used for controlling fuel impurity levels at the refuelling stations.

The new ISO/TC 197 standardization work on hydrogen quality assurance is, once approved, foreseen to last 2 years. It has been agreed between the new WG on hydrogen quality assurance and WG24 in charge of ISO 19880-1 on general requirements for hydrogen refuelling stations that ISO 199880-1 at the moment of finalisation will reference to ISO 19880-8, if finalised. If the work in the new working group on quality assurance is not finalised at the moment of finalisation of ISO 19880-1, the current specifications within ISO TR 19880-1 concerning hydrogen quality assurance will remain.
The standardization topic of hydrogen quality assurance is rather new and needs support to develop and mature. The internationally created working group within ISO/TC 197 seems an appropriate platform to further develop a standard on hydrogen quality assurance as European stakeholders would benefit from an international approach. It has been envisaged that in collaboration with ISO/TC 158 "analytical methods", a standard regarding hydrogen analytical methods could be developed. PNR activities in Europe in terms of development of a risk assessment approach (HyCORA) and development of gas metrology techniques for hydrogen purity analysis are at the benefit of standardization activities. Furthermore regarding the importance of gas metrology it is important that the laboratories performing the gas analysis or the measurements provided by the online gas analyser can provide measurements that are directly traceable to national standards. This requires accreditation by a relevant accreditation body.

PNR action:

- Develop online measurement techniques and detection apparatus for hydrogen quality assurance at refuelling stations.

Standardization actions:

- Develop an analytical standard dedicated to hydrogen impurities.
- Support ongoing standardization activities (e.g. on how to adopt European PNR work (FCH JU HyCORA project)) to develop a practical implementing method for hydrogen quality control.
- Development of a scheme to encourage existing gas laboratories to obtain accreditation for performing hydrogen purity analysis (e.g. by proficiency testing schemes)

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Standardization bodies, industrial and research organisations, research funding organisations

4.4.4 Hydrogen applications – On-board storage / vehicle regulations

Current situation – observed gaps:
The UNECE R134 (E/ECE/324/Rev.2/Add.133 –E/ECE/TRANS/505/Rev.2/Add.133) established in June 2015 (under UN 1958 agreement, as transposition of GTR No 13), the Global Technical Regulation No13 on hydrogen and fuel cell vehicles established in 2013 (under UN 1998 agreement) and the EC Regulation 79/2009 on type-approval of hydrogen-powered motor vehicles established in 2009 provide means for testing on-board hydrogen storage systems and associated components for application in hydrogen vehicles. The GTR has taken into account existing regulations (in EU, Japan, China, Korea, US) and harmonised them to obtain a global regulation. The existence of multiple regulatory frameworks in the EU allows automotive OEMs and system component suppliers to choose between the regulations to be used for vehicle type-approval. The testing requirements are an integral part of the regulation and an approach, like the New Approach applied to EU Directives, in which standards referred to from within the legal documents are used to accommodate for technical progress is not applied. A comparative analysis report prepared for the European Commission in 2011 has highlighted that there are significant differences between the GTR and EC regulations in the testing of on-board hydrogen storage systems. Also the scope between regulations differs as the GTR covers vehicles with gross mass of up to 4,536 kg whereas the EU regulation covers passenger vehicles and busses (Category M and N vehicles). Small vehicles (Category L) are not yet covered.
The standardization work in ISO/TC 197/WG 18 on gaseous hydrogen land vehicle fuel tanks and thermally-activated pressure relief devices (TPRD) (ISO 19881 and 19882) provide a means for harmonisation of testing schemes for on-board hydrogen storage systems.
PNR is performed to adapt test methodologies to the different types of on-board hydrogen storage tanks. Relevant failure modes need to be taken into account for performance testing. Type IV tanks (composite tanks with a polymer liner) show different ageing behaviour than type III tanks (composite tanks with a metal liner). Type IV tanks are not very sensitive to fatigue, but probably more to sustained stress. Failure modes should be clarified before reducing burst pressure requirements. Testing a limited number of tanks (1 to 3) in a deterministic way may not be representative of batch behaviour. The dispersion of burst pressure values increases after cycling, so the so-called 'lucky punch' could hide real average behaviour. A probabilistic approach is therefore considered to be more appropriate.
The bonfire test for hydrogen tanks is not really a fire resistance test but more a test for the TPRD performance. PNR to increase understanding of the behaviour of a pressurised tank under fire is ongoing e.g. in the EU supported FireComp project. In Japan, tests are conducted using various forms of thermal loads (not only fires, but other forms of thermal radiation).

The drop test for hydrogen tanks has been taken from natural gas tank standards, but lacks scientific basis. The EU supported HyPactor project is focussing on damage evolution under local mechanical impact, and on characterisation/evaluation techniques for damage quantification.
Fatigue testing for hydrogen tanks is now being performed on the basis of national or regional standards, as international standards do not exist.
Another item that needs further PNR work is the development of non-destructive techniques (NDT) to carry out periodic inspection of composite material pressure vessels (also valid for stationary applications). Acoustic emission (AE) looks promising for in-service inspection of composite pressure vessels, but is not proven to be fully reliable. Further PNR is needed to have a technique fully operational, with universal pass/fail criteria. NDT techniques need to be developed considering the findings from mechanical impact studies as removal from service mainly depends on the severity of impacts that a cylinder may have experienced in its operational lifetime.
Additionally, there could be a potential to further reduce the minimum safety factor (=burst pressure/nominal fill pressure) for tanks from 2.25, if justified by further test results such as type approval tests. Hydrogen shows a very low expansion compared to other gases, so the pressure developed (1.25*NWP at 85°C) is much lower than the actual design pressure (1.5*NWP). Therefore to avoid unnecessary margins, it should be possible to lower the design pressure to the maximum developed pressure at the maximum temperature.

PNR actions:

- Improvement of testing methodologies and procedures for mechanical impact testing of hydrogen tanks.
- Improvement of testing methodologies and procedures for thermal load testing of hydrogen tanks.
- Development of characterisation/evaluation techniques for damage quantification, especially acoustic emission techniques for in-service inspection of hydrogen tanks.
- Development of a probabilistic approach to determine hydrogen tank batch behaviour.

Standardization actions:

- Harmonisation and uniformity of test schemes for hydrogen tank standards developed within ISO/TC 197/WG 18 (e.g. fatigue testing, failure modes considerations, bonfire testing, drop testing, safety factor determination, periodic inspection testing).
- Facilitate future adoption of European standards for hydrogen tank testing.

Regulatory actions:

- Determine the need to update EC Regulation 79/2009 on type-approval of hydrogen-powered motor vehicles considering progressive improvements in regulations (e.g. GTR13, UNECE R134), standards (e.g. progress in ISO/TC 197/WG18) and advancements in research (e.g. EU supported projects: FireComp, HyComp, HyPactor, MATHRYCE) and feedback from deployment.
- Re-evaluation of regulations and standards on issues related to the interfaces between hydrogen infrastructure and vehicles.

Impact of proposed actions on technology deployment:

High

Urgency to start the proposed actions:
Start now

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Standardization bodies, regulatory bodies, industrial and research organisations, research funding organisations

4.4.5 Hydrogen applications – Distributed generation and fuel cells

Current situation – observed gaps:
Stationary fuel cells in distributed generation concern the conversion of locally produced or delivered hydrogen to electricity. Standardization of stationary fuel cell systems are covered within IEC/TC 105 and has addressed safety, performance and installation aspects of the fuel cell system itself in the IEC 62282-3 standard series. Improving testing methodologies for performance characterisation of single cells and modules is ongoing (e.g. for cross-leak testing and performance testing at sub-zero temperatures). The installation standard covers the installation requirements on site but does not include the power connection to the grid. National and regional codes are available that cover that topic. A recent study financed by the FCH JU on stationary fuel cell systems highlighted that R&D should be prioritised towards reducing the CAPEX: e.g. increasing the electrical efficiency of the system, reducing fuel cell degradation, increasing the lifetime of the fuel cell stack, improving power electronics and controls design, standardising BOP components, increasing cell power density and achieving thinner layers at cell level and substituting expensive materials (such as stainless steel) with alternative materials. EU supported projects have been performed to demonstrate systems at larger scale (e.g. ene.field for mCHP) and perform R&D on fuel cells and BOP components (e.g. FlumaBack). In Germany, the CALLUX project supported by national innovation plan (NIP) yields operating experience from a large volume of fuel cell CHPs. A number of further NIP projects facilitate R&D and demonstration of larger fuel cells for applications including industry and ships. A project accompanying regulative developments within IEC/TC 105, and especially EN 50465, aims at understanding and improving the fit between international standards and the technologies offered by German and other European manufacturers. Remote as well as uninterrupted power supply are further items addressed by NIP projects, furnishing operating experience valuable to standardization. Fuel cell systems for back-up power generation may require specific performance test methods to fulfil to the performance requirements for back-up power or uninterrupted power supply.

PNR action:

- Improving testing methodologies for performance characterisation of single cells, modules and systems is ongoing (e.g. for cross-leak testing and performance testing at sub-zero temperatures).

Standardization action:

- Development of harmonised RCS covering the installation of stationary fuel cell systems to the electricity grid.
- Development of testing methodologies for stationary fuel cell systems to provide back-up power, uninterrupted power supply or ancillary services to the grid.

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start within 5 years

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Standardization bodies, industrial and research organisations

4.4.6 Roadmap and conclusions

PNR and standardization actions have been identified for underground hydrogen storage in salt caverns, hydrogen distribution by trailers, hydrogen refuelling stations, on-board hydrogen storage in vehicles and distributed generation and fuel cells. The actions proposed for all these topics have been visualised in the Task Force 4 roadmap and includes timelines, prioritisation and urgency.

Experience with hydrogen underground storage in salt caverns is available and the amount of PNR/standardization to be performed can be finalised relatively fast. Also it is not expected that large-scale pure hydrogen storage will be required in the very near future.

Distributed generation and fuel cells seem to need further basic R&D to reduce cost and improve performance and durability characteristics of systems. Challenges for these topics are considered less of a priority for the near future than hydrogen distribution via trailers, on-board storage in vehicles and refuelling stations.

PNR and standardization activities for distribution of hydrogen via trailers to increase payload and reduce cost of delivery are important and is being addressed in phases within relevant standardization and regulatory frameworks, and an intermediate solution to raise pressure and volume levels seems to be found in standards.

Ongoing and developing PNR programmes to improve impact testing and damage characterisation of on-board storage systems and translate these results to standards and regulations is important to mature the commercial availability of hydrogen vehicles. Safety of on-board hydrogen storage systems has been addressed in standards and regulatory frameworks for many years both in international and European platforms.

Compared to all other topics, hydrogen refuelling stations receive top priority for PNR and standardization due to the amount of PNR that needs to be performed and the availability and development of relatively new international standards. EU standards are currently missing. Refuelling stations are deployed at a slow pace, and it is hoped that the AFID has a positive impact on deployment, so feedback of ongoing and newly-raised PNR activities and operations of all components, interfaces and interoperability issues is required to mature standards.

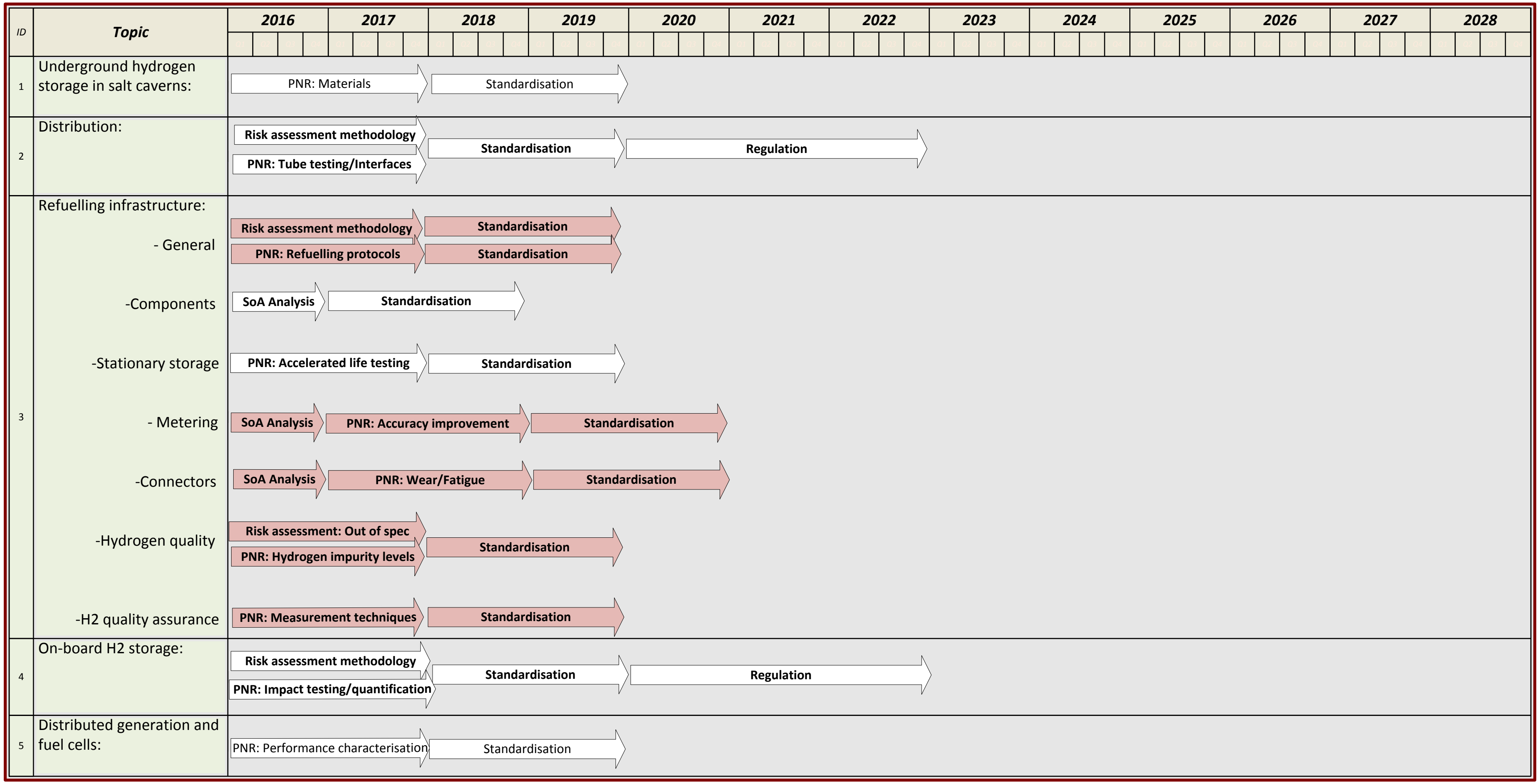


Figure 5 Roadmap Task Force 4

4.5 Task Force 5: Cross cutting

4.5.1 H2NG Safety – General considerations

The public acceptance of power-to-gas systems will depend on ensuring safety, i.e. the protection of life, property and environment. Different factors affecting safety need to be considered, such as the impact of hydrogen on the natural gas grid infrastructure and the fact that mixtures of hydrogen and methane have different properties compared to pure methane or pure hydrogen. The safety relevant properties of hydrogen and methane have been investigated intensively (e.g. projects HySafe, HyIndoor, e.g.), but knowledge gaps have been identified, in particular regarding the properties of mixtures in a wide range. To assess the behaviour of hydrogen/methane mixtures, research is needed to fill knowledge gaps concerning basic gas properties over wide compositional, temperature and pressure ranges. Some data exist, but usually only a few points for the whole range 0 to 100 %, for ambient temperature and only for 1, 10, and 100 bar. Combustion of hydrogen/air mixtures was studied largely at standard environmental conditions. Also application-related properties of hydrogen mixtures with methane need to be considered, including the calculation of properties such as methane number, Wobbe index, calorific content etc. based on the composition of the mixed gas.

All work with flammable gases must be performed in a safe manner. Safety measures depend on a thorough knowledge of the basic properties of the gas or gas mixture, in order to be able to determine the potential risks. In general safety measures cover prevention, detection, protection and intervention. Primary explosion protection means to prevent the formation of an explosive mixture. Secondary explosion protection should prevent the ignition of an explosive mixture. Tertiary or "constructive" explosion protection comprises measures to minimize the effects of an explosion. Explosion protection is ensured through compliance with national and international regulations and standards, such as the ATEX directives. The ATEX - Directive 2014/34/EU states that it is mandatory under European law for all equipment for use in a potentially explosive atmosphere must conform to specific safety standards. The atmosphere is defined as a mixture of flammable substances in the form of flammable gases, vapours, mists or dusts with air under atmospheric conditions. Zones are defined depending on the level of hazard probability (covered in standard IEC 60 079-10-1 Classification of areas – Explosive gas atmospheres). Gases can explode when present in specific percentage mixtures with air (LEL, UEL5[5]). The mixtures will also have different auto-ignition temperatures, minimum ignition energy, and maximum experimental safe gaps. These properties determine the gas group[6] · Although coal/town gas is already classified (group[6] IIB), further investigation into the gas properties of H2NG is needed in order to determine appropriate safety measures.

Primary explosion protection:

In many industrial applications combustible gas detectors are an integral part of the safety measures. Combustible gas sensor systems allow for a rapid detection of leaks and can trigger additional safety measures such as ventilation and system shut-down. Harmonisation of national vs. international standards and further research is required to improve their performance. In particular

[5] Upper and lower explosion limit

[6] Gas groups of the Ex certified equipment for use in potentially explosive atmospheres

for H2NG the effect of hydrogen on combustible gas sensors should be assessed. For H2NG an odorant could also be added so that leaks could be detected by smell (see 4.3.3.3 Effect of H2NG on odorization).

Secondary explosion protection:
Safety considerations for secondary explosion protection need to take the propensity of the gas mixture for auto-ignition into account. The ignition propensity of hydrogen-methane mixtures should be investigated further.

Tertiary explosion protection:
In case it is not possible to avoid having ignition sources in enclosures, at least the effects of a potential explosion should be limited. The effectiveness of mitigation measures on reducing risk should be an important focus of future research. Other safety aspects warranting further study are the structural response of enclosures (containers for example) to internal explosions for the indoor use of hydrogen and H2NG. Jet fires and explosions in containment or enclosure need to be studied in more detail, to enable the improvement of early detection and to fully understand the potential effect of explosions in containments. Studies of indoor fire behaviour, including self-extinction should be carried out [22].

To assess the safety of hydrogen/H2NG applications and infrastructure, the approach using Quantitative Risk Assessment (QRA) and physics-based models of gas behaviour needs further investigation. Due to lack of hydrogen and hydrogen-methane mixtures specific data, currently the deterministic hydrogen safety engineering methods prevail over the probabilistic methods for a design of particular system or facility. In addition, the general approach on how PtG plants are treated in terms of components should be analysed. An additional issue has been identified - the engineering correlations that are available in standards are not valid for all possible conditions. Because they are based on simplified models and correlation of limited experimental data, engineering tools can have a limited range of applicability and caution must be exercised so as to not extrapolate the results of the model beyond the applicability range.

4.5.1.1 Explosion related safety risks

Research actions:

- More detailed data is needed in particular on the safety relevant properties. These properties include the upper and lower explosion limit (LEL, UEL), the ignition energy and auto-ignition temperature for hydrogen/methane mixtures in the range 0 to 20 vol% H2 as function of temperature and pressure
- Research into ignition of hydrogen and H2NG by mechanically generated sources, electrostatic and corona discharge at different concentrations should be carried out

PNR/standardization action:

- Determination of hazardous zones defined in the ATEX directive

Impact of proposed actions on technology deployment:

Medium

Urgency to start the proposed actions:
Medium

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Research institutes and industry

4.5.1.2 Leakage related safety risks

Also relevant for H2 and H2NG safety is the assumed leak size, which is mostly related to the used equipment. The assumptions about leak size, pressures and duration of the release are important for the determination of the type and extent of hazardous zones. Currently used leak sizes may be unrealistic and lead to large hazardous zones. The assumed leak rate is also used to size the ventilation system. Relevant statistics on leak size and frequency are not available for many components of a H2NG or H2 installation. Pre-normative research should be performed, not only dependent on the equipment used, but also considering fluid conditions (pressure, temperature), and intrinsic parameters of the gas considered (LEL, heat capacities…). In particular the release of H2NG and hydrogen through non-circular openings, spontaneous ignition in complex geometries, validation of numerical models with flow visualization data and numerical calculation with validated predictive tools for defined release scenarios have been mentioned as areas for future research [22]. Synergies could be exploited through linking with activities under 4.3.3.1 Flow behaviour.

A well-founded probability model for hydrogen ignition originating from recent deterministic studies is required. Hydrogen-specific data is a pre-requisite for QRA evaluations, therefore a mechanism is needed to collect available data from H2NG and H2 installations. The results of this work could then be used to provide guidance and criteria for the screening and evaluation of external factors for risk assessments.

Pre-normative research actions:

- Release of H2NG and hydrogen through non-circular openings
- Spontaneous ignition in complex geometries
- Validation of numerical models with flow visualization data
- Numerical calculation with validated predictive tools for defined release scenarios
- Probability model for hydrogen ignition
- Collect available data from H2NG and H2 installations
- Evaluation of external factors for risk assessments

Standardization actions

- Harmonisation in the approach to determine hazardous zones defined in the ATEX directive considering the assumed leak sizes for H2NG
- Guidance and criteria may be documented in a TR standardization deliverable.

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Medium

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Research institutes, standardization bodies and component/equipment manufacturers

4.5.2 Gas detection systems

As hydrogen is a colourless, odourless, and tasteless gas, safety measures often include detection devices. General standards for flammable gas sensors exist, they should fulfil the requirements of EN IEC 60079-29-1 (Gas detectors – Performance requirements of detectors for flammable gases). The performance requirements, however, depend on the application. A specific standard (ISO 26142:2010) for hydrogen detection apparatus in stationary applications has been published. Novel applications may call for specific standards, and the existing standards do not define all relevant parameters. General standards on sensors for flammable gases cannot comprise all aspects of specific hydrogen sensor deployment, in particular the relevant environmental parameters. Therefore the development of standards for specific applications of hydrogen sensors, e.g. in leak detection should be pursued. For hydrogen/methane mixtures, appropriate sensors should be identified and validated (see 4.3.1.1.1 Gas analysis methods and instruments), and the effect of hydrogen on the performance of existing detection systems assessed. Sensors not working properly in spite of regular maintenance can cause problems by either triggering false alarms or not alerting to the presence of combustible gas mixtures. Currently the determination of the estimation of lifetime (EOL) of a sensor is not covered by existing standards. In terms of R&I efforts, self-calibration functions or warnings on approaching end of life should be investigated further. In addition, a harmonisation of standards related to gas detection is needed. Mutual recognition and harmonization of sensor as well as other safety related standards in Europe, North America and worldwide (ISO/IEC) should be extended and driven forward in order to facilitate market entry.

Research actions:

- Validation of the suitability of the various sensor types for measuring H2NG
- Assessment of their performance and reliability
- Investigation into EOL of sensors

Standardization actions:

- Development of application specific standards for both pure hydrogen and hydrogen/methane applications (e.g. leak detection).
- Harmonisation of sensor requirements and sensor testing protocols.
- Standards for estimation of lifetime (EOL) of sensors are needed.
- Portable and stationary combustible gas sensors are typically calibrated to detect methane. The effect of hydrogen on these sensors should be investigated.
- Other issues include improving the electrical and functional safety of gas detection systems.

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Medium

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Sensor manufacturers, standardization bodies and research institutes

4.5.3 Hydrogen compatibility of materials

To ensure safety and reliability of H2NG installations, the interaction of hydrogen with many types of materials should be known across a wide range of hydrogen concentrations, temperatures and pressures. A wealth of knowledge and experience on the safe use of hydrogen exists, but as hydrogen and H2NG will be used in new applications, knowledge gaps still remain. The compatibility of materials with hydrogen is a key issue, in particular as the injection of hydrogen into the gas grid affects the whole downstream infrastructure and all end-users.

As hydrogen is the smallest atom it can enter the structure of steel and other materials. The susceptibility of the material to hydrogen uptake is strongly depends on the material microstructure and the presence of defects. Under load hydrogen migrates towards stress concentration points (e.g. cracks and grain boundaries) where hydrogen pressure builds up. This pressure may exceed the local strength of the material, resulting in microscopic fractures. The absorption of atomic hydrogen into steels and certain other alloys generally reduces the material's strength and manifests itself in reduced ductility or load carrying capability or even cracking. According to ISO/TR 15916:2004 [7] (basic considerations for the safety of hydrogen systems), most metallic materials have a certain degree of sensitivity to hydrogen embrittlement. Materials coming into contact with hydrogen should be carefully selected and appropriate testing and analysis be performed. ISO/TR 15916:2004 [7] also provides information on the suitability of use of selected materials in hydrogen environment,

[7] Publication of ISO/PDTR 15916:2014 is imminent

but this list is by no means exhaustive. Tests techniques to investigate material compatibility should be conducted under conditions that simulate service or worst-case conditions. There are ASTM and ISO standards dealing with hydrogen uptake measurements and determination of susceptibility to hydrogen embrittlement, e.g. ISO 11114-4. At international level there is also the standard ISO 15330: 1999 preloading test for the detection of hydrogen embrittlement. These tests should be assessed as to their suitability and if needed updated to reflect typical H2NG use conditions.

PNR actions:

- List of materials compatible with H2NG systems, taking into account already collected data and available standardization deliverables such as the technical report ISO/TR 15916:2004 [7].
- Testing procedures such as the fatigue life test should be reviewed together with industry
- Correlation between specimen and component tests for the characterisation of susceptibility to hydrogen embrittlement and enhanced fatigue
- Accelerated fatigue testing
- Investigation of welds

Standardization actions

- An update of ISO/TR 15916:2004 based on the PNR
- Thorough review of the existing testing methods and possible adaptation of US or international standards to reflect European needs

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Medium

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Research institutes, standardization bodies, industry and testing laboratories.

4.5.4 Training and Education

The provision of adequate education and training for H2NG and hydrogen will prove critical for the current and future workforce. It is a prerequisite for the commercialisation of the technology. A capable workforce needs to understand the fundamental properties of combustible gases and the functioning of technology. With an increasing number of applications and the emergence of new businesses, the recruitment of qualified staff calls for dedicated training. The experience gained in hydrogen demonstration projects has revealed a lack of qualification in particular for vocational training.

In the past summer schools and other training measures have provided education on hydrogen safety and on particular aspects of technologies. These are isolated measures and often lack long term financial support. Standardization can support the necessary qualification of personnel through e.g. Technical Specifications (TS). CEN/BT has recognized the need to ensure market relevance of and compatibility between standards on Qualification of professions / personnel and has agreed that this could be facilitated by a common guidance for analysing the conditions for starting standardization on the issue and providing tools for drafting such standards. The CEN Guide 14 issues common policy guidance for addressing standardization on qualification of professions and personnel. As the main legislative reference at European level in relation to qualification of professions / personnel, CEN/BT/WG 192 has identified the "Directive 2005/36/EC on the recognition of professional qualifications".

PNR and standardization actions:

- Competency management system (CMS)

  A Technical Specification with guidance for a competency management system[8] could be of help to perform competency assessment within the organization
- Training about the safety aspects of hydrogen/H2NG

  Building on the outcomes of past and on-going projects such as HySafe, TrainHy-Prof, HyProfessionals and HyFacts, further training measures should be developed providing technically accurate and objective information to key target audiences involved in the use of hydrogen and fuel cells today.

Certification action:

- Create a certification of installers for H2 or H2NG systems with several levels for installation, start-up and maintenance

  Skill shortages have been identified, such as understanding of CHP concepts and optimization, difficulties in using troubleshoot guides, low ICT knowledge, interfacing with the electric grid operator and low multi-disciplinarity (plumbers vs electricians).
  In terms of pure hydrogen applications, automotive vocational training should be updated. Training is needed for stationary fuel cells installers and after sales operators. The appropriate education measures should be ensured by close coordination between industry and educational sectors. It should be ensured that the curriculum and organisational structure is maintained long term. A syllabus and curriculum should be defined, updated according to market development.

Standardization action:

[8] The purpose of a competency management system (CMS) is to control, in a logical and integrated manner, a cycle of activities within the organization that ensures competency of operations personnel, particularly in safety critical activities. The CMS enables personnel to be assessed and further developed, contributing to the goal of competent performance at work. A CMS should be user-friendly, workable and practical.

A Technical Specification could be developed including schemes with the needed training and their criteria in relation to the specific discipline. The scheme might be used with regard to the certification.

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start immediately

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Research, industry, training institutions, policy makers, consumer representations and standardization bodies

4.5.5 Energy policy/Regulation

4.5.5.1 Legal status of power-to-gas plants and of energy storage facilities

Urgent action is needed to clarify the legal status of power-to-gas plants. If PtG plants are treated as energy consumers they are subject to taxes and fees, which increases the cost of the hydrogen produced. As PtG plants render a service to the energy system the recommendation is that they should be classified and rewarded accordingly. For example in Germany, with the aim of promoting both the feeding in of both hydrogen and synthetic methane to the grid, both of these gases were included in the definition of biogas in section 3 para.10c of the Energy Act (EnWG). This classification is subject to the condition that they primarily originate from renewable energy sources. In practice this means that the injection of renewable hydrogen and synthetic methane is granted privileged connection, privileged injection, elimination of feed-in fees and fixed payment for avoided grid costs. National legislation has in this case enabled and supported the development of PtG technology. A European harmonised legal status for injection of H2 to the NG grid should be the next step, although the legal status of energy storage systems highly depends on national laws. Raising awareness of the importance of this topic could promote specific legislation, or at least include PtG as energy storage system, which is currently not covered at national level in the majority of countries.

Legal action:

- Clarification on legal status of PtG plants and energy storage facilities as they are not the end consumer but provide services to the integration of RES in the energy market.

  Possible actions include integration of specific provisions into the EU Renewable Energy Directive (2009/28/EC) and the EU Fuel Quality Directive (2009/30/EC + 2015/652/EU) at

European level and nationally, e.g. for Germany the BImSchG, BImSchV[9] and BioKraftQuotenG[10].

- Generally an exemption from final consumer levy and price mirroring of potential flexibility services to balancing the energy market should be evaluated in terms of decarbonisation/societal benefit. This is in line with the European Energy Union five guiding dimensions

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start immediately

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Public authorities, policy makers, industry

4.5.5.2 Clarification of Industrial Emissions Directive

In 2010, the Industrial Emissions Directive (IED) was issued. IED defines the obligations of large industrial facilities to avoid or minimise polluting emissions in the atmosphere, water and soil, as well as waste from industrial and agricultural installations. To this purpose, the operators of around 52 000 industrial installations are required to obtain an integrated permit from authorities in EU Member States [23].

A clarification of the IED on production of hydrogen should be sought. In the context of the development of H2 as fuel for vehicles or for integration of renewable energies, it is foreseen that electrolysers of various sizes (sometimes small) will be used for local hydrogen production. Presently hydrogen production falls under the IED and is submitted to a permitting process as production of inorganic chemical. (“ANNEX I Categories of activities referred to in Article 10”, 4. Chemical industry, 4.2. Production of inorganic chemicals). Yet the IED stipulates that production should be understood as “the production on an industrial scale by chemical processing of substances or groups of substances listed in sections 4.1 to 4.6”, leaving space for interpretation at national level. The permitting process of PtG plants is delayed as even small installations are treated as producers of

[9] Bundesimmisionsschutzgesetz and Bundesimmisionschutzverordnung (German air pollution control laws)
[10] Biokraftstoffquotengesetz (German law on biofuel quotas)

chemicals on an industrial scale. The existing directive, IED, refers to "large industrial production" without specifying the size, or capacity of such production[11].

In this context, it is questionable whether small electrolysers used for local production of hydrogen, e.g. in refuelling stations should be considered as production on an industrial scale and submitted to the same regulatory requirements as large reforming plants. According to a preliminary survey by INERIS it appears that the directive is always applied, also to electrolysers.

Recommended actions:

- Full survey of member states on how the directive is applied.
- Clarification of whether small scale electrolysers fall under the IED, in order to simplify the permitting process

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start immediately

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Public authorities, policy makers, industry

4.5.5.3 Certification of Green Hydrogen

Similar to the case of electricity or biogas it is physically not possible to verify the origin of hydrogen and a system of guarantee of origin is needed. Certification of green hydrogen is an important element of the future business case both for pure hydrogen and for H2NG. Certificates are used to ascertain the environmental value of energy produced by renewable sources, regardless of the delivery path.

The integration of renewable power into the energy system requires interaction between various actors. The value of green hydrogen is difficult to quantify, trade or invest in if there is lack of transparency and common understanding of the product and of the benefits that its use entails. The Renewable Energy Directive (RED) defines renewable energy sources, which green hydrogen would have to comply with for it to be eligible for renewable energy support. In particular the greenhouse gas savings targets have to be met. The EU supported CertifHy project sets out to define a widely acceptable definition of green hydrogen, design a robust Guarantee of Origin (GoO) scheme for green hydrogen and propose a roadmap to implement the initiative throughout the EU. The

[11] For example in Germany, this would mean national modification of the BImSchG and BImSchV which regards all (hydrogen) onsite production units as industrial plants which thus are subject to the full approval process (no matter if this are small decentralized electrolysers or large-scale SMR plants).

outcome of this process will feed into a proposal for a new European framework of GoO for green hydrogen that will include the development of harmonised rules and obligations for guarantees of origins in Europe. The results of the project, which ends in 10/2016 should be taken up and implemented accordingly.

Recommended actions:
The CertifHy project will look into questions such as what the purpose of the certificate should be, whether it should prove that hydrogen was produced in a sustainable manner from a renewable energy source, what the GHG footprint is, or whether it was produced efficiently. This work should be reviewed in terms of applicability to H2NG and continued.

- It should be clarified whether standards should be applied at EU level or if national rules can apply.
- Hydrogen products could be differentiated (blue, green hydrogen) depending on the production path.
- The greenhouse gas savings calculation method should be clarified.

Standardization action:

- Preferably at EU level a certification scheme in analogy with the existing standards for electricity EN 16325 should be developed via a standardization deliverable. The requirements for setting up a certification system could be the content of the standardization deliverable. Whether this could be done on a European or National level should be looked into. On a European level at least guidance could be given

Impact of proposed actions on technology deployment:
High

Urgency to start the proposed actions:
Start immediately

Estimated time required to finalise the proposed actions:
Between 5 and 10 years

Actors needed to fulfil the proposed actions:
Industry, consumer representatives, standardization bodies and accreditation bodies

4.5.6 Techno-economic assessment

An approach, guidance document or template for an exhaustive techno-economic evaluation of the cost of hydrogen injection into the natural gas grid adapted to the local, regional or national situation should be established. Such an evaluation should identify all relevant cost drivers, benefits and risks, considering both technical and financial aspects. Based on the outcome of the assessment, cost efficient strategies for adapting the infrastructure can then be developed and a roadmap for the injection of hydrogen prepared to support a macro-economically feasible transformation path towards higher limits for allowable hydrogen concentrations in the gas system.

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
Start immediately

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
TSOs, DSOs and consultancies

4.5.7 Terms and definitions

For the application of Hydrogen and hydrogen-NG mixtures in the energy chain and in different end-use applications, an unambiguous interpretation and consistent use of a common set of terms, definitions and symbols is critically important. A high priority is therefore the development of a Technical Report or Standard with the terms, definitions and symbols used for H2, H2NG and PtG.

For example the imprecise use of term "RCS" necessitates appropriate clarification to improve communication. As a starting point for further discussion the following definitions are proposed.
Regulations are the highest level of "coding", because they not only contain descriptions of the physical and operational features of the given technology or product, but also performance standards and limit values (tolerances) to be complied with, and implicit restrictions for the use of non-standard or non-compliant items or systems. Regulations are needed to ensure that public goods such as safety, security, sustainability, health, interoperability, … are not unduly compromised by the use of a given product or system over its complete life-cycle.

"Codes of practice" usually explain the basic functions of an equipment or product for safe handling and problem-preventive maintenance in order to guarantee trouble-free operation. These codes usually share at least some basic elements that are built around the generic features and functionality of the technology, and build a common understanding among the people how to deal with this type of product or system.

Standardization action:

- Agree on a common set of terms and definitions for H2 and H2NG The terms and definitions should be aligned as much as possible between the fields, to avoid potential conflict.

Impact of proposed actions on technology deployment:
Medium

Urgency to start the proposed actions:
High
To avoid confusion about terms and definitions it is of high importance to develop an unambiguous and consistent common set of terms, definitions and symbols within a specific defined field of work.

Estimated time required to finalise the proposed actions:
Less than 5 years

Actors needed to fulfil the proposed actions:
Research institutes, industry, standardization bodies , regulatory bodies and testing laboratories

4.5.8 Conclusions

The list of topics identified by TF5 included mainly items related to safety. The other key topic was certification. Also terminology, societal acceptance, metrology, testing, research and knowledge (focussed on education and training), recycling and dismantling and regulation were identified. For certain items the identified gaps were based on the cross cutting items from other TFs.

Urgent action needed was concluded about the clarification of the **legal status of power-to-hydrogen plants.** If PtH plants are treated as energy consumers they are subject to taxes and fees, which increases the cost of the hydrogen produced. As PtH plants render a service to the energy system, the recommendation is that they should be classified and rewarded accordingly. In addition the certification of green hydrogen has been identified as a priority challenge. Similar to the case of electricity or biogas it is physically not possible to verify the origin of hydrogen and a system of **guarantee of origin for hydrogen** is therefore needed. The PNR study CertifHy is ongoing and a certification scheme in analogy with the existing standards for electricity EN 16325 is a proposed next step. There is a need for a **clarification of Industrial Emissions Directive** on production of hydrogen. Also the techno-economic assessment related to the cost of hydrogen injection into the natural gas grid adapted to the local, regional or national situation should be established.

To assess the **safety of hydrogen/H2NG applications** and infrastructure it was addressed that explosion related safety risks need more research. The assumptions about **leak size,** pressures and duration of the release are important for the determination of the type and extent of hazardous zones. Pre-normative research should be performed dependent on the equipment used and also considering fluid conditions. Standardization actions is needed to realize harmonisation in the approach to determine hazardous zones defined in the ATEX directive considering the assumed leak sizes for H2NG.

For gas detection systems and sensors several topics have been addressed for PNR and standardization action. The development of standards for specific applications of hydrogen sensors, e.g. in leak detection should be pursued and for hydrogen/methane mixtures, appropriate sensors should be identified.

The **compatibility of materials** with hydrogen is a key issue. There is already a lot of available knowledge but for the use of hydrogen and H2NG in new applications, some knowledge gaps still remain, in particular as the injection of hydrogen into the gas grid may affect the whole downstream infrastructure and all end-users.

For the commercialisation of the hydrogen technologies **training and education** is a prerequisite. The provision of adequate education and training for H2NG and hydrogen will prove critical for the current and future workforce. PNR and standardization actions related to the competency of personnel and training about the safety aspects of hydrogen/H2NG were identified. Also certification for installers for H2 or H2NG applications was mentioned as a topic to address in the short term.

A standardization deliverable for **terms and definitions** is needed because it is important to agree on a common set of terms and definitions for PtG, H2NG and pure hydrogen applications. The terms and definitions should be aligned as much as possible between the fields to avoid potential conflict.

4.6 Other related technologies

Technologies that are considered relevant in the frame of H2NG but are outside of the scope of the SFEM Working Group Hydrogen are addressed in this section. The aim is to identify the major needs for research in the fields of methanation and green hydrogen production.

4.6.1 Methanation

Methanation technologies need several research actions in order to reach industrial maturity. In case of insurmountable compatibility problems of H2 with the existing installations methanisation of H2 may be an appropriate solution. Substitute Natural Gas (SNG) quality, durability and performance are the main topics to be addressed. Related to the reactors, research should be focus on reduction of complexity and the requirements for the multi-step reactors to reach the required SNG quality. Increase of operating pressure in the reactors, in order to reduce or avoid the SNG upgrading should be another research target. Regarding the high operation pressures, some technologies should reduce complexity. Also the improvement of flexibility for the basic modules should be addressed.

In methanation reactors, hydrogen is commonly supplied from an electrolyser (at relatively high pressures), so its purity is very high. However CO_2 streams may host impurities that need to be removed. Because the CO_2 stream is supplied at atmospheric pressures, therefore research is needed on the requirements for the CO_2 stream upgrading at low operating pressures.

Because methanation is an exothermal reaction, high temperatures can be reached within the reactor, which can lead to hotspots and catalyst metal sintering. This may reduce performance and lifetime of the equipment. Therefore, research has to be done to avoid or reduce these phenomena. Also investigations regarding the formulation of methanation catalyst to improve efficiency and durability are necessary.

SNG quality degradation during reactor operation is another topic to be looked into.

As far as standardization is concerned, the work carried out in answer to mandates M400 Gas quality (within CEN/TC 234/WG 11) and M475 Bio-methane (within CEN/TC 408) address the issue, since the objective is that SNG shall conform to the same requirements.

4.6.2 Green hydrogen production

In addition to hydrogen production by electrolysers from renewable electricity (wind or solar), already covered in TF2, there are other means for the production of hydrogen with a low carbon footprint. However, these technologies are either very costly or not yet mature enough. Some production routes require more research to reach a TRL high enough to be considered a real alternative for green hydrogen production.

1. High temperature water splitting:
High temperature water splitting can be achieved with solar power or by using nuclear process heat. Water spontaneously dissociates at around 2500 °C, but this thermolysis occurs at temperatures too high for usual process piping and equipment, therefore, catalysts are required to reduce the dissociation temperature. Durability and cost are the main challenges for this technology, so research actions should target these topics. Improvement of the stability of the catalyst/redox material in order to increase lifetime and reduce operational costs is one of the actions to be addressed. The internal heat recovery should be also be improved to reduce operational and capital costs and to increase efficiency.

2. Biological production:
Different technologies for the biological production of hydrogen are in R&D stage. One of these is fermentation in which organic matter is converted into hydrogen by a diverse group of bacteria. Fermentation includes photo-fermentation in which light is required for the production of hydrogen and dark fermentation which does not require the availability of light energy.

In anaerobic digestion, microorganisms decompose biodegradable material in the absence of oxygen. The process is used for waste treatment and/or fuels production. The main product of this digestion is methane, so in order to obtain hydrogen, a reforming process is needed.

It is also possible to produce hydrogen through a specific kind of algae (*C. reinhardtii*). These algae, in the absence of sulphur, switch from the production of oxygen, as in normal photosynthesis, to the production of hydrogen.

For these technologies, research should be prioritised towards increasing the yield of hydrogen produced. This can be reached through improving the efficiency of the processes and through upscaling the size of the biological reactors. These technologies also present a high potential to combined hydrogen production with the production of bio-chemical products.

4.6.3 Liquid hydrogen

In a scenario of increasing use of hydrogen for energy but with a lack of pipeline infrastructure for hydrogen distribution, liquid hydrogen is regarded as the most cost-effective way of hydrogen distribution. However this technology has some problems that have to be solved in order to be competitive. The relatively large amount of energy necessary for liquefaction and the continuous boil-off of liquid during storage are the main drawbacks for this technology. Current designs of liquefaction plants have been focused on CAPEX reduction, due to the high capital costs of this kind of facility. Because of relatively low hydrogen demand, the efficiency of these facilities is lower than what the technology allows. Thus research should be focused on improvement of efficiency of the liquefaction process, reduction of equipment costs and improvement of storage insulation. EU funded project results such as e.g. IDEALHY shall be taken into account.

In addition, there are safety issues related with storage and transport of LH2 that should be studied. There are knowledge gaps related to spillage of LH2. Dispersion is a poorly understood phenomenon that requires investigation.

Currently, there are standards for liquefied hydrogen related with transport, ISO 13984:1999 (Land vehicle fuelling system interface) and ISO 13985:2006 (Land vehicle fuel tanks). Liquid hydrogen is also present in the ECE/TRANS/242 International Carriage of Dangerous Goods by Road (ADR).

5. Near term challenges and roadmap

In chapter 4, priority actions have been identified based on the individual assessment per Task Force. In this chapter, an overall priority roadmap is presented and the actions needed in the near term described. Whereas PNR precedes standardization, for some topics PNR and Standardization actions could start in parallel to increase the time efficiency and reduce costs.

5.1 Near term actions roadmap

The priority roadmap contains all actions that are considered a top priority in the individual roadmaps. Actions are allocated priority status when it is considered that non-action would significantly hamper the uptake and deployment of hydrogen and H2NG technologies. Specifically for the H2NG technologies, the priority actions are assessed keeping in mind the expected gradual increase of hydrogen concentration in natural gas.

For all **electrolyser technologies** it is considered a priority to establish a PNR and standardization framework in which technologies can be compared, based on a consented approach. Such a framework further improves market transparency and efficiency. For the standardization framework to become established it is required to have a clearly defined set of key performance indicators (KPIs) with subsequent testing, measurement and calculation procedures methodologies. This framework should especially focus on specific features of intermittent renewable energies and includes dynamic operations, grid stabilisation and tuned operational strategies for specific end-user requirements. PNR is required to support the development of standardised KPIs in terms of performance and durability characterisation methodologies.

For the **gas grid infrastructure** and **end-users**, the first near term actions are set to enable increasing the acceptable concentration of hydrogen in natural gas. A hydrogen concentration limit above 2 vol% calls for a determination of the effect of hydrogen on porous rock underground storage, CNG vehicle on-board storage tanks, gas turbines and industrial processes as the highest priorities. Most of the challenges identified first require a thorough state of the art analysis, followed by further testing activities. PNR is prioritised for underground gas storage facility for porous rocks to enable the determination of the impact of hydrogen on micro-biology in terms of safety and integrity issues. The use of H2NG in natural gas vehicle steel tanks is also a key challenge, for which the PNR results should lead to a clear action plan in order to safely increase hydrogen levels above 2 vol%. Mitigation actions and adaptation of existing regulations should be considered as follow-up steps. PNR results should be translated into recommendations for standardization. Additional challenges identified in the range of 5-10 vol% hydrogen are the effects of hydrogen on industrial and residential burners and the propagation of smell for new odorants in the presence of hydrogen. Lastly, at higher concentrations of hydrogen (>10 vol%), the performance of compressors may be affected. All of the activities proposed should involve both DSOs and TSOs.

For pure **hydrogen technologies**, the priority actions for PNR and standardization are targeted to facilitate the uptake of hydrogen in the transport market, besides the industrial market one of the key markets envisaged for hydrogen. The AFID provides a clear need for standardization requirements aimed at ensuring interoperability of connectors, filling protocols and hydrogen quality. The latter would also include quality assurance. The requirements laid down in the

Measuring Instruments Directive establish a priority for accurate hydrogen metering. PNR is needed for identifying specific operational performance requirements for components (e.g. stationary hydrogen storage, connectors) as well as for the development of risk assessment methodologies for hydrogen quality and for the station-vehicle interface.

The cross-cutting topics included several items related to safety. The other main topic was certification. Also terminology, societal acceptance, metrology, testing, research and knowledge (focussed on education and training), recycling and dismantling and regulation were identified.

Urgent action needed was concluded about the clarification of the legal status of power-to-hydrogen plants. As PtH plants render a service to the energy system, the recommendation is that they should be classified and rewarded accordingly. In addition the certification of green hydrogen has been identified as a priority challenge, as well as a clarification of the industrial emission directive on the production of hydrogen. The cross-cutting items relate to all Task Forces and are therefore not depicted in the roadmap.

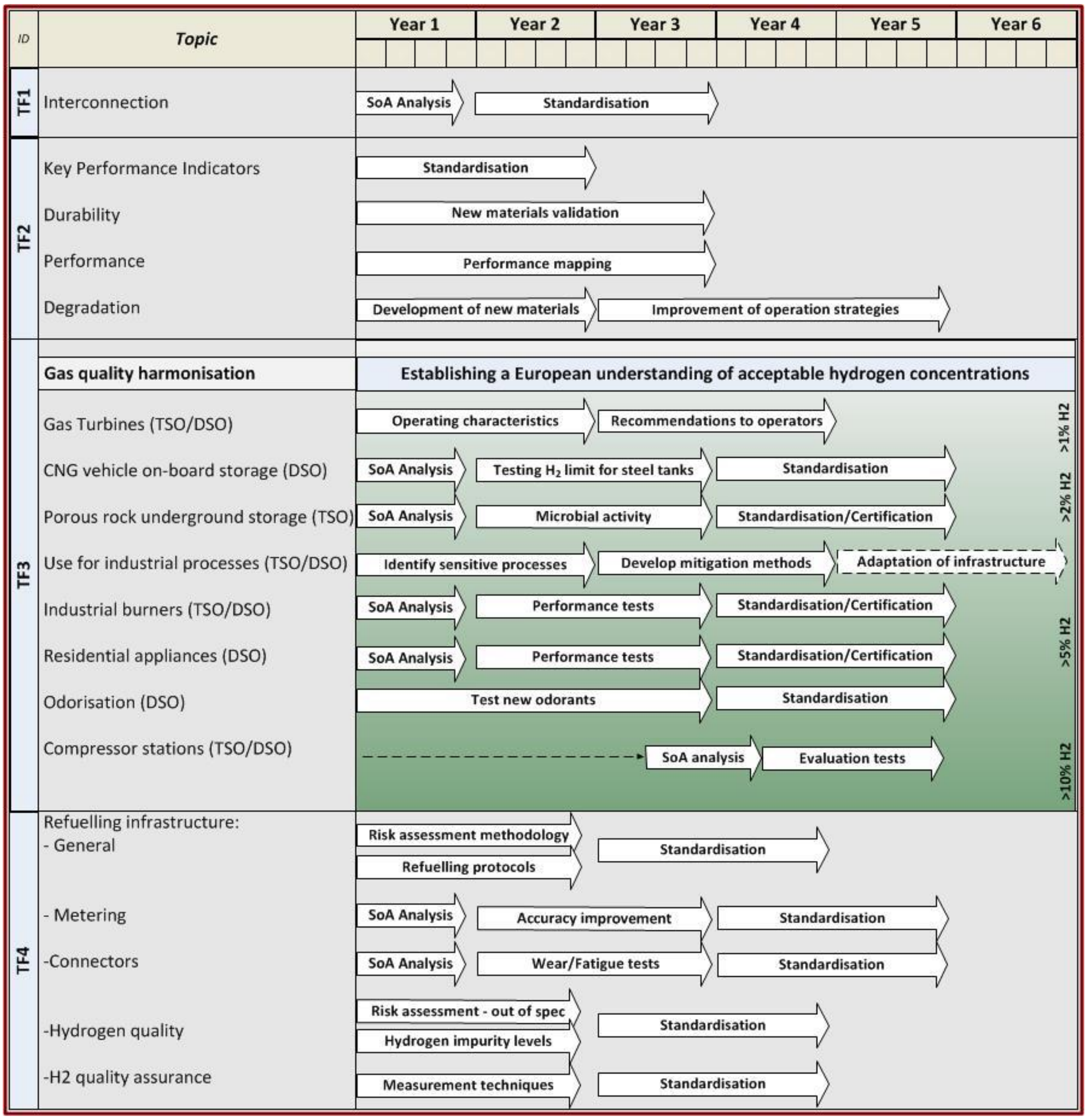


Figure 6 Roadmap of near term priorities

5.2 Short and near term standardization actions

Whereas a number of key challenges as described above require additional research or other activities before standards can be developed or revised, some are ready for standardization to start immediately or in the near term, as listed in table 1. Standardization actions that are identified as high priority but are already ongoing are not included in the list below.

Table 1: Short and near term standardization actions

Topic	Description	Standardization action
Electrolysers	Definition of key performance indicators	Update of ISO 22734 or New EN standard
Electrolysers	Include SOEC technology	Update of ISO 22734
Electrolysers	Definition of electrolyser system boundaries	Update of ISO 22734
Electrolysers	Oxygen quality specifications for cases in which the oxygen stream can be utilised.	Update of ISO 22734 or New EN standard
Electrolysers	Installation and operational standards	New EN standard
Gas grid infrastructure	Pre-mixing stations → Definition of requirements	New EN standard
Gas grid operation	Odorization → Definition and harmonisation of performance indicators	New EN standard Updates of standards: ISO/TR 16922:2013, EN ISO 13734:2013
Gas grid operation	Losses due to permeation → Set limit of acceptable hydrogen permeation	New EN standard
Gas analysis methods and instruments	Sensors for concentration monitoring and process control → Definition of requirements	New EN or ISO standard
Gas grid infrastructure	Suitability of seals and connections in the natural gas chain for H2NG →Definition of acceptable performance	TC/234, update of standard
Gas grid infrastructure	Determination of closing volume for excess flow valves → Definition of acceptable performance	TC/234, update of standard
Gas grid infrastructure	Condition monitoring, maintenance and repair procedures and related equipment → Update of PIMS standards	CEN/TC 234 Gas Infrastructure Update of standard EN 16348: 2013
Gas grid infrastructure	Grid integrity, impact on plastic pipes and rubber/plastic components	CEN/TC 234
Gas grid infrastructure	Equipment and devices installed in the gas chain including pressure regulators, valves etc. → Define suitability of the components	CEN/TC 69 Industrial valves EN ISO 15848
Gas analysis methods and instruments	→Define and harmonize key performance requirements for gas analysis instruments	ISO/TC 193, ISO/TC 158 Analysis of Gases Update of standards
Gas analysis methods and instruments	Sensors leak detection → Definition of requirements	Update of standard EN IEC 60079-29-1:2007
H2NG CNG vehicles – on board storage	Qualification of steel tanks for > 2% hydrogen →Update of ISO standards referring to R 110 regulation	ISO/TC 58 and ISO/TC 197
Residential appliances	Adaptive combustion control → standardization of more flexible devices	CEN/TC 109
Residential appliances	Definition of appliance category and test gases → inclusion of H2NG an gas appliance category in EN 437	CEN/TC 238

Topic	Description	Standardization action
Hydrogen applications	Refuelling infrastructure → performance requirements and safety of cooling devices	New ISO standard
General	Terms and definitions → Common set of terms and definitions for both PtG and pure hydrogen applications.	New EN standard
Safety	Explosion related safety risks → Determination of hazardous zones defined in the ATEX directive	New EN standard
Safety	Leakage related safety risks → Guidance and criteria for the screening and evaluation of external factors for risk assessments.	New EN standard
Safety	Gas detection systems → development and harmonisation of standards related to gas detection	Update of IEC 61779 and ISO 26142
Training and Education	Training and Education → Competency management system and schemes with the needed training and their criteria in relation to the specific discipline	New EN standards
Certification	Green Hydrogen → development of a certification scheme	New EN standard

6. Recommendations and next steps

6.1 Recommendations

The main result of the activities of the WG is a consented set of priority actions for research, PNR and standardization for the coming years in the field of hydrogen and H2NG. These priorities have been arrived at based on the results of a survey of the state of the art of both standardization and research on European and International level and the work of the dedicated Task Forces.

To efficiently and effectively address the identified priorities in a timely manner to enable full exploitation of the potential contribution of hydrogen and H2NG to EU integrated energy and climate policy objectives, the WG recommends CEN and CENELEC Technical Boards to endorse:

- Establishment of a new CEN/TC for hydrogen (6.2.1).
- Continuation of a platform for the complete hydrogen market in Europe (6.2.2). This platform should holistically cover research, pre-normative research and standardization for Power-to-Hydrogen and all related applications, including Power-to-Power.
- Dissemination of the outcome of the SFEM/WG activities through workshops or other activities organised by the SFEM/WG members and coordination team to European stakeholders not yet involved in the working group (6.2.3).

6.2 Next steps

6.2.1 Establishment of a new TC

The SFEM/WG Hydrogen experts recommend the establishment of a new CEN(/CENELEC) Technical Committee (TC). The main arguments for establishing the new TC are that currently there is no TC covering the wide range of topics identified by the WG and that standardization is the most appropriate way to tackle many of the critical issues identified. The scope of the new TC will include the standardization in the field of systems, devices and connections (e.g. PtG, PtP) for the production, storage, transport, measurement and use of hydrogen from renewables and other sources. Also overarching and cross cutting items are covered as part of this scope. Example of this are safety related items, training and education, management system, guarantee of origin etc. The scope also regards future topics related to hydrogen which possibly contribute to the development of the hydrogen market within Europe. The scope of the new TC will of course consider and liaise with existing TCs and work at European levels, as well as consider international activities from a European point of view, such as those developed in ISO/TC 197. It should liaise with international TCs and thoroughly assess what is needed in terms of adapting standards on a European level. Topics already covered by the scope of an existing TC will not be elaborated in the new TC. Indeed, the new TC should ensure a complete and multi sectorial holistic vision, and identify further market needs and gaps where new standardization developments would contribute to the development of a EU market. These identified needs and gaps could be addressed in the new TC or in existing TCs. Thus, a close liaison and cooperation with existing TCs is a key issue.

Considering the above, NEN, the Dutch National Standardization Body (NSB) proposes, to submit to CEN/CENELEC BTs the request for establishing the new Technical Committee. NEN also proposes that it will provide the secretariat of the new TC.

Because some of the topics listed and prioritized by the SFEM/WG could be more effectively and efficiently addressed by other CEN/TCs (e.g. TF3 topics by CEN/TC 234 that deals with Gas infrastructure), it is important to clearly define boundaries to the scope of the new TC. To mirror the work of the new TC it could be decided to bring the activities within the scope of an existing national standards committee or establish a new national mirror committee.

6.2.2 Continuation of the SFEM/Working Group Hydrogen

The WG hydrogen has performed well over the 9 months of its existence, has created a momentum for power-to-gas, hydrogen and H2NG, has reached out to a variety of stakeholders and most importantly has created a forum in which experts from the natural gas industry, hydrogen industry and power sector exchange knowledge and expertise and can address common issues.

Besides the establishment of a new TC, the continuation of the SFEM/WG Hydrogen as a forum for exchange and discussion is therefore proposed to ensure that the SFEM/WG Hydrogen activities are given the required follow-up. During the work of the WG hydrogen, a significant amount of information has been collected on past and ongoing research, pre-normative research and standardization activities as well as on gaps which have to be addressed to enable the technologies to reach the relevant markets. The SFEM/WG Hydrogen has proven itself a highly useful, expert and multi-stakeholder platform, covering a wide range of expertise in relation to hydrogen for all facets, including power to hydrogen, pure hydrogen and hydrogen admixture to natural gas. The main tasks of the continued SFEM/WG would be coordinating the ongoing work, identifying the gaps to be filled by standardization, research and PNR and ensuring that standardization, research and PNR activities are linked wherever possible. In concrete terms it will:

- keep this report up-to-date according to the relevant progress made, including mapping
- follow-up on the actions identified in the overall roadmap and the conclusions and roadmaps of the different Task Forces
- determine the progress toward the challenges identified
- monitor the state-of-the-art in terms of RCS, PNR and R&D
- follow-up on European and international RCS and PNR developments, update and prioritize RCS and PNR needs through a continuous global watch function
- consolidate and disseminate results to relevant stakeholders
- serve as a point-of-contact for established and new liaisons, including WGs from SFEM or from other CEN/CENELEC Strategic Fora
- continue to perform as a European "knowledge hub" for hydrogen and H2NG standardization issues
- advise the CEN/CENELEC and ISO/IEC board on prioritized standardization topics and on where (in which TC) they can be dealt with.

The follow-up SFEM/WG should remain an easy accessible and highly relevant platform to exchange expertise and information on developments and innovations, as well as on required research, PNR and standardization activities with regards to power to gas, hydrogen and H2NG. The platform should remain easily accessible for participation (low threshold to join) by experts without the need to register via a NSB. Guests would be able to participate and experts can provide their expertise to the relevant PNR working groups and/or standardization TCs.

During the work of the present SFEM/WG it was noted that common interest exists on topics where experts from the gas grid and hydrogen sectors see related challenges. Areas of common interest which can profit from continued sharing and exchanging expertise in the field of hydrogen or natural gas and benefit from synergies in the frame of a continuation of the SFEM/WG are:

- Underground gas storage
- Metering of H2NG
- Gas analysis and detection
- Maintenance and repair procedures
- Materials compatibility
- Flow modelling

In 2015 the SFEM/WG Hydrogen managed to attract the interest from more than 80 experts to participate (actively or as observer) from ca. 60 companies from 10 countries. Also the EC, represented by DG ENER, DG GROW, DG RTD, DG JRC and FCH2 JU participated. The latter expressed interest to have a direct link with SFEM/WG Hydrogen to receive relevant inputs for the identification of existing RCS and identification of gaps in pre-normative research which could be used as input for its multi annual work programme and successive annual work programmes. The FCH2 JU RCS strategy coordination group (SCG) could provide in that sense another relevant link. the SCG will define and oversee implementation of the FCH2 JU RCS strategy to ensure that the FCH2 JU programme appropriately and timely addresses safety issues and needs for standardization and regulation, collects and evaluates RCS-relevant information from demonstration projects and monitors PNR activities.

6.2.3 Dissemination

Further dissemination is recommended to make sure the results of the work by SFEM/WG Hydrogen, namely state of the art analysis of technology and standardization, identification of the main barriers for Power to Hydrogen and HCNG and prioritisation of required actions are shared with the relevant stakeholders.

The aim for the dissemination is to transmit relevant knowledge to appropriate target audiences, including research communities, practitioners, the public, policy makers and regulatory bodies. Based on the current experience, dissemination should also focus on European stakeholders not yet involved in the working group, in particular NGOs and governmental organisations. This will allow to:

- Stakeholders so far not involved to become aware of the work performed and derive benefits from it for their own field of work
- Encourage decision makers to implement the recommendations;

- inform decision makers and the general public on decarbonisation and energy security scenarios via the Hydrogen economy based on Power-to-Hydrogen by addressing technology-led solutions, where industry can play the major role.
- Encourage research to improve scientific knowledge on key aspects including performance, safety and durability.
- build a European ‘lead technology’ in this field, with relevant European standards providing the basis for future international standards.

A non-exhaustive listing of Target groups is:

- CEN/CENELEC
- EC DGs
- FCH2 JU
- FCH2 JU NEW IG (New Energy World Industry Grouping)
- FCH2 JU EC N.ERGHY (research grouping)
- Madrid Forum
- National and regional Policy and decision-makers
- Relevant CEN/CENELEC TCs and Sector Fora
- International, European and national profit and non-profit Associations e.g. IEA, Marcogaz, HIPS-NET, GERG
- National Industry Organizations e.g. Hydrogen platforms on a national level but also platforms dealing with e.g. the national grid, electrolysers, fuel cells
- Funding agencies

Annexes

Annex A: Methodology

The SFEM/WG Hydrogen was established taking into account the outcome of the Petten Workshop 'Putting Science into Standards: Power-to-Hydrogen and HCNG'. It was agreed on to have a holistic approach to frame technical issues of 'Power to Hydrogen and HCNG' in the wider context of standardization in CEN and CENELEC.

The WG Hydrogen began its work on 9th of February 2015 with a kick-off meeting attended by 35 experts. At that moment there were in total 48 experts registered for the SFEM/WG hydrogen. Two additional plenary meetings were held until the 21.09., when the final meeting of the group took place. The experts agreed to provide an inventory of relevant projects and recommendations for standardization to CEN/CENELEC and to prioritize the items identified. It was also decided to liaise to relevant standardization activities (e.g. ISO/TC 197, CEN/TC234, SFEM). The Task Force structure as described in 1.3 CEN/CENELEC SFEM/Working Group Hydrogen was set up to identify R&D gaps, perform mapping of standardization activities and gaps and indicate cross-cutting activities. The WG experts joined the TFs according to their expertise and ability to contribute time to this exercise. At the moment of the writing of the final report there are 80 experts from which 63 experts related to industry 'organizations' (54 organizations) and others from mainly the EC and EU standardization organizations (different DGs, FCH2 JU and CEN/CENELEC). The experts are registered from 11 different countries. From the 80 experts of the SFEM/WG Hydrogen a majority, 49 experts, joined one of more of the Task Forces. The Task Forces then elected conveners to organise the further steps, such as setting up dedicated TF meetings.

An overview of the landscape of the SFEM/WG Hydrogen with its members is given in the overview in Figure 7.

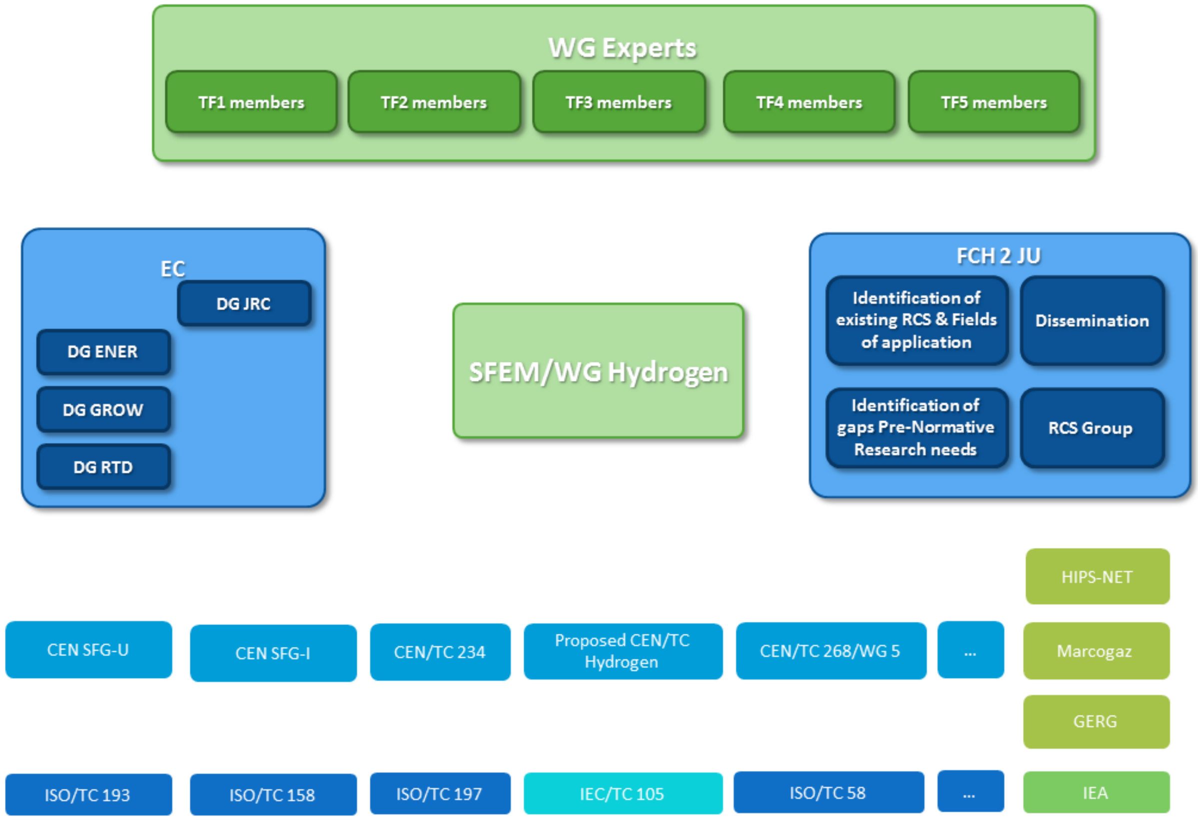


Figure 7 SFEM/WG Hydrogen overview

The first step after the Petten Workshop was a stakeholders analysis, not only with regard to experts but also with regard to relevant governmental organizations on both an European and International level and the relevant European and International Standardization committees with their work programs.

Five groups were identified to contact/link with:

1. Link with European and international standardization work programs
2. Link with the Fuel Cells and Hydrogen Joint Undertaking (FCH2 JU)
3. Link with JRC and other relevant EC Services (e.g. DG RTD, DG ENER and DG GROW)
4. Contact relevant stakeholders from gas sector, grids, electric supply, mobility etc.
5. Identify and contact the relevant research related to hydrogen

The following stakeholder groups were invited:

- CEN/CENELEC
- Relevant CEN/TCs e.g. Gas infrastructure, SFG-I etc.
- FCH2JU NEW IG (New Energy World Industry Grouping)
- FCH2JU EC N.ERGHY (representing the interests of European universities and research institutes in the Fuel Cell and Hydrogen Joint Technology Initiative FCH JTI)
- EC DG ENER
- EC DG Research & Innovation

- EC DG GROW
- EC JRC-Institute for Energy and Transport
- Via JRC participants list of workshop "putting science into standards: power to gas "
  Stakeholders related to:
  - system (scope)
  - research
- Via SFEM members national stakeholders:
- NSBs
  - National TSOs and DSOs; G and E
  - National mirror committees for European and international hydrogen related standardization e.g. ISO/TC 97 (Hydrogen and Fuel Cells)
  - Governments
  - National industry associations e.g. Hydrogen and Fuel Cell association, Heating industry
- Specific organizations f. i. Dutch project team Hazardous Substances Publication Series number 35 (PGS 35): 'Hydrogen - delivery installations for vehicles'
- Specific national and international stakeholders related to scope e.g.
  - TSOs and DSOs E and G grid
  - Electrolysers
  - Mobility
  - Storage
  - Metrology
  - End users e.g. (chemical) industry and heating industry
  - European industry associations
  - H_2 industry

A positive response was received from (not always immediately from the start but also during the process of work):
EC DG ENER, RTD, GROW and JRC, FCH2 JU, FCH2 JU NEW IG, CEN/CENELEC, ISO/TC 197, CEN/TC 234, CEN/TC 408, SFG-I, SFG-U and IEA have shown their interest and then contributed actively to the Working Group.

A complete overview of the type of organizations, a detailed overview of the research and knowledge institutes and per country are given in Figure 8-10. A complete list of the field of standardization work is given in Annex C.

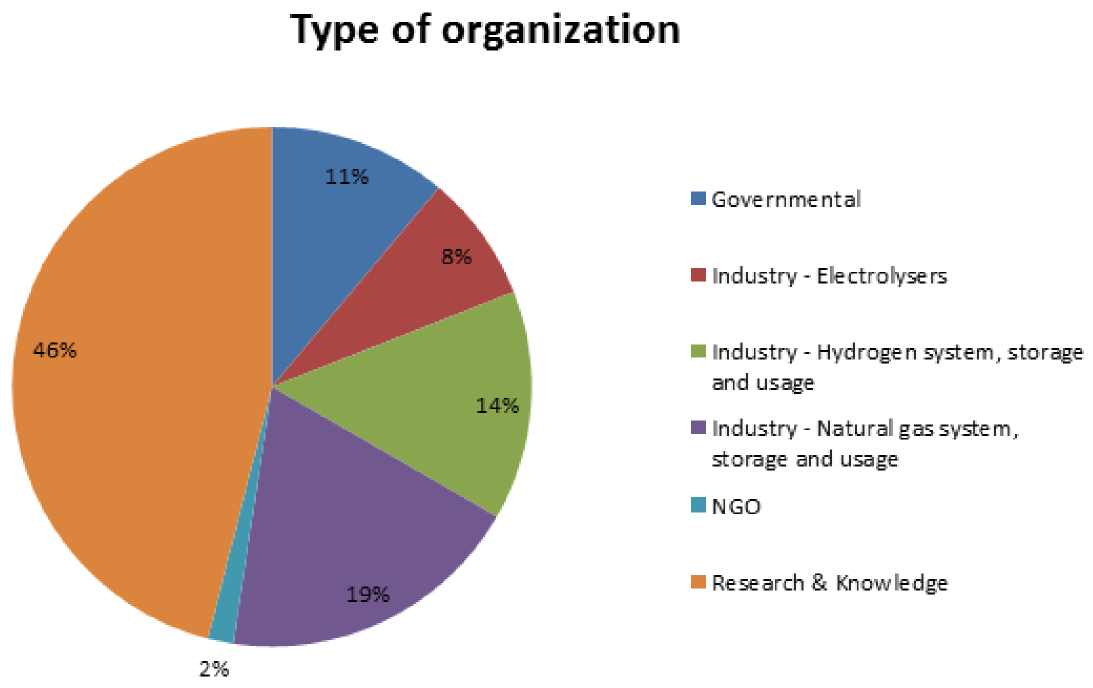


Figure 8 SFEM/WG Hydrogen experts per type of organization

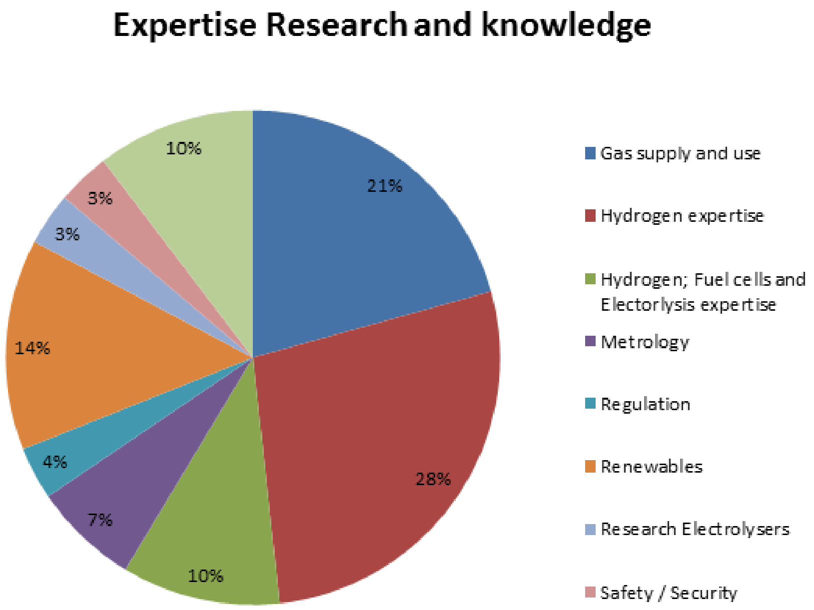


Figure 9 Areas of expertise

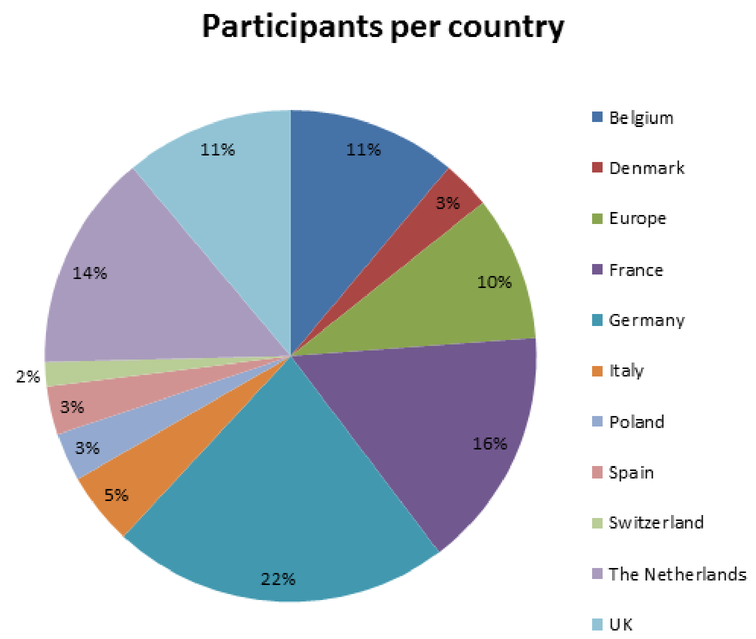


Figure 10 SFEM/WG Hydrogen experts per country

Organization and process

The 5 Task Forces started their work following the kick-off meeting. The input of the TF members was collected both for the mapping and for the challenges in a dedicated spreadsheet, the structure of which was refined further in the course of the work. The key challenges discussed in the Petten workshop 10/2014 were summarized in the documents to provide a starting point for further work.

General headings were then adapted by the experts and further divided into subtopics, according to the level of details required. The scope and therefore complexity of the structure of topics of the TFs varied, as for example TF2 covered one technology (electrolysis) and TF3 the entire gas system, storage plus end-users. This also meant that the list of challenges was far more extensive for TF3 than for the other TFs. The spreadsheet then served as a means to gather and track the input provided by the experts and was updated until a final consensus was reached within the TF. As TFs organized several telecoms and also coordinated their work with other TFs.

Below, an example is provided for the structure of the spreadsheet and the input provided by the experts. The information was updated periodically and discussed within each of the Task Forces. They were asked to identify research and standardization gaps and major challenges (what), describe the open issues, the activity type needed to address the issue and agree on the impact/priority of each of these items. In addition information was provided on the urgency (when) of action, the time needed to address the challenge and the appropriate actors (who) to implement these. In order to prioritize the challenges, aspects such as urgency, impact and effort involved were considered. In case of TF3, where an initial list of >100 items was reduced to the 40 most relevant topics, the experts decided to divide the challenges according to the hydrogen concentration limit. For a 2 vol% hydrogen concentration fewer aspects need to be considered than for 10 vol%. In addition not all challenges affect DSOs and TSOs equally, which formed another basis for grouping and ranking challenges. Finally a ranked list of the top level, near term action items was agreed upon, based on these considerations.

For the other TFs the prioritization exercise was more straightforward, given there were far fewer items to begin with. For TFs 2 and 4 the actions related to market introduction/commercialisation of the technologies were considered of highest importance.

Table 2: Example of spreadsheet to collect input for TF3 analysing research

Nr.	Topic	Subtopic	Description of open issues	Ongoing projects covering/partly covering the open issues (known, if yes additional information)	Requested/needed activity type to cover challenge	Priority/Impact (1=high/show stopper, 3= low)
1.1	Hydrogen storage	HCNG storage in steel or composite tanks	R110 defines as a maximum limit of 2 Vol.-% hydrogen in CNG as a fuel. The reason for this is the expected susceptibility of steel tanks regarding hydrogen. This limit needs to be technically proved.		Investigation if steel tanks for CNG vehicles can accommodate more than 2 Vol.-% of hydrogen. Giving motivation to manufactures to use composite tanks (that have no hydrogen limitation) in the future.	1

Table 3: Example of spreadsheet to collect input from TF3 analysing gap related to standardization

Urgency start immediately, medium term (within 5 years), later	time needed (short=5 , medium =5-10, long term>10 years)	Explanation for priority	Recommended actors	Detailed Description	Source	Link to CEN/TC's etc.	Status (finished, open)
start immediately	short term	Will allow a higher injection of hydrogen in the distribution grid. Most limiting factor for H2 injection in the Distribution grid.	TSO, DSO, tank manufactures, car manufacturer, material experts/testing laboratories	SoA-Analysis on the effect of hydrogen on steel tanks used in the NG-vehicles Determination of a technical acceptably hydrogen concentration for CNG 1 tanks Adoption of the current available standard (ISO R 110) Identification of transition paths that enables the use of cars with CNG 1 and modern tanks (eg. type 4) that enable higher hydrogen concentrations	all	CEN/TC 408 CEN/TC 234 ISO/TC 193 HIPS-NET/HYREADY	open

The Task Forces have worked with an excel input sheet developed for this purpose to map and identify normative and standardization needs and challenges on topics with the scope of work.

These needs are described in chapter 4 and have been put forward into actions. These actions have been prioritised in terms of impact and urgency and are depicted in individual roadmaps.

The roadmaps depict:

- the actions as an arrow in which a keyword reflects the type of action that is needed
- the impact of the actions on technology deployment is highlighted with the font of the keyword, in which a keyword in bold representing a high impact
- the urgency to start the actions is highlighted along the time axis, in which a high urgency is reflected as a need to start now (meaning 2016)
- the estimated time that is required to finalise the actions is highlighted as the length of the arrow
- the highest priority actions are coloured in red

The highest priority near term action items across all Task Forces are also shown in an action plan in chapter 5. Further analysis of key challenges also lead to the identification of areas of common interest.
The next steps on how to address the identified actions are discussed in chapter 6.

This report presents the results of the work carried out in the Task Forces and is the final deliverable of the WG.

Annex B: How does standardization work and what are standards?

The following sections given an overview of the standardization process at European level in general, the responsibility of a Technical Committee (TC) and the working groups. It also describes the way the SFEM experts could join a CEN/CENELEC TC. Via the National Standardization Body (NSB) they can ensure to follow the work and attend the plenary meetings or participate in a working group where the standards development is being performed. If a CEN member (country) is interested to follow and influence the work from the TC, a national mirror committee should be established. The members are the national stakeholders. The NSB should take the appropriate actions. It could be the case that there is a national mirror committee who will adopt the activities of a new TC under their scope.

Standardization in general

CEN/CENELEC's core business is the development of standards that meet the needs of the market. Standardization is performed in a 'bottom-up' approach, thereby ensuring the market relevance of the resulting deliverables.

Each Technical Committee shall establish and secure the CEN Technical Board approval for a programme of work with precise title, scope and scheduled target dates for the critical stages of each project. This should not be in conflict with the scope of another TC. The TC takes this work program in its Business Plan.

Another possibility is a Joint CEN/CENELEC Technical Committees and joint CEN/CENELEC Working Groups. A Joint CEN/CENELEC TC is applicable where both CEN and CENELEC have some aspects in common. In the case of the Power to Gas the connection with the actors from the electricity grid is of importance therefore a CEN/CENELEC TC should be considered.

The secretary of the TC, shall in consultation with the chairman, ensure that the Technical Committee functions efficiently and, in particular, that agreed timetables are kept to.

National Standardization Bodies

The standardization system in Europe is based on the national pillars, which are the National Standardization Bodies (NSBs). CEN's National Members are the National Standardization Bodies (NSBs) of the 28 European Union countries, the Former Yugoslav Republic of Macedonia, and Turkey plus three countries of the European Free Trade Association (Iceland, Norway and Switzerland). There is one member per country.

A NSB is the one stop shop for all stakeholders and is the main focal point of access to the concerted system, which comprises regional (European) and international (ISO) standardization. It is the responsibility of the CEN National Members to implement European Standards as national standards. The National Standardization Bodies distribute and sell the implemented European Standard and have to withdraw any conflicting national standards.

Membership of the TC

CEN/CENELEC Members (NSBs) who have an interest in a TC project should indicate that to CEN. It is the responsibility of the NSB for sending in national comments on TC documents. It is also the responsibility of the NSB for the appointment and registration of their delegates to TC meetings.

These delegates could be current SFEM/WG Hydrogen experts/members. These TC meetings should be held when documentation is sufficiently well established to ensure satisfactory progress and with agenda of sufficient substance, from the technical standpoint, to justify the attendance of the delegates. The delegates represent their respective national point of view. This principle allows the TCs to take balanced decisions that reflect a wide consensus.

Representatives of bodies such as the European Commission, the EFTA Secretariat and other international and European organizations with particular interests in the work, having been accorded formal liaison, may also attend TC meetings as observers and without voting rights. Such organizations shall have access to the documents and shall, likewise, send advance notification of the observer who will be attending. Observers from other TC may likewise be invited to attend meetings.

Participation in Working Groups (Preparation of standards)
If experts from the SFEM/WG Hydrogen are interested in working on the development of the standards, which are prioritized, they should contact the relevant NSB to have the registered as expert in the relevant Working Group. Based on the outcome of the SFEM/WG Hydrogen work it is anticipated that more WGs will be established. The procedure is described below.

The preparation of the standards belongs to TC. The TCs work on the basis of national participation by the CEN Members (NSBs). The real standards development, though, is undertaken by working groups (WGs) where experts, appointed by the NSBs but speaking in a personal capacity, come together and develop a draft that will become the future standard. This reflects an embedded principle of 'direct participation' in the standardization activities. A Working Group (WG) is established by the Technical Committee to undertake a specific task within a target date. The Working Group experts should be aware of national positions on the subject in order to minimize the risk of rejection of the draft standard at a later stage. A Working Group may, however, also include experts appointed by organizations which have observer status in the parent body. Each Working Group shall have a convenor who is responsible for the proper conduct of the work, with or without the help of a secretary.

New work item proposals
There are different possibilities for the submission of a New Work Item Proposal.

1. Requests of national origin for CEN/CENELEC standardization work shall be presented, for consideration, to the relevant CEN/CENELEC national member (NSB), which may submit proposals for new projects to the CEN/CENELEC Technical Board.
2. Proposals may also be made by CEN/CENELEC technical bodies, the European Commission or the EFTA Secretariat, by international organizations or by European trade, professional, technical or scientific organizations. Such proposals shall be presented to the CEN/CENELEC Management Centre, for submission to the Technical Board. The work program for the CEN/CENELEC TC includes the recommendation for the work items to be dealt with.

The CEN/CENELEC Technical Board shall decide whether or not a project will be pursued and, if so, how it should be dealt with, in the light of all relevant information

Liaisons
Technical Committees working in related fields shall establish and maintain liaison. Liaison shall include the exchange of basic documents, including new work item proposals and working drafts.
Bodies such as the European Commission, the EFTA Secretariat and other international and European organizations with particular interests in the work may also been accorded as a formal liaison. The liaison representatives may attend Technical Committee meetings as observers and without voting rights. Such organizations shall have access to the documents and shall, likewise, send advance notification of the observer who will be attending. Observers from other Technical Committees may likewise be invited to attend meetings.

CEN and ISO, and CENELEC and IEC work closely together according to the agreement on technical cooperation between CEN and ISO of 1991 (Vienna Agreement), revised in 2001. This would also be the agreement applicable for the liaison with ISO/TC 197 for adoption the relevant work for the European market via the new TC.

What is a standard?
A standard is a document that sets out requirements for a specific item, material, component, system or service, or describes in detail a particular method or procedure. Standards facilitate international trade by ensuring compatibility and interoperability of components, products and services. They bring benefits to businesses and consumers in terms of reducing costs, enhancing performance and improving safety.

Standards are developed and defined through a process of sharing knowledge and building consensus among technical experts nominated by interested parties and other stakeholders - including businesses, consumers and environmental groups, among others.

The formal definition of a standard is a "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" [24].

There are several different types of standards. Basically, standards include requirements and/or recommendations in relation to products, systems, processes or services. Standards can also be a way to describe a measurement or test method or to establish a common terminology within a specific sector.

Standards are voluntary which means that there is no automatic legal obligation to apply them. However, laws and regulations may refer to standards and even make compliance with them compulsory.

Besides European Standards, CEN produces other reference documents which can be developed quickly and easily: Workshop Agreements, Technical Specifications, Technical Reports and Guides. [24]

Annex C: Standards

CEN/TC 58 Safety and control devices for burners and appliances burning gaseous or liquid fuels

CEN/TC 69 Industrial valves

- EN ISO 15848-1 *2015 - Industrial valves — Measurement, test and qualification procedures for fugitive emissions —Part 1: Classification system and qualification procedures for type testing of valves*
- EN ISO 15848-2: *2015 -(EN 16325:2013 prA1:2015): Industrial valves — Measurement, test and qualification procedures for fugitive emissions — Part 2: Production acceptance test of valves*

CEN/TC 192 Fire and Rescue Service Equipment

CEN/TC 185 Fasteners

- EN ISO 15330: 1999 Fasteners - Preloading test for the detection of hydrogen embrittlement - Parallel bearing surface method

CEN/TC 234 Gas Infrastructure

- EN 1594:2-2013 *Gas infrastructure - Pipelines for maximum operating pressure over 16 bar - Functional requirements*
- EN 1775:2007 *Gas supply - Gas pipework for buildings - Maximum operating pressure less than or equal to 5 bar - Functional recommendations*
- EN 1918-1:1998 (*prEN 1918-1:2014) Gas supply systems - Underground gas storage - Part 1: Functional recommendations for storage in aquifers*
- EN 1918-2:1998 *(prEN 1918-2:2014) Gas supply systems - Underground gas storage - Part 2: Functional recommendations for storage in oil and gas fields*
- EN 1918-3: 1998 *(prEN 1918-3:2014) Gas supply systems - Underground gas storage - Part 3: Functional recommendations for storage in solution-mined salt cavities*
- EN 1918-4:1998 (*prEN 1918-4:2014) Gas supply systems - Underground gas storage - Part 4: Functional recommendations for storage in rock caverns*
- EN 1918-5:1998 *(prEN 1918-5:2014) Gas supply systems - Underground gas storage - Part 5:Functional recommendations for surface facilities*
- EN 12007 series *Gas infrastructure - Pipelines for maximum operating pressure up to and including 16 bar*
- EN 15001-1:2009 *Gas Infrastructure - Gas installation pipework with an operating pressure greater than 0,5 bar for industrial installations and greater than 5 bar for industrial and non-industrial installations - Part 1: Detailed functional requirements for design, materials, construction, inspection and testing*
- EN 16348: 2013 - *Gas infrastructure - Safety Management System (SMS) for gas transmission infrastructure and Pipeline Integrity Management System (PIMS) for gas transmission pipelines – Functional requirements*
- EN 16726 (*prEN 16726:2014) Gas infrastructure - Quality of gas - Group H*

CEN/TC 238 Test gases, test pressures and categories of appliances

- EN 437:2003 + A1:2009 Test gases - test pressures - appliance categories.

CEN/TC 268 Cryogenic vessels and specific hydrogen technologies applications

CEN/TC 408 Project Committee - Natural gas and biomethane for use in transport and biomethane for injection in the natural gas grid

CEN/CLC JWG 2

- EN 16325: 2013 (under development A1:2015)- *Guarantees of Origin related to energy - Guarantees of Origin for Electricity*

ISO/TC 22 on Road Vehicles

ISO/TC 58 Gas Cylinders (and CEN/TC 23)

- EN 12245:2009+A1:2011 *(under development) Transportable gas cylinders - Fully wrapped composite cylinders*
- EN ISO 11114-4 2005 *Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement*
- ISO 9809-1:2010 Gas cylinders -- Refillable seamless steel gas cylinders -- Design, construction and testing
- ISO 1114-1 (work in progress) Transportable gas cylinders -- Compatibility of cylinder and valve materials with gas contents -- Part 4: Test methods for selecting steels resistant to hydrogen embrittlement
- ISO 11119-1 *2012 Gas cylinders — Refillable composite gas cylinders and tubes — Design, construction and testing — Part 1: Hoop wrapped fibre reinforced composite gas cylinders and tubes up to 450 l*
- ISO 11119-2 *2012/Amd 1:2014 Gas cylinders — Refillable composite gas cylinders and tubes — Design, construction and testing — Part 2: Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450 l with load-sharing metal liners*
- ISO 11119-3 G*as cylinders — Refillable composite gas cylinders and tubes — Design, construction and testing — Part 3: Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450L with non-load-sharing metallic or non-metallic liners*
- ISO 11119-4 (ISO/DIS 11119-4) *Gas cylinders -- Refillable composite gas cylinders -- Design, construction and testing -- Part 4: Fully wrapped fibre reinforced composite gas cylinders up to 150 l with load-sharing welded metallic liners*
- ISO 11439 *:2013 Gas cylinders — High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles*
- ISO 11515 *:2013 Gas cylinders — Refillable composite reinforced tubes of water capacity between 450 L and 3000 L — Design, construction and testing*
- ISO 17519 (*ISO/DIS 17519:2015) Gas cylinders -- Refillable permanently mounted composite tubes for transportation*

ISO/TC 158 Analysis of Gases

ISO/TC 193 Natural Gas

- EN ISO 6974:2012 Natural gas — Determination of composition and associated uncertainty by gas chromatography
- ISO/TR 16922:2013 Natural gas – Odorization
- EN ISO 13734*:2013- Natural gas - Organic components used as odorants - Requirements and test methods*

ISO/TC 197 Hydrogen Technologies

- ISO 13984:*1999 Liquid hydrogen -- Land vehicle fuelling system interface*
- ISO 13985:*2006 Liquid hydrogen -- Land vehicle fuel tanks*
- ISO 14687 (currently in preliminary stage, target date 2018) ISO 14687-2*:2012 Hydrogen fuel — Product specification — Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles*
- ISO/TS 15869:*2009 Gaseous hydrogen and hydrogen blends -- Land vehicle fuel tanks*
- ISO/TR 15916:2004 *(under revision) Basic considerations for the safety of hydrogen systems*
- ISO/TR 15916:*2004 Basic considerations for the safety of hydrogen systems*
- ISO 17268:*2012 (under revision in preparatory stage) Gaseous hydrogen land vehicle refuelling connection devices*
- ISO 19880-1 *(ISO/DTR 19880-1) Gaseous hydrogen -- Fueling stations -- Part 1: General requirements*
- ISO 19880-*2 (ISO/CD 19880-2) Gaseous hydrogen -- Fueling stations -- Part 2: Dispensers*
- ISO 19880-8
- ISO 19881 *(ISO/CD 19881) Gaseous Hydrogen -- Land Vehicle Fuel Tanks*
- ISO 19882 *(ISO/AWI 19882) Gaseous hydrogen -- Land vehicle fuel tanks -- Thermally activated pressure relief devices*
- ISO/TS 20100*:2008 Gaseous hydrogen -- Fuelling stations*
- ISO 22734-1*: 2008 Hydrogen generators using water electrolysis process — Part 1: Industrial and commercial applications*
- ISO 22734-2: *2011 Hydrogen generators using water electrolysis process — Part 2: Residential applications*
- ISO 26142:*2010 Hydrogen detection apparatus —Stationary applications*

ISO/PC 252 Natural gas fuelling stations for vehicles

IEC/TC 31 Equipment for explosive atmospheres

- EN IEC 60079-10-1:2015 *Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres*
- EN IEC 60079-29-1:2007 *Gas detectors – Performance requirements of detectors for flammable gases*

IEC/TC 105 on Fuel Cell Technologies

- IEC 62282-3: *2013 Fuel cell technologies – Part 3-201: Stationary fuel cell power systems – Performance test methods for small fuel cell power systems*

Other organizations

- ASME B31.8:2014 *Gas Transmission and Distribution Piping Systems*
- ASME B31.G:1991 Manual for determining the remaining strength of corroded pipelines
- DNV-RP-F101: 2015 Corroded pipelines
- SAE J2600:2012. Compressed Hydrogen Surface Vehicle Fueling Connection Devices
- SAE J2601:2014 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles

Mandates and regulation

- UN Model Regulations on the Transport of Dangerous Goods
- UNECE European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR)
- UNECE UN Vehicle Regulations R110 CNG and LNG vehicles
- UNECE UN Vehicle Regulations R134Hydrogen and Fuel Cell Vehicle Safety

- EU Directive 94/9/EC ATmosphères Explosibles (ATEX)
- EU Directive 2009/28/EC Renewable Energy Directive (RED)
- EU Directive 2009/30/EC Fuel Quality Directive (FQD)
- EU Directive 2009/142/EC the Gas Appliance Directive (GAD)
- EU Directive 2009/137/EC The Measuring Instruments Directive (MID)
- EU Directive 2010/35/EU Transportable Pressure Equipment Directive (TPED)
- EU Directive 2010/75/EU Industrial Emissions Directive (IED)
- EU Directive 2012/27/EU Energy Efficiency Directive (EED)
- EU Directive 2014/94/EU on the deployment of Alternative Fuels Infrastructure (AFID)
- EU Mandate M/400 to CEN "Gas quality" (SA/CEN/08/06.002)
- EU Mandate M/475 to CEN for standards for biomethane for use in transport and injection in natural gas pipelines
- EU Mandate M/533 COMMISSION IMPLEMENTING DECISION C(2015) 1330 of 12.3.2015 on a standardization request addressed to the European standardization organisations, in accordance with Regulation (EU) No 1025/2012 of the European Parliament and of the Council, to draft European standards for alternative fuels infrastructure

Germany

- BImSchG, BImSch Bundesimmisionsschutzgesetz (German law on biofuel quotas)
- BioKraftQuotenG Bundesimmisionschutzverordnung (German air pollution control laws)
- Energy Act (EnWG)

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Annex E: Abbreviations and Terms

Abbreviations

ATEX	ATmosphères EXplosibles
AFID	Alternative Fuels Infrastructure Directive
BOP	Balance Of Plant
CEN	Comité Européen de Normalisation
CENELEC	Comité Européen de Normalisation Électrotechnique
CEN/TC	Technical Committee within CEN
CEF	Connecting Europe Facility
CFD	Computational Fluid-Dynamics
CNG	Compressed Natural Gas
EC DG JRC	European Commission – Directorate General Joint Research Centre
EC DG ENER	European Commission - Directorate-General for Energy
EC DG GROW	European Commission – Directorate – General Internal Market, Industry, Entrepreneurship and SMEs
EC DG RTD	European Commission - Directorate-General for Research and Innovation
EED	The Energy Efficiency Directive
EDGaR	Energy Delta Gas Research
DSO-G	Distribution System Operation-Gas
FC	Fuel Cell
FCH JU	Fuel Cells and Hydrogen Joint Undertaking
FCH2 JU	Fuel Cells and Hydrogen 2 Joint Undertaking (Second generation)
FCEVs	Fuel Cell Electric vehicles
GAD	Gas Appliances Directive
GERG	Groupe Européen de recherches gazières (the european gas research group)
H2NG	Hydrogen and Natural Gas mixture
HCNG	Hydrogen Compressed Natural Gas. NOTE: The WG hydrogen discussed the use of this or other possible terms to describe hydrogen and natural gas mixtures. The term HCNG was not thought suitable by the group as CNG is related to mobility, and therefore decided to adopt the term H2NG.
H2	Hydrogen
HIPS-NET	Hydrogen in Pipeline System - NET
IEA	International Energy Agency
IED	Industrial Emissions Directive
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
OEMs	Original Equipment Manufacturers
NG	Natural Gas
MID	Measuring Instruments Directive
NSB	National Standards Body
PC	Project Committee
PEM	Proton-Exchange Membrane
PEMFC	Proton-Exchange Membrane Fuel Cell

PGC	Process Gas Chromatographer
PIMS	Pipeline Integrity Management System
PNR	Pre-Normative Research
PO	Programme Officer
PtG	Power-to-Gas
PtH	Power-to-Hydrogen
RDI	Research Development and Innovation
RCS	Regulation Codes and Standards
RED	Renewable Energy Directive
RES	Renewable Energy Sources
SAE	Society of Automotive Engineers
SoA	state-of-the-art
SOEL	Solid Oxide Electrolysers
SNG	Substitute Natural Gas[12]
SFEM/WG Hydrogen	Joint CEN/CENELEC Sector Forum Energy Management – Working Group Hydrogen
SFG	Sector Forum Gas
SFG-U	Sector Forum Gas – Utilisation
SMR	Steam Methane Reforming
TC	Technical Committee
TEN-E	trans-European Energy Networks
TF	Taskforce
TPED	Transportable Pressure Equipment Directive
TPRD	Thermally-activated Pressure Relief Devices
TSO-G	Transmission System Operator - Gas
UGS	Underground Gas Storage
WG	Work group

Terms

Gas system: Gas infrastructure, components and storage

Hydrogen system: Hydrogen infrastructure, components and storage

[12] SNG may also refer to Synthetic Natural Gas.

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