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Sector Forum Energy Management – Working Group Hydrogen

2018 update report

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Joint Research Centre

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Bernard Gindroz, Chair of Sector Forum Energy Management

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Executive Summary

Since 2015 and the publication of the Sector Forum Energy Management Working Group Hydrogen Report [1], major improvements have been made and new projects and relevant initiatives launched. This is not a revision but an update to the 2015 Report, as the content of the original report, its organization, its general strategic plan priorities remain fully valid and relevant for creating a market for hydrogen in the energy system.

Following the requirements of the stakeholders committed to the work, the 2015 report has made recommendations to :

- further support Research, Development & Innovation, (RDI);
- boost Pre-Normative Research (PNR);
- develop appropriate standardization work.

Thus, since 2016, several programs have been launched both at national and EU levels, such as through the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). Additional PNR work has been promoted in these programs and new standardization activities have been initiated, especially within the CEN/CENELEC Joint Technical Committee 6 (Hydrogen in Energy Systems) created in 2016.

Consistent with this increased interest, commitment and activity, it was agreed within the working group that an update to the 2015 report would be very useful for the hydrogen and natural gas communities, policy makers, research institutes, standardization bodies, NGOs and consumers.

The present update will apply to those sections of the existing 2015 report where relevant improvements and developments have been either achieved or initiated. In addition, some new challenges have been identified, and priorities adjusted according to the present situation.

This has been made possible thanks to the continuous effort of the experts engaged in the CEN/CENELEC SFEM Working Group Hydrogen, the work of the JRC and support by NEN.

The main objective of the SFEM/WG Hydrogen is to perform an analysis on the state-of-the-art technology and standardization, and a gap analysis on the main barriers including challenges and needs. A second objective is to establish contact with key stakeholders from the gas sector, electricity supply, mobility and the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) in order to perform the work in the most effective way and to have broad support from the stakeholders to identify the key challenges. Furthermore, the link to EC services (JRC, DG RTD, DG ENER and 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, FCH 2 JU, IEA Task 38, ISO, IEC). There is a regular exchange of information with the RCS strategy coordination group of the FCH JU.

There is also a link to the recently established SFEM WG on Energy Storage.

The scope of the working group covered the production of hydrogen through electrolysis and the transportation, distribution and usage of pure hydrogen or hydrogen in natural gas dominant mixtures (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, which is key to a successful market uptake.

KEY OUTCOMES of SFEM/WG Hydrogen activities in the period 2015-2018

The priority challenges identified in the 2015 report have been updated 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 near term key challenges, which are the outcome of a prioritisation exercise, are visualised in a roadmap (Figure 9).

For **electricity grid connection and electrolyser technologies** topics, the activities related to the provision of grid services by electrolysers are considered as having high priority. Partial load, intermittent operation and fast response will be some of the performance requirements for electrolysers when coupled to renewable energy sources or for provision of ancillary services to the electricity grid. The on-going PNR activities on test procedures should feed into the appropriate standardisation work. Control strategies for integrating electrolysers with intermittent renewable energies involves the mapping of operational boundaries, which need to be aligned with the requirements from grid operator side. There are on-going activities, but further work is likely to be required. Future development of electrolysers should focus on up-scaling the systems to the required multi-MW level.

Key challenges and topics for standardization related to the **admixture of hydrogen to natural gas** have been identified. To date there is still no understanding of an acceptable hydrogen concentration in the natural gas system at European level. It is clear that there are still a number of technical challenges, depending on the hydrogen concentration[1], as different components of the gas system or end-user appliances and processes will be affected. For hydrogen admixture levels above 2 vol%, the hydrogen concentration limit for steel tanks for CNG vehicles remains a barrier. In addition, further investigations are needed for the operation of gas turbines, in particular with variable natural gas – hydrogen mixtures, and the effect of hydrogen on industrial processes. To increase the concentration of hydrogen above 5 vol%, there are still knowledge gaps to be filled concerning the compatibility of hydrogen with porous rock underground gas storage. Ensuring safety and performance of compressor stations has not yet been tackled in an adequate manner. Gas sensors are a key enabling technology for the safe distribution and use of natural gas, therefore their performance in the presence of hydrogen should be ascertained. Although a lot of knowledge has been amassed on this topic, the effect of hydrogen on the large variety of materials in the gas grid and at end-use level warrants further attention. The performance of gas engines with variable hydrogen concentration has been identified as another potential area where more research is needed. In general the impact of time-varying H2NG blends on the performance of end user applications should be taken into account, together with the potential impacts on safety, efficiency, lifetime and environmental performance. In order to reduce system transition costs, the gas infrastructure, as well as any new end use appliances brought on the market, should be "hydrogen ready" for the targeted hydrogen concentrations. The additional costs that could arise from this measure should be distributed in a fair manner, with direct costs for customers remaining as low as possible. Regulatory bodies should be approached about this issue as soon as possible, as this would fall under their remit. Early standardisation can support the reduction of transition costs.

Pre normative research (PNR) and standardization challenges and needs related to the hydrogen system and the use of pure hydrogen have been analysed. For pure **hydrogen technologies**, the priority actions for PNR and standardization are targeted to facilitate the uptake of hydrogen in the transport market. The AFID provides a clear timeline regarding standardization, aimed at ensuring interoperability of connectors, filling protocols and hydrogen quality. Although many of the gaps

[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 hydrogen concentration

identified in 2015 have been filled, or are receiving a sufficient level of attention, some issues related to Hydrogen Refuelling Stations (HRS) remain. One of these topics is the research needed to develop refuelling protocols for medium/heavy duty vehicles. For the HRS it is still necessary to develop risk assessment methodologies for failure modes of hydrogen refuelling stations in order to understand the consequences for the on-board hydrogen storage system. For fuel cell development, the medium and heavy duty transport applications will need further PNR and standardisation work. For the use of hydrogen and fuel cells for maritime and train applications, both PNR and standards are needed. For maritime applications, projects are facing barriers due to a lack of standards. A recent study on the use of fuel cell in shipping [2] mentions a large number of gaps such as bunkering of liquid and gaseous hydrogen fuel, onboard storage systems and fuel cell systems.

The update report also identifies **cross-cutting items** such as hydrogen and H2NG safety, where some knowledge gaps remain. Already identified in 2015, at policy level, the Industrial Emission Directive regarding the production of hydrogen and the legal status of power-to-hydrogen plants still need further clarification. Sustainability aspects were highlighted by the WG experts, noting that more work is still needed on life cycle assessment of power-to-gas technologies. Furthermore, the recycling of critical raw materials such that they can be fully integrated into a circular economy approach, is an important aspect. A critical issue is the development of the appropriate guarantees of origin for green hydrogen, however, there are already ongoing activities at PNR and standardisation level with the target of EU wide deployment of the scheme.

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

Recommendations:

- Continuation of a platform for the consideration of hydrogen in the energy system in Europe. This platform should holistically cover research, pre-normative research and standardization for Power-to-Hydrogen and all related applications, including Power-to Hydrogen-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.

1. Introduction

A workshop in the frame of the JRC DG GROW initiative "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 and engage with the stakeholders involved. This report is the result of work performed in the Sector Forum Energy Management / Working Group Hydrogen, which was set-up as a 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. The WG performed an analysis of the state of the art of power-to-hydrogen and related technologies and of the main barriers. A report was published in 2015 [1]and this document provides an update of that report.

1.1 Background

The goal of a resilient Energy Union with ambitious climate policy at its core is to provide European consumers with secure, sustainable, competitive and affordable energy. This is the main aim of the Energy Union strategy. Achieving this goal requires a fundamental transformation of Europe's Energy System. In the recently adopted Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources (known as the recast Renewable Energy Directive, RED II [3]), states that Member States shall collectively ensure that the share of energy from renewable sources in the Union's gross final consumption of energy in 2030 is at least 32 %. The directive also calls for a 14% share of renewable fuel in the road and rail transport sector by 2030.

In a future, largely decarbonised, energy system there will be times when there is a lack of both solar and wind energy. An option to cover demand at these times is high-capacity, long-duration (seasonal) energy storage provided through / chemical energy storage. In particular, the hydrogen produced from renewable energy sources (power-to-hydrogen) can be utilized by multiple end users: industrial, residential, transportation, power generation. Hydrogen can also be admixed to natural gas, exploiting the huge storage capacity of the existing gas grid. In this manner, 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 Energy Union Package (2015) [4] already referred to energy storage as part of the strategy to diversify energy supply and to play a role in the development of a connected market. Energy storage is a key enabler to decarbonisation and addresses all 5 pillars of Energy Union[2]. Energy storage is often understood as providing services for the electrical grid. However, energy storage can also support the linking together of infrastructures within the energy system, i.e. the gas, electricity and heat grids. Storage can be used to connect sectors, in particular the residential, commercial, transport and industry sectors. This is referred to as sectoral integration, which is described in

[2] Securing energy supplies, expanding the internal energy market, increasing energy efficiency, reducing emissions and decarbonising the economy, supporting research and innovation.

SWD(2017)61 [5]. The conversion of renewable electricity to other energy carriers, such as heat or gas, can help to increase the share of renewable energy within the end-use applications in the residential, industry or transport sectors, where directly achieving decarbonisation is technologically more difficult and more expensive than for power generation.

The Accelerating Clean Energy Innovation communication [6] mentions that there is a need for new solutions for energy storage, and developing a broader portfolio of cost-effective renewable technologies. The Commission announced in this communication that more than €2 billion from the Horizon 2020 work programme for 2018-2020 are earmarked to support research and innovation projects in four priority areas, one of which is developing affordable and integrated energy storage solutions.

The RED II sees the need to support the integration of energy from renewable sources into the transmission and distribution gas grid and the use of energy storage systems for variable production of energy from renewable sources. The current framework for the integration of renewable electricity does yet not include provisions for the integration of gas from renewable sources into the gas grid. Member States are asked to assess the need to extend the existing gas network infrastructure to facilitate the integration of gas from renewable sources.

The decarbonisation of the heat and transport sectors can only be achieved through electrification and the use of hydrogen or low-carbon synthetic fuels. The conversion of excess electrical energy to hydrogen, to be subsequently used for mobility, is another means to increase flexibility and interconnection of the energy systems. In the RED II, renewable liquid and gaseous transport fuels of non-biological origin are recognised as being important in order to increase the share of renewable energy. However, to ensure that renewable fuels of non-biological origin contribute to greenhouse gas reduction, the electricity used for the fuel production should be of renewable origin. The Directive (EU) 2018/2001 (RED II) also states that EU member states need to extend existing Guarantees of Origin (GoOs) schemes to include renewable gases.

Other relevant policy documents are the Clean Energy for all Europeans package, especially the texts of new electricity market design proposals [7], i.e. Electricity Regulation and Electricity Directive, and the upcoming gas regulation.

During the meeting of the European Gas Regulatory Forum (Madrid Forum)[8] on October 2018, the role of gases for the decarbonisation of the European Energy Sector was discussed, and low-carbon gases, such as hydrogen, were recognized as playing a significant role in the energy transition. The Forum mentioned that this work will be facilitated by the use of a unified terminology for renewable and low-carbon gases and technologies, a point which had also been identified by the SFEM WG in the 2015 report. The Forum also stated that further assessment is needed on the suitability of the gas grid infrastructure and the end-user applications for injection of increasing volumes of hydrogen.

The work of the SFEM WG hydrogen can be regarded as an important step in initiating and moving forward for addressing these issues.

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 after 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. The central issue was that of integrating power-to-gas into the energy system. The hydrogen produced by 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. Furthermore, the use of pure hydrogen was addressed, with the focus placed on the most economically relevant markets.

The following Task Forces have been established within the WG:

o **Task Force 1/2** concerns the interaction of the **electricity grid** with an electrolyser. The Task Forces 1 (grid connection) and 2 (electrolysers) were merged in 2017 due to the strong links between the two. The electricity grid is, in the context of this report, considered as 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"). Challenges related to the **electrolyser** itself, as a means to convert and store the electricity received from the grid into hydrogen, are also covered.

o **Task Force 3** concerns the **natural gas system (gas infrastructure, components and storage)** into which 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[3]. Besides the natural gas grid and the equipment/components therein, the **end-users** connected to the natural gas grid are considered. These include end-users connected to the transmission grid, such as industrial end-users and large underground storage facilities as well as end-users connected to the distribution grid, like small scale stationary storage systems, refuelling stations, transportation (vehicles, trucks), residential appliances and dispatchable power equipment (re-electrification). Furthermore, the storage of the mixture of hydrogen and natural gas was covered under this Task Force.

o **Task Force 4** concerns the **hydrogen system (infrastructure, components and storage)** and **end-users** of pure hydrogen. Whilst individual countries in Europe are strongly considering using 100% hydrogen in the existing natural gas infrastructure, the task force has decided that this application falls outside of the scope of work for this revised report, as the near term deployment across Europe as a whole is considered more limited. However, means of distribution such as trailers and cylinder bundles are included within the scope of the WG, along with industrial end-users, large scale underground storage in salt caverns, small scale stationary storage systems, hydrogen refuelling

[3] Future work could also consider 100% hydrogen in transmission or distribution networks, apart from topics already covered in TF4.

stations, transportation (vehicles, trucks), residential appliances and dispatchable power (re-electrification, e.g. fuel cells).

o **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 aspects (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 cross-cutting 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'

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 the major needs and challenges of the main types of green hydrogen production as well as on methanation in section 4.6.

2.2 Objectives

The objectives and main expected outcomes of the SFEM WG Hydrogen are: an analysis of the state of the art of technology and standardization, and a gap analysis to identify the main barriers including challenges and needs. The WG should:

o Identify and prioritize the main research and PNR needs and standardization gaps;

o 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”, CEN/CLC/JTC 6 “Hydrogen in the energy system”) and international standardization activities (e.g. ISO/TC 197 "Hydrogen technologies", IEC/TC 105 "Fuel Cell technologies");

o Map relevant current research and PNR;

o Establish contact with key stakeholders from the gas sector, grids, electric supply, mobility; link with the Fuel Cells and Hydrogen Joint Undertaking (FCH 2 JU);

o Link to EC services, JRC, DG RTD, DG ENER, DG GROW, in order to cover regulatory and policy development and links to standardization policy

o 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 2 JU, IEA, ISO, IEC)

o Identify recommended actions, means and the timeline of implementation

o Disseminate results.

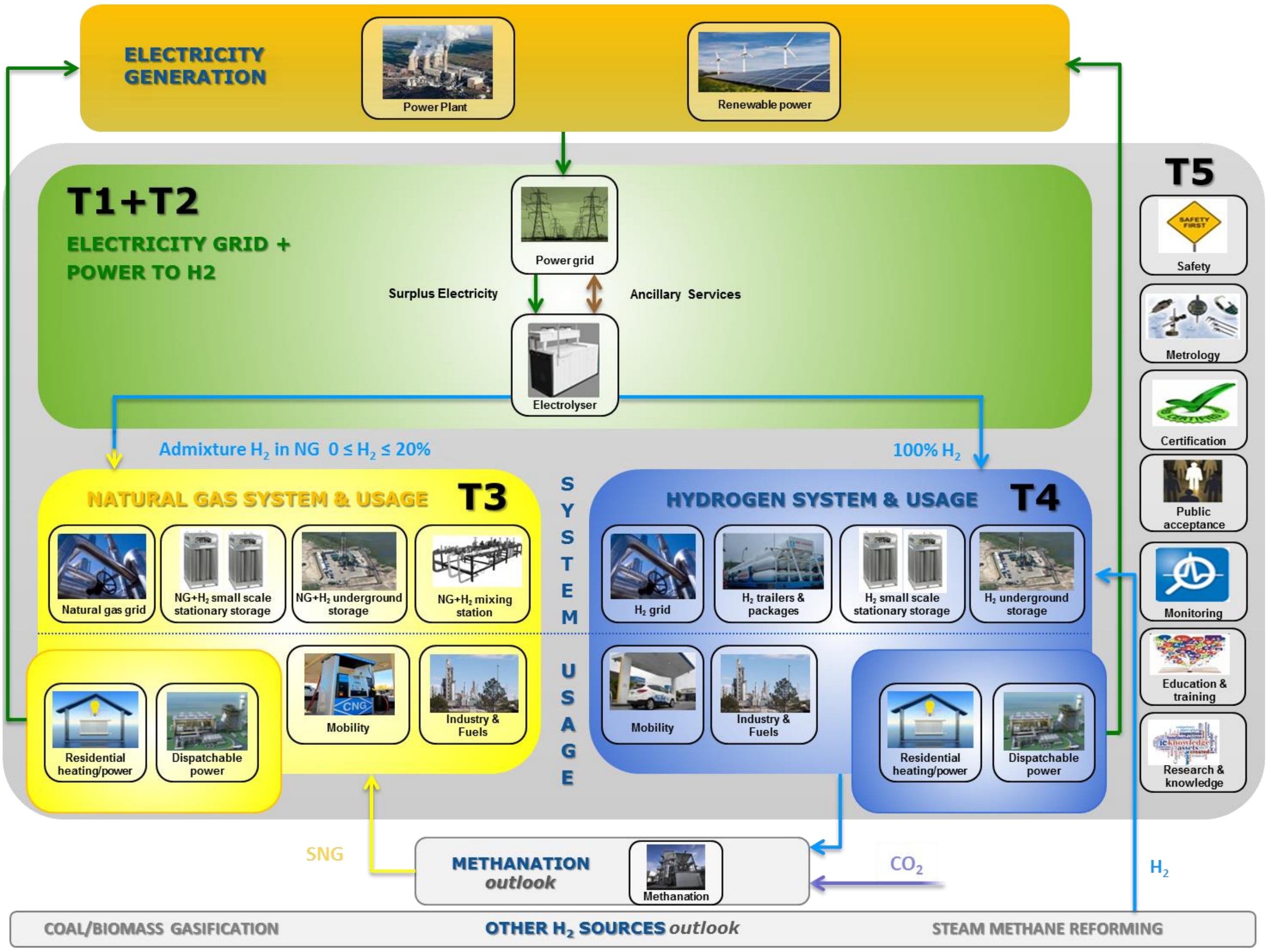

Figure 1 Scope of work of the CEN-CENELEC SFEM WG Hydrogen

3. Standardisation landscape/mapping

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 as comprehensive an overview of standardization committees as possible, an inventory of relevant technical committees at international (ISO and IEC) and European (CEN/CENELEC) levels 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, for example:

- CEN/CLC/JTC 6, which is the European standardization committee on hydrogen in energy systems and was established in 2016 following the recommendation in the SFEM/WG hydrogen report 2015;
- ISO/TC 197, which is the international standardization platform on hydrogen technologies
- IEC/TC 105, which is the international standardization platform on fuel cell technologies
- CEN/TC 234, which is the European standardization committee on natural gas infrastructure including 'non-conventional gases'; the EN 16726 " Gas infrastructure - Quality of gas - Group H" includes an informative annex on the admissible concentrations of hydrogen in natural gas systems.
- CEN/TC 268, which is the European standardization committee on cryogenic vessels and specific hydrogen technology applications. CEN/TC 268/WG 5 is the WG dealing with specific hydrogen technology applications with a clearly defined scope for the one-off preparation of standards for hydrogen technologies which meet the European mandate on the Directive for the deployment of alternative fuels infrastructure (AFID EU 2014/94, under the mandate M533).

CEN-CLC/JTC 6 *“Hydrogen in energy systems”*

One of the main recommendations of the SFEM/WG Hydrogen 2015 report to CEN and CENELEC Technical Boards was to support the establishment of a new CEN/TC for hydrogen in order to develop the necessary standards, since most of the topics identified by the working group fall within the scope of CEN. It was envisaged that this could become a joint CEN/CENELEC Technical Committee in the future. The proposal for a new field of technical activity was submitted by NEN. First a new CEN/TC was created: CEN/TC 446 on hydrogen with a provisional title and scope. The secretariat of CEN/TC 446 was allocated to NEN. CENELEC BT noted the CEN/BT Decision BT 11/2016 and agreed to the creation of a Joint CEN-CENELEC Technical Committee (JTC) on hydrogen under the Secretariat of NEN, with the aim of carrying out CEN/CENELEC harmonization work. This procedure is applicable where both CEN and CENELEC have some aspects in common. CEN and CENELEC BT asked the new JTC to submit its final title and scope for BT approval by the end of July

2016. CEN/TC 446 submitted its final title and scope, taking into consideration the comments expressed during the consultation as well as the discussions at the 79th BT meeting, for BT approval by the end of July 2016. The new Joint Technical Committee has thus been numbered CEN/CENELEC JTC 6 and named: “Hydrogen in energy systems” and was launched in 2016.

The rationale behind the establishment of the CEN-CLC/JTC 6 was that there is no European TC on hydrogen covering the wide range of topics identified by the SFEM WG Hydrogen. Standardization is the most appropriate way to tackle many of the critical issues identified. Any topic already covered by the scope of an existing TC will not be elaborated in CEN-CLC/JTC 6.

Current structure of the *CEN-CLC/JTC 6:*

- *WG 1: Terms and Definitions*
- *WG 2: Guarantee of Origin*
- *WG 3: Hydrogen safety*
- *Adhoc group: interface electrolyser to the e-grid*

CEN/TC 234 ‘*Gas Infrastructure’*

CEN/TC 234 has decided to take hydrogen in natural gas (H2NG) into account with the intention to extend the existing standards for hydrogen in gas infrastructure where necessary. A NWIP for a series of standards on injection/blending facilities for renewables (H2/Biomethane) is in balloting at the time being. Further needs for new standards, e.g. pressure control, has still to be identified. It has been decided that a Technical Report (TR) '*Consequences of hydrogen in the natural gas infrastructure*' will be developed. The scope of the TR as proposed is: ‘*There is extensive research and impact assessment work is done and/or in progress, concerning the use of hydrogen in various percentages mixed with natural gas up to 100 %. These impact studies are focusing on the use of existing gas networks through to dedicated gas networks for hydrogen. These studies also embrace the associated fittings and other components for all of the technologies within the gas supply chain, particularly with regard to the introduction of hydrogen in its various percentages. This CEN technical report, written in preparation of future standardization, provides guidance on the impacts of the injection of H2 into the gas infrastructure in accordance with decision CEN/TC 234 09/2017.*

This report examines the effects on each part of the gas infrastructure in the scope of the CEN/TC 234 Working Groups on the basis of available studies, reports and research. Due to several limitations at different hydrogen concentrations, the impacts are specified.

The information from this report is intended to define the CEN/TC 234 work program for the coverage of H2NG.

The TR will addionally provide justifications for pre-normative research.

The CEN/TC 234 WGs have been asked to examine concentrations and determine the relevant standardization aspects for the existing gas infrastructure. The table below, based on available SFEM WG H2 TF 3 findings, will be used as a basis by the TC 234 WGs.

Table 1 - CEN/TC 234 H2NG priority topics related to the concentrations (<2; <5, <10 vol-%H2)

Summary of identified actions H_2 in the gas grid		
2 vol.-% H2	**5 vol.-% H2**	**10 vol.-% H2**
Gas turbines (e.g. performance/durability/legal iss.)	Same as for 2 vol.-% H2 plus:	Same as for 2 and 5vol.-% H2 plus:
Underground storages (porous) (e.g. bacteria growth)	**CNG on board tanks** Fatigue induced failure /vehicle regulation and standardisation	**Compressors** (e.g. performance)
Gas as feedstock (e.g. effect on processes regarding performance, efficiency)		**Underground storages (caverns)** Installations and bacteria growth in underground cavern storages
		Safety and grid integrity
		Industrial/residential burners and engines (e.g. performance)

CEN/TC 268/WG 5 – '*Specific hydrogen technologies applications*'

A Directive on the deployment of alternative fuel infrastructure was adopted in 2014. The main alternative fuel options are electricity, hydrogen, biofuels and natural gas. This Directive aims to ensure the build-up of alternative fuel infrastructure and the implementation of common technical specifications for this infrastructure in the European Union. International standards were available and referenced in the Directive 2014/98/EU as an intermediate solution. CEN/TC 268 (WG 5) is in charge of the development of European standards supporting this Directive for hydrogen technologies. A mentioned above, the preparation of standards for hydrogen technologies has been requested under the mandate M533.

ISO/TC 197 '*Hydrogen Technologies*'

The scope of ISO/TC 197 is standardization in the field of systems and devices for the production, storage, transport, measurement and use of hydrogen. The activities of ISO/TC 197 are therefore an relevant input for the SFEM/WG Hydrogen TF 4 activities. ISO/TC 197 collaborates with SFEM/WG Hydrogen on the topics:

Hydrogen:

- Follow up on EU Directive AFI standards related to hydrogen
- Other hydrogen technologies within the current TC197 program, for example:
  - Electrolysers
  - Ground storage
  - Fuelling family standards
- Other international / EU activities involving strategic coordination of RCS development and implementation

Umbrella Agreement:

- Establish standardization framework under Vienna Agreement

CEN-CENELEC/JTC 6 will be the mirror committee to ISO/TC 197 *'Hydrogen technologies'* for those topics not yet covered by another CEN/TC, in particular the work covered by Standardisation Request M/533 on hydrogen vehicle refuelling stations and associated equipment and procedures. These topics are being dealt with by CEN/TC 268/WG 5.

IEC/TC 105 '*Fuel Cell Technologies*'

The scope of IEC/TC 105 is standardization in the field of systems and devices for use of hydrogen with fuel cells. The activities of IEC/TC 105 are therefore a relevant input for the SFEM/WG Hydrogen TF 4 activities. IEC/TC 105 collaborates with SFEM/WG Hydrogen on the topics:

- Fuel cell technologies within the current TC105 program, for example:
  - Reversible fuel cells
  - Portable fuel cells
  - Stationary fuel cells
  - Fuel cells for non road applications (e.g. industrial trucks)

Other standardization developments

Apart from 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 complying with the ATEX regulation, safety and detection systems will need to be (re)considered.

The EC Annual Work Programme 2017 includes the **Standardization Request on Hydrogen/ Action 5.**

In 2017 the European Commission included a Standardization Request in the Annual Union Work Program on standardization regarding Hydrogen. For more information, see *action 5* - http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016SC0185. In reply to this request, the CEN/CENELEC Management Centre (CCMC) has set up a “Standardization Request Ad-hoc Group” (SRAHG). The role of this SRAHG is the coordination of CEN, CLC and partners inputs during SR drafting. Participants are CEN BT members, concerned TCs, Sector Fora representatives and ISO/IEC representatives. The SRAHG will advise the BT(s) on the acceptance, or not, of the SR. The current status is that the Standardization Request is being drafted.

Madrid Forum

The Madrid Forum was set up to discuss issues regarding the creation of the internal gas market. The thirty-first meeting of the EUROPEAN GAS REGULATORY FORUM took place 16-17 October 2018. An key topic was the discussion on the role of gases in the decarbonisation of the EU's energy sector. The Forum agrees on "no regret building blocks" supporting the low-carbon energy transition, which represent the priorities for upcoming work.

Some important statements in the conclusions [8] – in relation to research, pre-normative research and standardization - were:

- Renewable and low-carbon gases (in particular biogas, biomethane and hydrogen) should play a significant and growing role in the energy transition. The potential of their domestic production, cross-border trade, import and integration will need to be further assessed.
- To facilitate this work, the use of a unified terminology for renewable and low-carbon gases and technologies is necessary.
- To enable the successful integration of renewable gases, support for technology development, innovation and deployment also at industrial scale is necessary. In addition, further analysis of the economic conditions under which the renewable gases are to be developed on the market is equally important.
- For all work areas and assessments, the execution of pilot and demonstration projects is essential and their results as well as lessons learnt from the electricity and other sectors should be taken into account.
- To facilitate the energy transition and the integration of new sources of gases (including hydrogen), the regulatory framework should be flexible as far as possible and be adjusted with the aim of removing potential regulatory barriers and of providing market-based solutions. At the same time, the full and correct implementation of the gas Network Codes in all Member States remains a priority.
- To support the (cross-border) trade of renewable gases, a comprehensive system of European wide certification or guarantees of origin should be developed in the context of the revised Renewable Energy Directive. A similar system should be envisaged for low-carbon gases.
- Sector coupling (i.e. closely linking the electricity and gas sectors, both in terms of their markets and infrastructure) benefits both gas and electricity systems. Therefore, it should be assessed how the regulatory framework could reflect the overall system value including also energy storage and LNG.
- Changes to the gas quality range are expected due to the injection of growing volumes of biomethane, synthetic methane and hydrogen. Therefore, renewable and low-carbon gases should be included in the European standard for H-gas[4] quality. The Forum invites CEN to continue its work in support of the use of renewables in gas infrastructure and gas applications and to report back to the next Madrid Forum.
- Further assessment is needed to establish the suitability of the gas grids, storage facilities and end-user appliances for the injection of an increasing volume of hydrogen, including an estimate of the necessary refurbishment costs.

[4] High-calorific natural gas

- Difficulties of injecting fuel gases of increasingly different qualities into the gas network need to be assessed with the aim to overcome them. First experiences can provide valuable input and sharing of best practices is essential. Digitalisation could be part of the solution.

Standardization overview

In Figure 2, the relevant standardization activities are grouped according to the main focus and depicted within the TF schematic. Although a thorough effort has been made, it cannot be said with full certainty that all standardization activities are included. With this in mind, a standardization overview for P2H has been created (see Figure 2). The scope for the overview 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. Please note that additional information is included in Figure 2. The black bold font indicates the Technical Committees (TCs) working on standards covering both technical and cross-cutting issues (mainly related to safety, measurement and testing). The black italic font indicates TCs which are working on standards related to purely technical aspects. Finally the red font has been used to identify the TCs that are working on both H2 and H2NG.

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

- CEN/CLC/JTC 6 on Hydrogen in Energy Systems
- CEN/TC 234 on Gas Infrastructure
- CEN/TC 268 on Cryogenic Vessels and Hydrogen Technologies
- ISO/TC 197 on Hydrogen Technologies
- 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 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

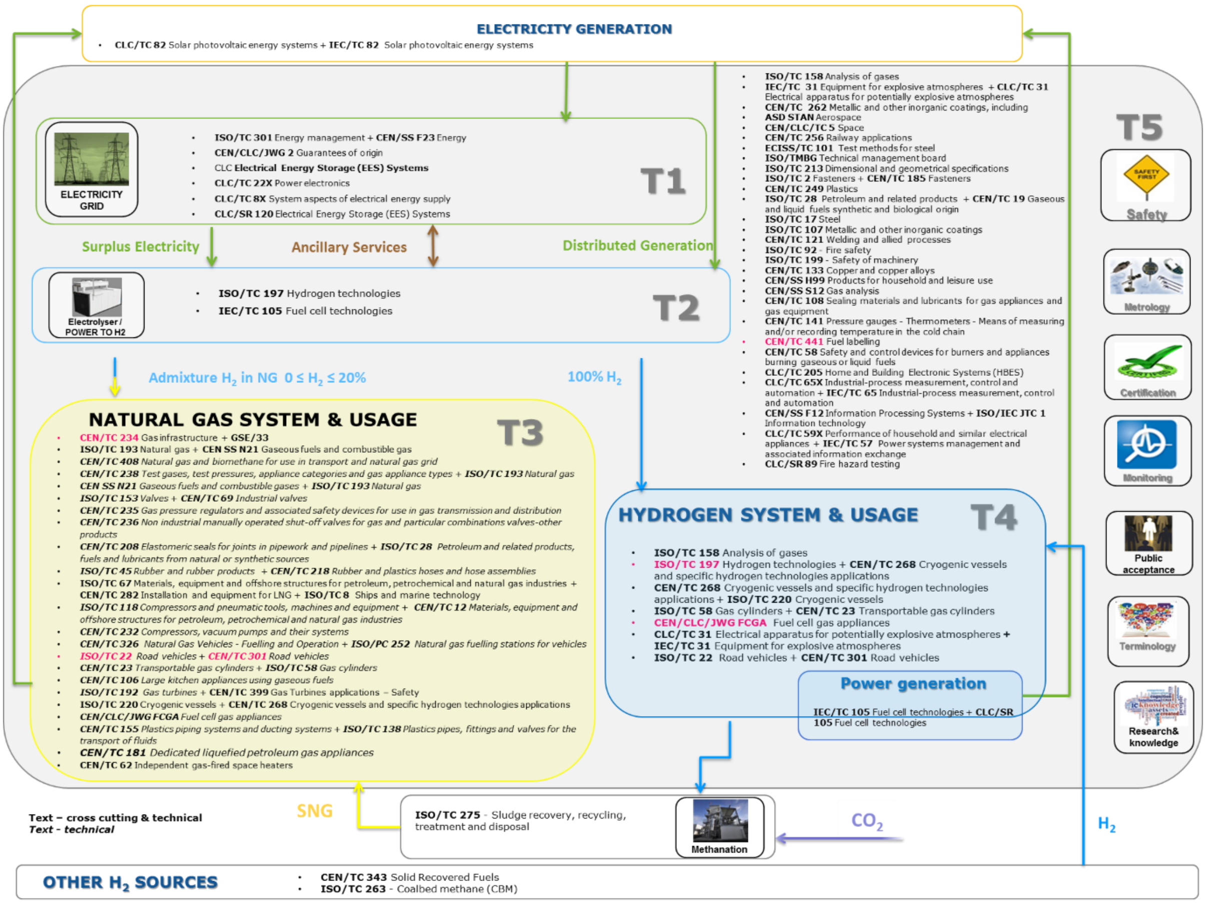

Figure 2 The mapping of the cooperation between the ISO/IEC and CEN/CLC Technical Committees in the scope of work of the CEN-CENELEC SFEM WG Hydrogen

4. Pre-normative research and standardization challenges

In the timeperiod 2016-2018, each Task Force regularly provided updates on the relevant on-going activities related to the pre-normative research and standardization challenges identified in the 2015 report. In addition, the Task Force members listed any new challenges and also reviewed the prioritisation. This chapter describes per Task Force the standardizations actions, pre-normative research actions and gives a roadmap.

4.1 Stakeholder survey

Input from stakeholders from the natural gas sector, not formally part of the WG, were collected through a survey.

An ongoing study under the CEN SFGas relates to mandate M/400 regarding gas quality. This mandate was approved in 2008 and requested the development of a standard for gas quality parameters for H-gas (incl. the Wobbe index). The pre-normative study was launched in 2016. The working group is composed of CEN Members (NSB), experts from related CEN/TCs and (European) organisations/experts of related sectors such as gas producers (natural gas, biomethane, other renewables), shippers/traders, operators (grid, storage and LNG), appliance manufacturers (domestic/industrial) and EU bodies (EC, ACER, ENTSOG). The delegates have been nominated by their national standardisation bodies or industry associations.

As the admixture of hydrogen has an impact on gas quality, in 2018, the members of the SF Gas Study on natural gas quality were contacted by the SFGas secretariat on behalf of the WG and asked to provide information on research and standardisation challenges related to hydrogen. The participants to the survey were from the TSO/DSO perspective: ENTSOG, Open Grid Europe, Enagas,S.A., GRTgaz, Rahain Terega; the associations Figawa, GRZI e.V., VHB e.V., farecogaz e.V., EURO-air e.V., Afecor; and from industry OCI Nitrogen. Close to 50 challenges were identified through the survey. From the TSO perspective, the need for a roadmap related to the admixture of hydrogen to natural gas was regarded as having high priority, together with an analysis of the flexibility of the gas network to accommodate H2NG and the effects of hydrogen on compressibility and energy calculations for billing. Gas appliance manufacturers mentioned change of flame velocity, material specifications for metal and rubber/synthetic materials as well as performance of metering and pressure control as challenges needing further investigation. From the industry perspective, the effect of variations in hydrogen concentration on the use of natural gas as feedstock are a concern. The combustion of natural gas with different or changing calorific value will affect the mass energy balance of furnaces. Appropriate control systems and the impact on flue gas composition should be investigated. Other challenges mentioned were hydrogen embrittlement , and the effect of hydrogen on underground storage facilities and gas turbines. The answers provided are considered within the sections on the various TF's, in particular in TF3.

4.2 Task Force 1/2 – Electricity Grid Connection and Electrolysers

In the table below an update of the status of the PNR and standardisation actions within the scope of TF 1/2, as defined in the SFEM WG Hydrogen report of 2015, is described. It identifies the remaining gaps as well as a timeline. The impact, urgency, time for finalisation and timing of PNR and standardisation activities are proposed.

There will be a wide range of energy storage applications at all levels of the electricity system ranging from energy generation, transmission, and distribution down to the customer or load site.

Thus, new opportunities to use energy storage for grid stability services have to be considered. The response time of some energy storage systems is very fast, which makes these extremely suitable for the frequency containment reserve of balancing services and voltage control services, as both require a rapid response time. Electrolysers can meet the requirements for providing these ancillary services.

The production of hydrogen from surplus electricity, if re-converted to electricity5, can avoid the installation of fossil/renewable generation capacity and replace electricity network expansion.

However, hydrogen produced with the help of an electrolysis process - as a major contributor to balancing the electricity grid - requires technical issues to be considered, in addition to safety requirements considered by Task Force 5 in this report. Task Force 1/2 of the CEN/CENELEC SFEM WG Hydrogen identified several key issues where pre-normative research and standardization development could provide solutions:

- Grid connection requirements;
- Grid service requirements (measurement methods and test procedures for electrolyser performance);
- Control strategies for integrating electrolysers with intermittent renewable energies (mapping operational boundaries and management systems).

In terms of the electricity grid, an electrolyser can be classified as any other customer using the grid to consume electricity. There are technical requirements that electrolysers need to fulfil for grid connection. It depends on the system operator (TSO or DSO, voltage level) which technical requirements apply, to limit grid disturbance. Multi megawatt electrolysers are most likely to be connected to the medium voltage level or directly to the high voltage/medium voltage substations. According to the research performed in the project ElyIntegration, technical requirements concerning the restriction of grid disturbances are not expected to be critical [9].

Electrical grid operators require grid services to maintain a secure, reliable and balanced electrical power system. These grid services keep the balance between supply and demand, or help the system recover after a power system event. The ancillary services are expected to see an increase in demand with the increasing penetration of intermittent renewables and distributed energy

[5] Although a low round-trip efficiency of around 35% should be considered.

resources. Electrolysers can offer a variety of electrical grid services, but some challenges still need to be addressed to fully realize their potential. There are many past and ongoing activities to demonstrate the ability of electrolysers to provide grids services in the EU (examples are the projects REFHYNE, H2Future, Energiepark Mainz and Demo4Grid, among many others) while projects like Qualygrids are investigating electrolyser testing protocols for the provision of grid services, in view of standardisation of these protocols. A similar effort is undertaken by the JRC at cell and stack level for low temperature electrolysis.

The challenges are at technical and regulatory level, as outlined below.

4.2.1 Grid connection and grid services

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
GRID CONNECTION							
*** 2015 PNR action: <u>Interconnection of electrolyser to the electricity grid</u>** Challenges related to interconnection, including physical connection and communication between electrolyser and grid control system	*Projects ELYIntegration, Demo4Grid, HyBalance, H2Future ElyIntegration and QualyGridS performed a SoA mapping exercise and have identified the requirements.	No major challenges related to grid disturbance expected according to ElyIntegration research. Other challenges may arise, depending on the outcome of the ongoing pilot projects.	None	To be determined as a result of the ongoing PNR activities	PNR: current – 2022 (depending on project) Standardisation: (see below)	***PNR:*** ***TBC on completion of existing projects*** ***Standardisation:*** ***TBC on completion of existing projects***	Electrolyser manufacturers, e-DSO, e-TSO, Standardization bodies, industrial and research organisations
GRID SERVICES							
***2015 PNR action:** Development of measurement methods and test procedures for electrolyser performance dedicated to the needs of ancillary service requirements	* QualyGridS Harmonisation of pre-qualification tests. Lack of harmonised testing procedures (addressed by QualyGridS and other projects, but gaps may remain,) *H2ME2 has published testing protocols for balancing products * see below for general testing protocol topics	Depends on project outcomes. Investigation into ability for electrolysers with 4-quadrature dynamic VAR compensation for power factor control in distribution networks, not transmission networks. Standardisation: Qualygrids aims to develop input for a standard on testing protocols	**None**	To be determined as a result of the ongoing or future PNR activities	PNR: current – 2019 (depending on project)	***PNR:*** ***TBC on completion of existing projects*** ***Standardisation:*** ***TBC on completion of existing projects***	Electrolyser manufacturers, industrial and research organisations
*** 2018 PNR action:** Frequency, voltage control and other grid service requirements of grid operators – technical oriented	*ElyIntegration, QualyGridS, Demo4Grid and other projects QualyGridS project aims to establish standardized testing protocols for WEs to perform electrical grid services	Recommendation to map needs from TSO-DSO about future trends of ancillary services (i.e. in bid blocks, quality remuneration, service stacking) For the provision of control reserve as a transmission grid service, technical requirements such as ramping abilities have to be considered for assessing the technical suitability of electrolysers.	**None**	To be determined as a result of the ongoing and future PNR activities	PNR: current – 2022 (depending on project) Standardisation: N/A	***PNR:*** ***TBC on completion of existing projects*** ***Standardisation:*** ***TBC on completion of existing projects***	Electrolysers manufacturers, e-DSO, e-TSO, Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
*** 2018 PNR action:** Harmonisation of requirements National regulations have different requirements for grid services, which is a barrier for the access to markets.	*ElyIntegration, QualyGridS, Demo4Grid and other projects Mapping and clarification of national requirements Has been carried out for some member states by ElyIntegration and other projects overview of all EU member states not yet provided. Not all member states accept demand response in reserve markets	Due to the structural differences among countries, the implementation of frequency control and the corresponding requirements can vary from country to country.[10]	**None**	To be determined as a result of the ongoing PNR activities	PNR: current – 2022 (depending on project) Standardisation: N/A	***PNR:*** ***TBC on completion of existing projects*** ***Standardisation:*** ***TBC on completion of existing projects***	
CONTROL STRATEGIES							
***2018 PNR action:** Control strategies for integrating electrolysers with intermittent renewable energies (mapping operational boundaries)	Electrolyser demonstration projects such as DEMO4GRID, HYBALANCE and others.					*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2016-2020*** *Timing Standardisation:* ***2020-2023***	Electrolysers manufacturers, e-DSO, e-TSO, Standardization bodies, industrial and research organisations

4.2.2 Electrolyser performance

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
Electrolyser Operation							
*** 2015 PNR action:** **Key Performance Indicators** (including definition of boundaries)* Status 2018: PNR gap considered sufficiently addressed.	Terminology LT electrolysis report to be published 2019.	Mapping relevant issues and requirements from the e-grid. Terminology HT electrolysis work ongoing.	Possibility for continuation of ISO 22734 into performance requirements, e.g. as second part, discussed within ISO TC 197 plenary 2018, however no clear need for a standard to be developed identified at this stage.	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.		***PNR:*** *Impact:* ***Low*** *Urgency:* ***Start in around 5 years*** *Time for finalisation:* ***TBC on completion of existing projects*** *Timing:* ***unknown*** ***Standardisation:*** *Impact:* ***Medium*** *Urgency:* ***TBC on completion of existing projects*** *Time for finalisation:* ***TBC on completion of existing projects*** *Timing:* ***unknown***	e-DSO, e-TSO, Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
***2018 PNR action:** Development of measurement methods and test procedures for electrolyser performance – single cells, stacks and systems testing protocols	* JRC is coordinating harmonisation efforts on LTWE and HTE testing protocols. With support and feedback from partners of relevant EL FCH 2 JU-funded projects, JRC currently drafts [LTWE testing protocols] for single cells and short stacks including stressor tests, operating condition and load cycles as well as for system testing for grid connected and off-grid applications. JRC document ISBN 978-92-79-90388-5 on Terminology for low-temp electrolysis published in 2018. This activity will expand to HTE terminology and testing protocols in the course of 2019.	Depends on outcomes. HTE work is commencing in 2019.	None	None	PNR: expected to be finalised in 2019. N/A	***PNR:*** ***TBC on completion of existing work*** ***Standardisation:*** ***TBC on completion of existing projects***	Electrolysers manufacturers, industrial and research organisations
*** 2015 PNR action:** **<u>Hydrogen quality assurance</u>**	Covered in TF4 in the context of HRS. No identified PNR / standardisation requirements for non-HRS applications at this time.						
*** 2015 PNR action:** **<u>Hydrogen quality</u>**	Covered in TF4 in the context of HRS and hydrogen vehicles. Placeholder in ISO 14687 (Grades A-C & E) but no identified PNR / standardisation requirements for non-HRS applications at this time.						

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
*** 2015 PNR action:** **<u>Safety</u>** **<u>Note: See also:</u>** 2018 PNR action: Upscaling system to MW-range Task Force 5: H2 Safety	Part of ongoing R&D / deployment projects for electrolysers, for example RefHyne, HyBalance, Demo4grid, H2Future,…	Testing methodologies and procedures for safety requirements are developed for single cells, stack modules and systems. Validation of pressure resistant membranes and electrodes.	ISO 22734 in the process of being revised to address issues with implementation of this standard for larger electrolyser systems than originally intended when ISO 22734-1: 2008 was written.	To be identified following completion of the ISO 22734 review, and application to electrolysers being manufactured and used according to the revised standard. General guidance on best practice for hydrogen systems in confined spaces, for example, as an additional part to ISO 15916, would facilitate best practice being applied to electrolysers built into enclosures / buildings.	PNR: current – 2022 (depending on project) Standardisation: current – 2019/2020	***PNR:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025*** ***Standardisation:*** *Impact:* ***Unknown*** *Urgency:* ***TBC on completion of existing projects*** *Time for finalisation:* ***TBC on completion of existing projects*** *Timing:* ***2020+***	
*** 2015 PNR action:** **<u>Oxygen quality</u>** ***2018 PNR action:** **<u>Oxygen production and storage</u>**	Oxygen quality seems to be more of a standardisation than PNR topic. No currently ongoing activities	Efficient storage of the oxygen produced by the electrolyzer. The safety of the system including oxygen production and storage must be ensured as well.	ISO 22734 is being updated, but not with any additional detail on how to generate and store oxygen, nor a specification for the quality of oxygen needed if it is to be used as a co-product.	ISO 22734 may need to be updated to add more detail concerning the production of oxygen. The quality of the oxygen produced by electrolysis must be ensured with a suitable standard. The safety of the system including oxygen must be ensured as well.	Nothing currently	***PNR:*** *Impact:* ***Low*** *Urgency:* ***Reconsider within 5 years*** *Time for finalisation:* ***unknown*** *Timing:* ***unknown*** ***Standardisation:*** *Impact:* ***Medium*** *Urgency:* ***Reconsider within 5 years*** *Time for finalisation:* ***unknown*** *Timing:* ***unknown***	Standardization bodies, industrial and research organizations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
Electrolyser R&D							
*** 2018 PNR action:** **Upscaling system to MW (10-1000)-range**	Ongoing projects: RefHyne, H2Future, HyBalance, Demo4Grid and others.	Manufacturing and safety aspects to be considered. The development of manufacturing techniques and production chains with increased automation needed and in-line quality control.	Covered by ISO 22734 – in process of revision	ISO 22734 may need to be updated to add more detail concerning larger scale electrolysers. To be established following publication of the revised ISO 22734, and the completion of any future projects.	PNR: current – 2022 (depending on project) Standardisation: N/A	***PNR:*** *Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Within 5 years*** *Timing:* ***current-2023*** ***Standardisation:*** *Impact:* ***Unknown*** *Urgency:* ***TBC on completion of existing projects*** *Time for finalisation:* ***TBC on completion of existing projects*** *Timing:* ***2021+***	
*** 2018 PNR action:** **High pressure electrolysis**	Ongoing projects: FCH JU Project REFHYNE is developing a 10MW PEM electrolyser operating at 30bar. Projects NEPTUNE and PRETZEL are developing 100bar electrolysers are 10s of kW scale.	Understanding of limitations (if any) on electrolysis at sufficiently high pressures for injection directly into the transmission network, or to avoid/reduce the need for additional compression in other applications (e.g. HRS)	Covered by ISO 22734 – in process of revision	ISO 22734 may need to be updated to add more detail concerning higher pressure electrolysers. To be established following publication of the revised ISO 22734, and the completion of any future projects.	Nothing currently	***PNR:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025*** ***Standardisation:*** ***TBC on completion of future projects***	Industrial and research organizations, Standardization bodies if necessary

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
*** 2018 PNR action:** **Cost reduction (e.g. Reduction of precious metal content)**	Several FCH JU projects are addressing the reduction of PGM, both for PEM and alkaline electrolysers. Examples are the projects MEGASTACK, HPEM2GAS and PRETZEL. In terms of cost reduction, the projects NEXPEL, NOVEL and MEGASTACK focussed on BPP[6].	Development of advanced, durable electrocatalysts with a low loading of precious metals.Development of cheaper stacks components such as BPP, with higherpower and energy densities. More work is needed to fully reach the target of high performance and low cost.	None	Not applicable, although performance of electrolysers could be covered in a possible second part of ISO 22734 in the future	PNR: current – 2023 (depending on project) Standardisation: N/A	***PNR:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025*** ***Standardisation:*** ***TBC on completion of future projects***	Industrial and research organizations
*** 2018 PNR action:** **Degradation (e.g. Development of new materials / Improvement of operation strategies / development of diagnostic tools)**	Several FCH JU projects are partially addressing the issue of degradation, in particular for dynamic operation.	Determination of degradation rate as a function of op. conditions. More research is needed to reach sufficient durability.	None	Not applicable, although performance of electrolysers could be covered in a second part of ISO 22734 in the future	PNR: current – 2023 (depending on project) Standardisation: N/A	***PNR:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025*** ***Standardisation:*** ***TBC on completion of future projects***	Industrial and research organizations

[6] Bi-polar Plate

4.2.3 Additional Electricity Grid and Electrolyser PNR and standardisation actions since the 2015 report

Many of the PNR and R&D activities proposed in the 2015 report are covered by on-going research activities, typically as part of FCH 2 JU funded projects. In terms of new activities, the harmonisation of national requirements for the provision of grid services by electrolysers has been identified, as well as the development of the appropriate control strategies. For electrolysers to play a major role for the integration of renewable energy sources, an upscaling to multi-MW scale is needed, which requires the development of manufacturing. The degradation of electrolysers when operating under dynamic conditions needs further research effort. Cost reduction, in particular through lower use of PGM, was also mentioned as a challenge.

4.2.4 Roadmap and conclusions for Electricity Grid and Electrolyser

As stated in the 2015 report, PNR and standardization actions have been identified for the appropriate connection of electrolysers onto the e-grid, as well as their efficient operation. However, following the strategic work conducted within CEN/CENELEC SFEM WG Hydrogen and JRC Petten, as well as the first development of the CEN/CENELEC JTC6 "hydrogen in energy systems", new issues have been identified which need to be addressed in order to boost the hydrogen market, both at P2G level and for pure hydrogen applications.

Several electrolyser research and demonstration projects have been launched in the framework of the H2020 program, the FCH 2 JU program, and through work undertaken at JRC and performed by other stakeholders. The results of these projects are already feeding CEN/CENELEC activities thanks to a wide stakeholder participation. However, in addition to PNR and Standardization recommended actions, several key R&D issues still need to be addressed, especially considering:

- Upscaling systems to the MW-range (including manufacturing aspects);
- Cost reduction (e.g. reduction of precious metal content, increased power and energy densities, simplified balance of plant components);
- Degradation (e.g. development of new materials/improvement of operation strategies/development of diagnostics tools);

There are on-going activities supporting the potential role of electrolysers in ancillary service market market applications through the development of standardised testing protocols. JRC is coordinating harmonisation efforts on LTWE and HTE testing protocols, with support and feedback from partners of relevant FCH 2 JU-funded projects. Other important topics are related to the development of systems able to efficiently store both hydrogen and oxygen. If oxygen is stored and not vented, it becomes feasible to generate additional revenue by providing oxygen for industrial use Use of both the hydrogen and oxygen from an electrolyser in an oxygen-enhanced biomass gacifier can double the yield of biofuel produced for a given amount of biomass feedstock. In addition, PNR actions are recommended for the development of advanced electrocatalysts for electrolyzers with a low loading of platinum-group metals, taking advantage on the recent progresses in materials science and membrane science. This PNR action on electrocatalysts would reduce costs and be in line with European goals on the use of critical raw materials.

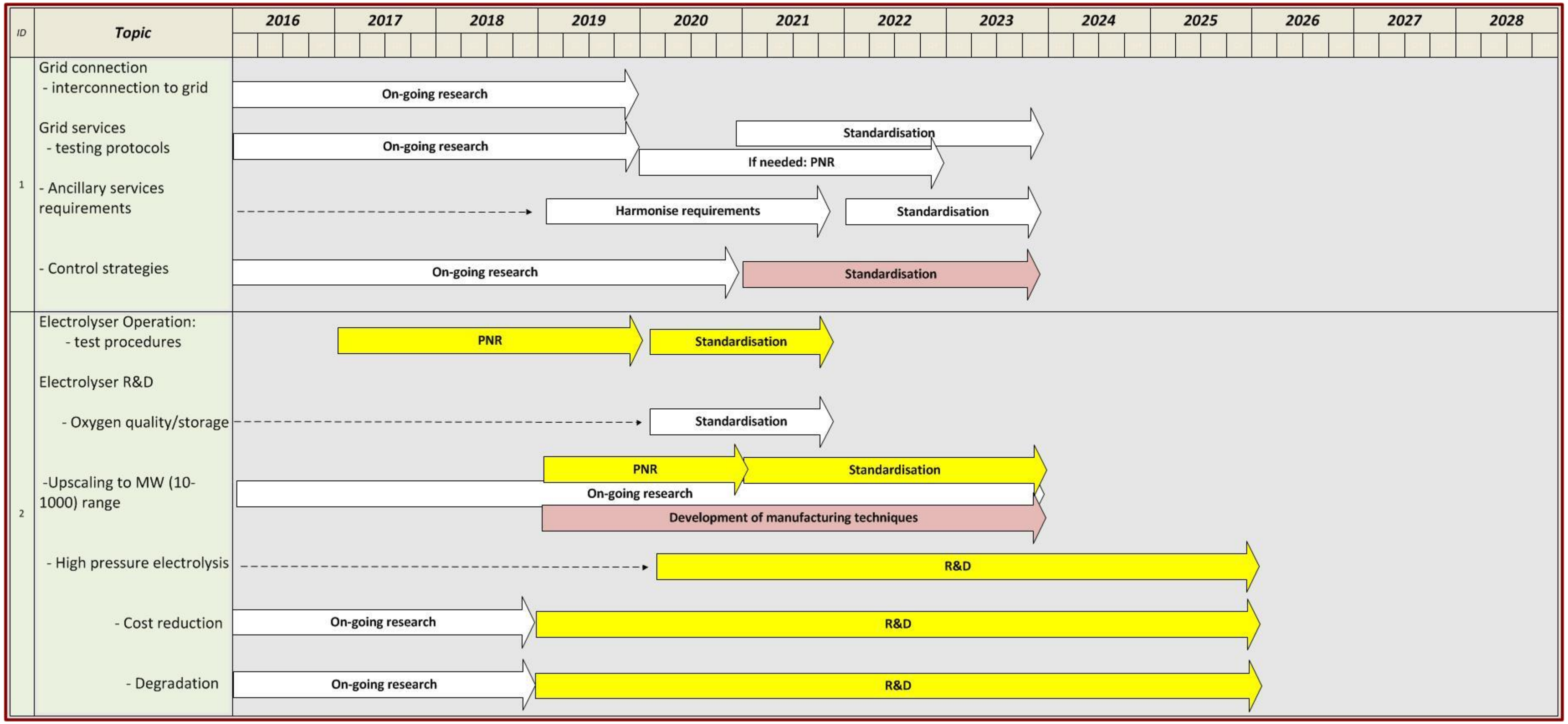

Figure 3 PNR and Standardisation actions for electrolysers and grid connection. Yellow marks new activities compared to the 2015 report, red the actions with the highest impact.

4.3 Task Force 3: Natural gas system and usage

In the table below, an update of the status of the PNR and standardisation actions within the scope of TF 3, as defined in the SFEM WG Hydrogen report of 2015, is described. The impact, urgency, time for finalisation and timing of PNR and standardisation activities are proposed.

4.3.1 Gas system

4.3.1.1 Natural Gas Quality

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
Natural Gas quality							
*** 2015 PNR action: <u>SFGas WG H-gas quality study.</u>** Launched in May 2016, to be finalized 2019. Current focus on Wobbe Index; Gross Calorific Value will be covered in line with the Wobbe Index; the impact of hydrogen on Wobbe Index and Gross Calorific Value are covered. Also the interrelation of Hydrogen (and Biomethane) and Oxygen will be analysed in a TF. The study is to give recommendations to TC 234 for the revision of EN 16726:2015 and other standards under CEN/TC 234 which may be impacted.. **⇒Topic relevance: >5 vol% H_2** ⇒ 2018 status PNR action: ongoing study[7]	SFGas study at European level, several studies at national level, for example DVGW Hauptstudie.		Published in 2015. SFG/WG Gas Quality Study to deliver input on WI, GCV and O for revision. CEN/TC 234 WG 11 analysis the impact of H2 on the other H-gas quality parameter.	EN 16726:2015 published, however, hydrogen is only mentioned in an informative annex, with no maximum level specified in the normative part. "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)." Farecogaz[8] members have agreed that for manufacturers the identification of possible mixtures is a starting point, especially for the gas meters. Furthermore, it was proposed that new gas families are described, not only based on Wobbe index. GCV should be considered to reflect application needs. In order to determine whether the current gas system equipment is suitable for (future) mixtures including hydrogen, it is recommended new gas families are described which are not only based on Wobbe index, because different mixtures may have the same Wobbe index but have different impact on the gas system. Standardization of the gases is seen as the starting point for any practical research and has to be executed as soon as possible. See also **<u>New gas categories including variable H_2 concentrations</u>**	PNR: Evaluation of results in 2019. Standardisation assumed after.	*Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2016-2019*** *Timing Standardisation:* ***2020-2023***	Standardization bodies, industrial and research organisations

[7] SFGas Pre-normative study on H-gas quality parameters, 2016 - 2019

[8] The European Association of Manufacturers of Gas Meters, Gas Pressure Regulators and associated Safety Devices and Stations

4.3.1.2 Equipment and Devices

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
Gas Analysis							
*** 2015 PNR action: <u>Adaptation of gas analysis methods</u>** Previous activities: 2012 DVGW G 3/02/12 Report published **⇒Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: No PNR performed as this is the responsibility of the manufacturer and suitable certified devices are available. Minor impact of hydrogen addition on the measurement devices. Devices are available		PGC needs to be replaced, models able to measure hydrogen exist.	ISO 6974 series Parts 1 (2012),2(2012),4(2010),6 (ISO 6974-6:2002/Cor 1:2003) published. Parts 3 and 5 currently under review by ISO TC 193 and CEN TC 238 Natural gas — Determination of composition with defined uncertainty by gas chromatography	ISO 6974 consists of the following parts, under the general title Natural Gas — Determination of composition and associated uncertainty by gas chromatography: — Part 1: General guidelines and calculation of composition — Part 2: Uncertainty calculations — Part 3: Determination of hydrogen, helium, oxygen, nitrogen, carbon dioxide and hydrocarbons up to C8 using two packed columns — Part 4: Determination of nitrogen, carbon dioxide and C1 to C5 and C6+ hydrocarbons for a laboratory and on-line measuring system using two columns — Part 5: Determination of nitrogen, carbon dioxide and C1 to C5 and C6+ hydrocarbons for a laboratory and on-line process application using three columns — Part 6: Determination of hydrogen, helium, oxygen, nitrogen, carbon dioxide and C1 to C8 hydrocarbons using three capillary columns Future subsequent parts of ISO 6974 are planned. Revision of the standards is ongoing	***PNR: NA*** ***Standardisation:*** *Ongoing, input based on hydrogen developments to be proposed if relevant*		Manufacturers and standardization bodies

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
*** 2015 PNR action: <u>New gas analysis devices for H_2>5%</u>** ⇒ 2018 status PNR action: No PNR performed (apart from sensors)	Current activities focussing on sensors, see below	State of the art analysis, research and development				*Impact: **Low*** *Urgency: **Start immediately*** *Time for finalisation: **Less than 5 years*** *Timing PNR: **2023*** *Timing Standardisation: start the moment input from PNR is mature enough*	Manufacturers, research institutes and standardisation bodies
*** 2015 PNR action: <u>Gas analysis: sensors</u>** **⇒Topic relevance: >5 vol% H_2** ⇒ 2018 status PNR action: PNR performed as part of several ongoing projects. Detection of H_2 in buildings. Investigation existing sensors. Currently focussing on domestic applications.	Hydeploy project/GRHYD grid project. PNR work by BAM and JRC	Potential gaps regarding in line measurements. Follow up work is expected. Further work on suitability of combustible gas safety sensors for H2NG is needed. Work should focus on leak detection of H2/natural gas blend, through testing with different kinds of sensors, and development of new sensors for H2(blends).	Safety: EN 60079-10-1:2015, IEC 60079-10-1:2015 + COR1:2015 Published. Current stage 60.60 next stage 65.31 NWIP CEN/TC 237? / ISO TR 15916:2015 Current standard for hydrogen sensor is **ISO 26142:2010.** In addition, when deploying hydrogen sensors other standards should be followed, such as, for instance, the ones related to electric components	Definition of requirements. The text of document 31J/253/FDIS, future edition 2 of IEC 60079-10-1, prepared by SC 31J "Classification of hazardous areas and installation requirements", of IEC/TC 31 "Equipment for explosive atmospheres" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60079-10-1:2015. The following dates are fixed: • latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2016-07-13 • latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2018-10-13 This document supersedes EN 60079-10-1:2009.	PNR results expected in 2022. Standardisation assumed in the next revision cycle.	*Impact: **High*** *Urgency: **Start immediately*** *Time for finalisation: **Less than 5 years*** *Timing PNR: - **2022*** *Timing Standardisation: **2021-2024***	TSO/DSO, sensor manufacturers, research institutes, certification and standardisation bodies
*** 2015 PNR action: <u>Pressure regulators and valves</u>** **⇒Topic relevance: >10 vol% H_2** ⇒ 2018 status PNR action: PNR performed as part of several ongoing projects. A pure H_2 grid will be constructed and natural gas pressure regulators will be used. Increased knowledge about suitability expected. H21: Testing of existing pressure reduction and valves for 100% H_2.	H2-Netz, H21, Hydeploy; H100 (SGN), The Green Village (Delft, NL)	Larger stations with preheating are not covered. Low number of stations covered in the projects.Material issues are not well covered. Blends are not well covered.	PN-EN 15848-1 / PN-EN 15848-2 / EN 334 / EN 14382 / EN 331 / EN 15069 Amendment 1 (ISO 15848-1:2015/Amd 1:2017) / EN ISO 15848-2:2015		PNR results expected in 2025. Standardisation assumed in the next revision cycle.	*Impact: **Low*** *Urgency: **Start within 5 years*** *Time for finalisation: **Less than 5 years*** *Timing PNR: **2025*** *Timing Standardisation: **2022-2026***	Manufacturers, TSOs, DSOs, standardization bodies and testing laboratories.

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers Existing activities	 Recommended additional activities	Actors involved
*** 2015 PNR action: <u>Sealings and connections</u>** **⇒Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: PNR performed as part of Hydeploy project, but not sufficient to cover all knowledge gaps. WN investigates flanges and ball valves HyDeploy are testing whether the current procedures for connections and repairs are still valid for the blend circumstance.	WN, Hydeploy	New connections (not in place in town gas area) should be investigated. Technical gap: integrity of internal sealing (valves, for example) and external (flat seal, crimped connection, insulating joint for example) with H_2-natural gas blends.	EN 549 / EN 682 published EN 682:2002/A1:2005 prEN 549 under revision. Current status 40.60 next stage 45.99.0979	Definition of acceptable performance	PNR results expected in 2022. Standardisation assumed in the next revision cycle.	*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2022*** *Timing Standardisation:* ***2021-2024***	TSOs, DSOs, standardization bodies and testing laboratories
*** 2015 PNR action: <u>Excess flow valves</u>** **⇒Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: PNR performed as part of H2-Netz project. Device will be tested but with 100% H_2.	H2-Netz	Mixtures of H2NG, larger sample would be good.	Only national standards have been identified	Devices will be tested in a dedicated test program	PNR results expected in 2020. Standardisation Assumed in the next revision cycle.	*Impact:* ***Medium*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2021*** *Timing Standardisation:* ***2020-2023***	Grid operators, industry

4.3.1.3 Installations and other components

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers Existing activities	Recommended additional activities	Actors involved
INSTALLATIONS AND OTHER COMPONENTS							
*** 2015 PNR action: <u>Underground storage</u>** (Porous rocks) **⇒Topic relevance: >5 vol% H_2** ⇒ 2018 status PNR action: PNR performed as part of several ongoing projects. Good and comprehensive investigations at microbiological and geological/mineralogical level.	Hyunder, RAG sun conversion, Hypos UGS	Extrapolation of results to other storage facilities	EN 1918-1:2016 aquifers EN 1918-2:2016 depleted oil and gas fields	H2NG not mentioned	PNR results expected in 2021. Standardisation assumed in the next revision cycle.	*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Between 5 and 10 years*** *Timing PNR:* ***2022*** *Timing Standardisation:* ***2022-2025***	Natural Gas Storage operators, TSOs and qualified laboratories
*** 2015 PNR action: <u>Compressor stations</u>** **⇒Topic relevance: >5 vol% H_2** ⇒ 2018 status PNR action: No ongoing PNR activities.	Although not directly covering the gap, there is ongoing work in the UK on the effect of blends on CHP engines.	**<u>Limitation of existing compressors</u>** (capacity/performance, material aspects) Evaluation of leak gas/oil systems **<u>Risk assessment regarding changed gas compositions</u>** Risk assessment of cooling efficiency, H_2 speed, materials integrity, electrical connection sealings **<u>Technical gap</u>**: in the case of an integrated compressor, what is the integrity of the electric engine with the cooling of a H_2 / natural gas blend. Effects on compressability factor and related energy calculations.	EN ISO 10440 / EN ISO 10439 / EN 1012 10440 published 2001&2007 10439 updated 2015 / 1012 2010-2012 EN 12583: in revision, H2 related analysis ongoing	Not clear if H2NG is covered, possible need for improvement	PNR results expected in 2024. Further, standardisation assumed as soon as relevant PNR input is available	*Impact:* ***High*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR: 2023* *Timing Standardisation: 2022 - 2025*	TSOs, Compressor OEM, "Sealing" suppliers, Integrated EMD manufacturer (EMD = Electrical Motor Drive)

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
*** 2015 PNR action: <u>Pre-mixing stations</u>** ⇒ 2018 status PNR action: PNR performed as part of several on-going projects.	Hydeploy GRHYD	In general **<u>best practice</u>** needs to be identified as a basis for standardisation. There may be some open **<u>modelling issues</u>** (mixing/dew point).	In CEN TC 234, a NWIP for a series of 4 standards on the injection/blending facilities for renewables is in enquiry (03-05/2019).	Definition of requirements; incorporation of PNR results when available.	PNR results expected in 2024. Standardisation assumed as soon as NWIP are approved, incorporation of relevant PNR information is when available.	*Impact: **Low*** *Urgency: **Start immediately*** *Time for finalisation: **Less than 5 years*** *Timing PNR: 2024* *Timing Standardisation: 2023 - 2026*	TSOs, DSOs, standardization bodies and research institutes

4.3.1.4 Grid Integrity

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
GRID INTEGRITY							
*** 2015 PNR action <u>Grid Corrosion H_2<10% (pipeline integrity)</u>** ⇒ 2018 status PNR action: PNR performed as part of several ongoing projects, but insufficient to cover all knowledge gaps. Only regional materials considered, and investigated for cracks. Lab as well as network tests are performed with specific blends. Different materials will be investigated. Focus is on steel and plastics. Specimen of the grid will be investigated. Pressure range 40 mbar - 1.5 bar.	H2 PIMS, Hydeploy up to 20 vol.-%	**<u>Broader material range</u>** (European perspective) should be covered for transmission lines. Low pressure: more materials should be covered Distributed generation increasingly required reverse flows, also in the natural gas grid. Reverse flow rquire a quick decrease in pressure, which may have an effect on laminated pipelines, leading to safety issues in case of hydrogen admixture (accumulation of gas in the delaminated region)	EN 16348 (TSO) Management system standard. Most probably no need for specific adaptation EN 15399 (DSO)	Material testing and developing a pipeline integrity management system for natural gas/hydrogen mixtures.	PNR results expected in 2023. Standardisation assumed in the next revision cycle.	*Impact: **High*** *Urgency: **Start immediately*** *Time for finalisation:* ***Between 5 to 10 years*** *Timing PNR: 2023* *Timing Standardisation: 2021 - 2024*	TSOs, DSOs, testing laboratories, standardization bodies, companies offering inline inspection technology for transportation pipelines, research institutes and pipes manufacturers

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
GRID INTEGRITY							
* **2015 PNR action <u>Grid Corrosion H_2>10% (pipeline integrity)</u>** ⇒ 2018 status PNR action: See above	See above					*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR: 2023* *Timing Standardisation: 2021 - 2024*	
* **2018 PNR action <u>Conversion of NG infrastructure to pure H_2 infrastructure</u>** a) Grid Corrosion existing grids with pure hydrogen (pipeline integrity) b) Hydrogen appliances ⇒ 2018 status PNR action: some on-going PNR activities	* H100 study on conversion of Scottish PE grid to 100% H_2. *Leeds City Gate: [11] *Appraisal of domestic hydrogen appliances: [12] UK is funding R&D on 100% hydrogen appliances and all equipment downstream of the meter.	The first generation of hydrogen appliances will need to be developed	b) Product Standards for Domestic Natural Gas Appliances: Cookers (hobs and ovens): BS EN 30-1-1:2008+A3:2013 Boilers BS EN 15502-1:2012+A1:2015 Fires and Space Heating BS EN 613:2001; BS EN 509:2000; BS EN 14829:2007; BS EN 14438:2006; BS EN 13278:2013; BS EN 1266:2002; BS 7977-2:2003; BS 7977-1:2009+A1:2013; BS EN 1266:2002; BSEN1266 : 2002; BSEN509 : 2000	Revision of the standards should be planned		*Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR: 2022* *Timing Standardisation: 2021 - 2024*	

4.3.1.5 Grid Operation

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
GRID OPERATION							
*** 2015 PNR action** **<u>Flow behaviour</u>** **⇒Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: Evaluate impact of renewable gases, including hydrogen, on existing gas meters and address standardization needs for calibration and certification	Existing software models are used (e.g. in Leeds)	PNR proposed by EMPIR projects				*Impact:* ***Medium*** *Urgency: **Start within 5 years*** *Time for finalisation:* ***2023*** *Timing PNR: 2020-2023* *Timing Standardisation:2021 - 2024*	
*** 2015 PNR action** **<u>Pipeline monitoring</u>** **⇒Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: PNR on condition monitoring, maintenance and repair procedures and related equipment performed as part of several ongoing projects.	H2-PIMS (HYPOS, GER) HYREADY	Inline inspection for crack like defects --> manufacturer development of PIMS for H2NG	EN 1594, EN 12007 EN16348 (TSO), CEN/TS 15399 (DSO 12007 currently under review / 16348 Published 2013/EN 15399	Update of PIMS standards Studying the feasibility to use current ILI tools (geometric, MFL-A, MFL-C and EMAT) in various H2NG mixtures. Building intelligent tool dedicated to circumferential crack detection and sizing, usable in various H2NG mixtures. Studying the feasibility to use stopple and hot tapping operations in various H2NG mixtures.	PNR results expected in 2024. Standardisation assumed as soon as relevant PNR is available.	*Impact:* ***High*** *Urgency: **Start immediately*** *Time for finalisation:* ***Between 5 and 10 years*** *Timing PNR:* ***2024*** *Timing Standardisation:**2022 - 2026***	TSOs and DSOs, research institutes and ILI companies

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
*** 2015 PNR action <u>Odorisation</u>** **⇒Topic relevance: >20 vol% H_2** See also TF5 topic on odorisation of 100% H_2 ⇒ 2018 status PNR action: PNR performed as part of on-going national projects.	H2-Netz (HYPOS, GER)	Projects have national focus. Not clear if all odorants used in Europe will be considered. PNR needed on odorization of H2/natural gas blend. For concentrations up to 40vol% experience from town gas can be used, but further tests are recommended. for a literature survey followed by olfactory tests on the blend (with different percentage of H2) and analysis of the level of odorization of the blends should be preformed. Investigation on new (sulfur free) odorants needed, although these odorants are currently not considered a panacea.	ISO TR 16922 published 2013 EN ISO 13734 published 2013	Testing of different odorants. Definition and harmonisation of performance indicators.		*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Between 5 and 10 years*** *Timing PNR: 2019 - 2022* *Timing Standardisation:2021 - 2024*	TSO, mainly in Europe DSO, gas odorants suppliers, esearch institutes and standardization bodies.
*** 2015 PNR action <u>Permeation (non-metallic materials)</u>** **⇒Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: PNR performed as part of several on-going projects.	Different b2b-projects GRHYD H2-Netz Naturalhy, HIPS (the project)	Standardisation		Set limit of acceptable hydrogen permeation. Standardisation is considered as useful considering discussions on emissions.		*Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2025*** *Timing Standardisation:****2023 - 2027***	Research institutes, standardization bodies and testing laboratories
*** 2015 PNR action <u>Separation including membranes</u>** **⇒Topic relevance: >10 vol% H_2** ⇒ 2018 status PNR action: PNR performed as part of several ongoing projects.	HYPOS H2-Mem HYGRID project ongoing	Important topic, additional R&D would be helpful. Identification of best practices, reducing costs and standardisation. Membrane filters – different materials.				*Impact: Low* *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Between 5 and 10 years*** *Timing PNR:* ***2025*** *Timing Standardisation:****2024 - 2028***	TSOs, DSOs, standardization bodies and research institutes

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
*** 2015 PNR action: <u>Metrology/billing</u>** **⇒Topic relevance: >10 vol% H_2** ⇒ 2018 status PNR action: No PNR performed. Related to flow behaviour.	EMPIR project on Flow metering of non-conventional gases (biogas, biomethane, hydrogen, syngas and mixtures with natural gas). This project will focus on metrology research necessary to support the standardisation in flow metering of non-conventional gases with specific objectives to identify the typical uses for which the impact (non-impact) of non-conventional gases is not evaluated in terms of measurement accuracy, costs and life time, and defining an acceptable range of gas compositions, suitable to support the new "non-conventional" framework. Also to develop traceable methods for the calibration of flow meters that are used to measure non-conventional gases quantity.	Clarification on a European level of control and billing aspect				*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2020*** *(optional)* *Timing Standardisation:****2020 - 2023***	TSOs, manufacturers, institutes of metrology

4.3.2 H2NG End-Users

4.3.2.1 CNG Vehicles

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
ON-BOARD STORAGE							
*** 2015 PNR action** **<u>Qualification methods for steel tanks for H2NG with hydrogen concentrations above 2 vol%</u>** Establishment of test methodologies for characterising the durability (including under cycling conditions) of steel tanks ⇒ 2018 status PNR action: Some tests may have been performed by automotive companies, but no further information is available.		PNR to cover materials properties for H_2 concentrations between 2-20%.	EN Regulations: Adaptation of ECE R 110, in the process of being published EN ISO 11439 / ISO/TS 15869	Standardisation: Update of ISO 15500 (15500 (Road vehicles -- Compressed natural gas (CNG) fuel system components). 11439 published 2013 / 15869:2009 standard was last reviewed and confirmed in 2016. Therefore this version remains current. Updates after PNR.		*Impact:* ***High*** *Urgency:* ***start immediately*** *Time for finalisation:**between 3-7 years*** *Timing PNR: 2020* *Timing Standardisation:2020 - 2023*	TSOs, DSOs, tank manufacturers, OEMs, material experts/testing laboratories and standardization bodies.
COMBUSTION SYSTEM							
*** 2015 PNR action** **<u>Effect of hydrogen on the combustion on different engine types</u>** **⇒Topic relevance: >10 vol% H_2** ⇒ 2018 status PNR action: No PNR performed		Varying H_2 concentration for automotive applications				*Impact:* ***High*** *Urgency:* ***start immediately*** *Time for finalisation:**between 3-7 years*** *Timing PNR:* ***2022*** *Timing Standardisation: 2022 - 2024*	Research institutes, engine manufacturers
REFUELING STATION							
*** 2018 PNR action:** **<u>Proof of accurate performance (measuring)</u>** **⇒Topic relevance: >5 vol% H_2** ⇒ 2018 status PNR action: in progress		Clarification on a European level of billing aspect					TSOs, manufacturers, institutes of metrology

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
*** 2018 PNR action: <u>Refueling station (Effect on components as compressor and storages)</u>** **⇒Topic relevance: >5 vol% H_2** ⇒ 2018 status PNR action: in progress			prEN ISO 16923	To be coordinated with ISO 19880-1 and component standards. This standard will focus on safety aspects of dispenser equipment whereas performance of the fill will be governed by the filling station standard.	SF Gas infrastructure: Initiative to analyse interfaces with standardisation of other fuels respect to Multi-fuel retails stations and the integration of alternative fuels	*Impact: **High*** *Urgency: **start immediately*** *Time for finalisation:**between 3-7 years*** *Timing PNR: 2022* *Timing Standardisation: 2022 - 2024*	

4.3.2.2 Residential appliances

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status standards	Remaining standardisation gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
RESIDENTIAL APPLIANCES							
*** 2015 PNR action <u>Testing and Certification of appliances</u>** **⇒Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: in progress	DVGW BEIS – hydrogen innovation for heating. KIWA NL is also preparing a certification system for hydrogen applications.	In order to reduce system transition costs, new end use appliances brought on the market, should be "hydrogen ready".	EN 437, appliance harmonized standards (GAD) revision being almost completed. Update needed to take into account communication from MS on the gases used on their territory (RAG Regulation on Gas Appliances)	Either inclusion of H2NG as gas appliance category or more likely modification of test gas. Certification actions: • Evaluation of performance • Certification of appliances for H2NG	Results from BEIS 2021	*Impact: **High*** *Urgency: **Start immediately*** *Time for finalisation: **Less than 5 years*** *Timing PNR: 2019* *Timing Standardisation:2020 - 2023*	Manufacturers, end-users, safety regulators, certification bodies, standardization bodies, heating sector and DSOs

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status standards	Remaining standardisation gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
*** 2015 PNR action <u>Adaptive combustion control</u>** **⇒Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: Research in progress on flexible combustion control.	GERG project on Self regulated gas boilers The Green Village (Delft, NL), Hydrogreenn (Hoogeveen), both for 100% H_2	Testing self regulated boilers on gas blends of 30% hydrogen	CEN/TC58 CEN/TC 48, 49, 58, 62, 106, 131, 109, 180, 244, 270, 299, 326, 399	Standardization of more flexible devices	PNR results end 2018	*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2019*** *Timing Standardisation:****2020 - 2023***	H2NG suppliers, appliance manufacturers, standardization bodies, notified bodies and testing facilities for the GAD
*** 2015 PNR action <u>Combustion; incl. Investigation of suitability of burners and impact on flue gas composition (emissions)</u>** **⇒Topic relevance: >10 vol% H_2** ⇒ 2018 status PNR action: Results of Naturalhy, Klanxbühl	FCH JU, call 2018 (no project funded)					*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR: 2019* *Timing Standardisation:2020 - 2022*	Manufacturers, end-users, safety regulators, certification bodies, heating sector and DSOs
*** 2015 PNR action <u>Updating material specifications for metal and rubber / synthetic materials</u>** **⇒Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: In progress, material testing flexible hoses including permeation are part of the scope.	DVGW "end use device materials	Material specifications for metal and rubber / synthetic materials. There is an expected effect of cost reduction if H2NG compatible devices/components are installed.		Develop, standardise and bring more flexible devices in the market	PNR results end 2018	*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2018*** *Timing Standardisation:****2019 - 2022***	Manufacturers, end-users, safety regulators, certification bodies, heating sector and DSOs, manufacturers of "raw and half materials"
*** 2015 PNR action <u>New gas categories including variable H_2 concentrations</u>** **⇒Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: n/a		Definition of test gases, definition of EU gas category	Revision to be launched when Member states have provided the communication on gases used on their territory as required by GAR	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:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR: 2019* *Timing Standardisation:2019 - 2022*	H2NG suppliers, appliance manufacturers, standardization bodies, notified bodies and testing facilities for the GAD

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status standards	Remaining standardisation gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
* **2015 PNR action** **Gas pipework in buildings** **⇒Topic relevance: >20 vol% H_2** ⇒ 2018 status **PNR action: ongoing**	Klanxbühl/Neukirchen E.ON Energiepark Mainz HyDeploy at Keele University	Gap analysis of materials Both materials/equipment and the way they are installed have to be checked: Some materials such as rubber hoses for the connection of gas appliances are not suitable and are to be replaced. Regarding installations, risk of leakage being higher with H2NG than with NG due to the higher permeability of hydrogen.	EN 1775	Last version 2007, potentially update needed	CEN/TC 234 analysis of H2NG aspects and inclusion in CEN TR (functioning as CEN/TC 234 Roadmap)	*Impact:* ***Medium*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR: 2019* *Timing Standardisation:****2020 - 2022***	Manufacturer, DSOS, testing laboratories (optional)

4.3.2.3 Gas turbines and gas engines

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
GAS TURBINES AND GAS ENGINES							
* **2015 PNR action** **Gas turbines including variable H_2 concentrations** Investigation of materials Operating characteristics, testing **⇒Topic relevance: >2 vol% H_2** ⇒ 2018 status PNR action: Ongoing PNR, some results already published	HYREADY HIPS-NET Hydrogen in Natural Gas impacts on gas engines and CHP Survey Manufacturer (SFEM/DBI)	Compatibility of gas turbines e.g. in power plants with H_2 enriched fuel gas. Studies on reliability of gas turbines in dependence of hydrogen content. PNR only focussed on a few CHPs being tested. Dependent on the findings it may only be applicable to certain types of CHP	ISO 3977-4:2002 This standard was last reviewed and confirmed in 2017. Therefore this version remains current.			*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2019*** *Timing Standardisation:****2020 - 2022***	OEMS of gas turbines, associations, gas network operators, research institutes

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers Existing activities	 Recommended additional activities	Actors involved
* **2018 PNR action** **Gas engines including variable H_2 concentrations** ⇒**Topic relevance: >5 vol% H_2**						*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2019*** *Timing Standardisation:****2020 - 2022***	OEMS of gas turbines, associations, gas network operators, research institutes
* **2018 PNR action** **Modification of gas turbines for new compositions up to 100% H2**		Higher hydrogen content can lead to backfire, thermoacoustic problems, etc.					OEMS of gas turbines, associations, research institutes

4.3.2.3 Industrial use

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers Existing activities	 Recommended additional activities	Actors involved
EFFECT OF HYDROGEN ON INDUSTRIAL PROCESSES							
* **2015 PNR action** **Identify sensitive processes** ⇒**Topic relevance: >2 vol% H_2** ⇒ 2018 status PNR action: desk-based study for an area of UK for blends for Industrial applications	Industrial and network blend – delivering reduced carbon intensity of the network.	>1 Vol% hydrogen can lead to safety shutdowns, backfire, negative impact on reliability of processes in the chemical industry. Feedstock usage: quick fluctuations of hydrogen concentration in natural gas can cause problems. Gap remains on what changes are required to Industrial processes or equipment	EN 15001-1, EN 15001-2 in formal vote			*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***t.b.c*** *Timing Standardisation: t.b.c.*	End users of natural gas as a feedstock, natural gas suppliers, associations, research institutes

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline Roadmap identifiers: Existing activities	Timeline Roadmap identifiers: Recommended additional activities	Actors involved
* **2015 PNR action** **Develop mitigation measures** ⇒**Topic relevance: >2 vol% H_2** ⇒ 2018 status PNR action: partial information available	Some information available from research in Germany (DVGW, GWI) DVGW G 201615	Development and installation of mitigation measures for sensitive industrial applications. To reduce transition costs, processes should be hydrogen ready (and more flexible regarding gas composition fluctuations). The mass energy balance of the reforming furnace will change. Verify new mass energy balance and modification of the control system.		Identification of relevant TC and transfer of PNR results in European standard		*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***t.b.c.*** *Timing Standardisation: t.b.c.*	Consumers which use natural gas as a feedstock
BURNERS							
* **2015 PNR action** **SoA analysis** ⇒**Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: No known activities		Investigate suitability of burners and impact on flue gas composition (emissions)	ISO 13577 / ISO 13579 13577 1&3(2016),2&4(2014) 13579 Parts 1-4(2013), Part 11 (2017)			*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***t.b.c.*** *Timing Standardisation:2020* ***- 2022***	Burner manufacturers, national authorities
* **2015 PNR action** **Performance testing** ⇒**Topic relevance: >20 vol% H_2** ⇒ 2018 status PNR action: No known activities						*Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR: t.b.c.* *Timing Standardisation:2020 - 2022*	TSOs, DSOs, standardization bodies and research institutes

4.3.3 Additional Natural Gas system and usage PNR and standardisation actions since the 2015 report

Since the publication of the 2015 report, some new challenges have been identified. These are briefly highlighted in yellow in the section 4.3.1 and 4.3.2 and expanded upon in this section.

The new challenges have been mainly identified at the grid level, addressing the field of installations and other components, grid operation and pipeline integrity. At the end-user/appliance level, new areas of interest have been defined at industrial level for gas turbines and in the field of hydrogen separation techniques/technologies.

1. Conversion of natural gas infrastructure to pure hydrogen infrastructure: one of the greatest changes in comparison to 2015 is the rapid development of projects not only analysing, but actually performing a conversion of the existing natural gas infrastructure into a 100% hydrogen network, in one of the largest UK cities (Leeds). Feasibility studies are ongoing for Scotland. The project has been designed to minimise disruption for existing customers, and to deliver heat to customers at the same cost as currently achieved with natural gas. The project has shown that the gas network has the correct capacity for such a conversion with a minimal new infrastructure required (compared to alternatives).

2. Compressor stations: There is still a need for improvements before the inclusion of H2NG into existing standards. The key issues identified are the limitations of existing compressors in terms of material/performance, as well as the evaluation of leakages in gas/oil systems. Additionally, risk assessments regarding changes in gas compositions due to H_2 blending into NG is needed. Among the issues are the cooling efficiency, H_2 flow velocity, materials integrity and electrical connection sealings. A technical gap has also been defined in the case of an integrated compressor. An open question remains concerning the integrity of the electric engine with the cooling by a H2NG blend.

3. Metrology/billing: The issues of metrology and billing has been identified as having high impact and as an urgent to be addressed. There are activities in the field of metrology and billing which are currently funded through EMPIR. The remaining gaps are starting to be covered, but there is still an urgent need to have accurate metering systems for hydrogen billing purposes.

4. Refueling station: a challenge has been identified regarding the proof of accurate performance (measuring) for H2NG refuelling. For >5 vol% H_2, further activities are needed. In addition, the effect of hydrogen on CNG station components such as the compressor and storage should be assessed.

5. Modification of gas turbines/ gas engines for new compositions: With an increasing H_2 content in the H2NG blend, the possibility of backfire and thermoacoustic problems increases. For gas engines, the effect of variable H_2 concentrations should be investigated. In this field, no ongoing publically funded projects are known, but industry research activities have been identified.

6. Separation of H_2 from H2NG: With the growing maturity of the on-going P2H and energy storage related projects the different possible concentrations of hydrogen, depending on the foreseen usage, have become apparent. Pure hydrogen is of greater value when used as a high purity

technical gas/fuel, than mixed as H2NG. Furthermore there could be the need to reduce the H2 concentration for sensitive end use technologies. Therefore, the need emerges for the development of H_2 separation. Alternatively approaches focused on H_2 elimination from H2NG by methanation are investigated.

7. Remaining gap grid corrosion (pipeline integrity): This is not a new subject/area of interest, but in any case worth mentioning, as the materials compatibility and leak tightness of the assets subjected to H2NG of variable composition still raises concerns (see also 4.5.2 Hydrogen compatibility of materials). According to the expert input into the PNR mapping, there is not a single ongoing PNR action/project covering pipeline integrity in terms of corrosion phenomena. PNR related to pipeline integrity is performed as part of several ongoing projects, but unfortunately at an insufficient level to cover all the defined knowledge gaps. Only materials used regionally are investigated and the major focus is on crack development and propagation. Within those projects, laboratory and field tests are performed with the use of H2NG of various compositions. The material focus is on steel and polymers (plastics) using pressures from 1.5-40 bar. Therefore the gap, from the European perspective, consists of the need to cover the broader variety of materials as well as pressures from 40-100 bar. Presently, there are concerns regarding the forecasted timeline for finalisation of PNR in 2023, while the high impact and the high urgency have been indicated by the parties involved.

4.3.4 Roadmap for Natural gas system and usage

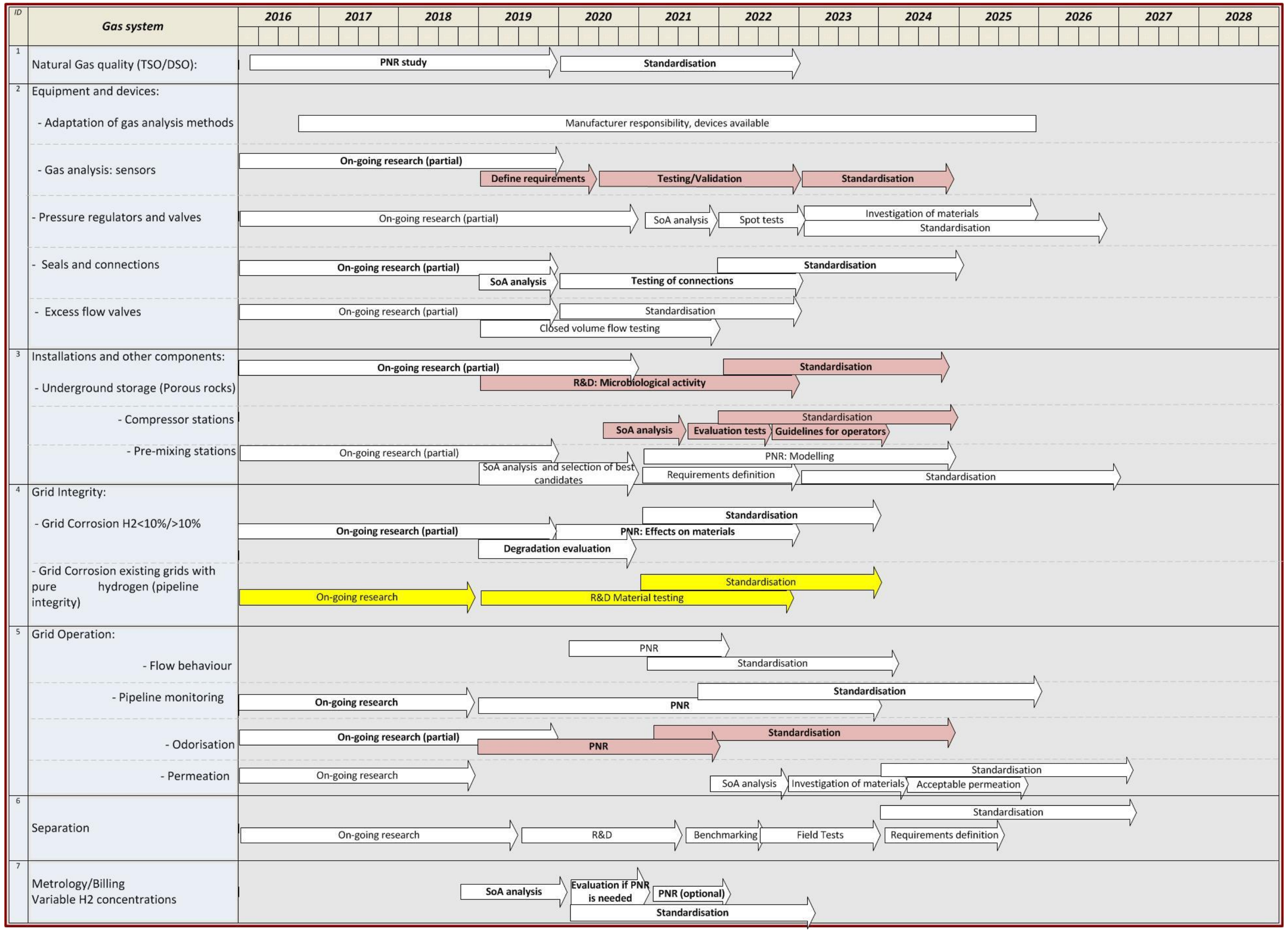

Figure 4 PNR and Standardisation actions roadmap for grid integrity issues. Yellow marks new activities compared to the 2015 report, red the actions with the highest impact.

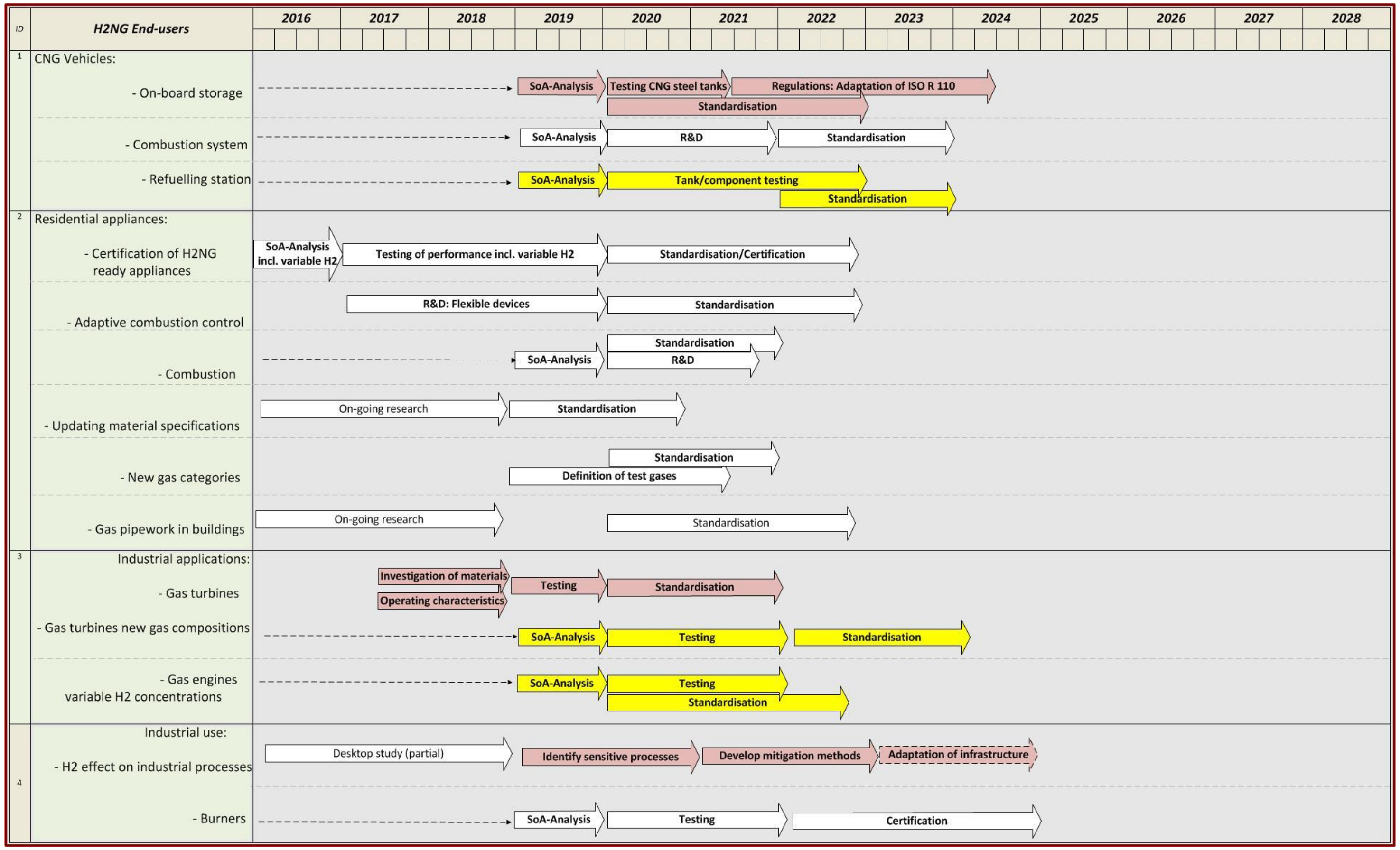

Figure 5 PNR and Standardisation actions roadmap for end-use issues. Yellow marks new activities compared to the 2015 report, red the actions with the highest impact.

4.3.4.1 Changes in terms of prioritisation for the natural gas system and usage

In the 2015 report, many actions related to the compressor stations, odorization and underground storage have been indicated as most urgent to address at the grid level. More fields of standardisation activities have been identified at the end user appliances level. The activities to be started in the short term at that time were given as CNG on-board storage tanks and certification of the residential appliances and burners. The need for the recommendations for turbines have been expressed. As fields to address next, metrology/billing, testing mass/energy balance, testing flame velocity in CNG/H2NG combustion systems, materials specifications, reliability tests for turbines and the possible impact on the industrial process while using H2NG as a feedstock have been indicated.

According to the mapping performed as a part of this report update, the following changes have been observed:

1. The testing and development (if needed) of appropriate gas sensors for H2NG, for concentrations of hydrogen above 5 vol% is seen as having a higher priority in 2018. Research is being performed as part of several ongoing projects, with the focus on detection of H2(NG) in buildings, for domestic applications. The investigation of the effect of hydrogen on the performance of combustible gas sensors needs further attention.

2. The effect of hydrogen admixture on the operation of CNG refueling stations has also been given higher priority compared to 2015. Apart from the necessary assessment of metering accuracy, the compatibility of station components with hydrogen should be investigated.

3. The effect of hydrogen on industrial processes (thermal and feedstock) is also seen as a more critical issue compared to 2015. Sensitive processes need to be identified and possible mitigation measures developed. Standardisation is considered as an important measure to ensure that infrastructure and end use appliances/processes adoption starts early as possible to reduce the total transformations costs.

4.4 Task Force 4: Hydrogen system and usage

In the table below an update of the status of the PNR and standardisation actions within the scope of TF 4, as defined in the SFEM WG Hydrogen report of 2015, is described. The impact, urgency, time for finalisation and timing of PNR and standardisation activities are proposed.

4.4.1 Hydrogen infrastructure

4.4.1.1 Underground Hydrogen Storage in Salt Caverns

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
Underground Hydrogen Storage in Salt Caverns							
* 2015 PNR action: Materials compatibility and durability of especially cement mixtures, but also steels and non-metallic materials for use in hydrogen storage facilities. ⇨ 2018 status PNR action: Being addressed for porous rock formations by H2Store (finished: focus micro-biological interaction), Underground Sun Storage (finished, focus H2NG in porous rock storage, testing on material integrity of steels and rubbers) and HyINTEGER (until 2018) projects. Research performed on (among others) material alterations for rocks, steels, cement, seals due to hydrogen.	* HyINTEGER project (2016-2018) * H2Store project (2012 - 2015) * RAG Underground Sun Storage project (2013-2017) (both German projects "EnergieSpeicher") * HYPOS H2 UGS (2018-2021) • HyUnder project (2012-2014)	PNR gap being addressed, status to be evaluated after the finalisation of HyINTEGER	* 2015 STD 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. ⇨ 2018 status STD action: EN 1918-3 "Functional recommendations for storage in solution-mined salt caverns" has been updated in 2016 but does not include specific requirements for hydrogen. Standard replaces EN 1918-3:1998. Standardisation action still relevant	Update of standards is still necessary and may take advantage of ongoing PNR activities. Possible revision of EN1918 in two years. The following aspects will be discussed: • Enlarge the scope to all other gases (NG, H2GN, H2) • Address mixing of different gas quality in reservoirs and thus fluctuating gas composition • Adress cushion gas calculation (higher for H2 due to compressibility factor) • Subsurface reactivity of hydrogen (corrosion/brittleness) (pre-normative research) • Material resistance (well completion, steel used for wet gas)	None at present	*PNR:* *Impact:* **Medium** *Urgency: Start within 5 years* *Time for finalisation: Less than 10 years* *Timing: 2020-2025* *Standardisation:* *start as soon as relevant PNR information is available*	Standardization bodies, industrial and research organisations

4.4.1.2 Distribution by tube/cylinder trailers

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
DISTRIBUTION BY TUBE/CYLINDER TRAILERS							
*** 2015 PNR actions: Further develop <u>probabilistic methodology</u> to determine safety factors for composite vessels.** ⇒ 2018 status PNR action: Further work is required	No PNR activities ongoing	PNR gap remains	*** 2015 STD action: Development of an informative annex for ISO 11119-X standards and ISO 11515 which introduces the concept of <u>probabilistic risk approach</u> to determine safety factors.** ⇒ 2018 status STD action: An update of standards in the ISO 11119-X series has not started. An amendment (which includes a reduction of qualification test impact energy from 1220J to 488J) to ISO 11515:2013 has progressed to the FDIS stage, which is the last stage before publication	Standardisation need remains. In the FCHJU call topic description in 2017 the development of a standardisation roadmap for relevant work performed in ISO TC 58 SC3 WG 35 (ISO 17519), WG 32 (ISO 11515) and WG 27 (ISO 11119-X series) in view of the ADR was requested. No proposal was received but the need remains relevant.	PNR: N/A	***PNR:*** *Impact:* **Medium** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 10 years*** *Timing:* ***2020-2025*** ***Standardisation:*** *Impact:* **Medium** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 10 years*** *Timing:* ***2020-2025***	Standardization bodies, industrial and research organisations
*** 2015 PNR action: Develop methods for <u>cylinder testing and requalification</u>** ⇒ 2018 status PNR action: PNR is missing. FCHJU HyPactor has proposed recommendations for in service cylinders. Cylinders that have been impacted by an energy higher than threshold energy are to be rejected from further service. Further testing with higher impact energy might be beneficial for evaluation of "impacted in service" cylinders (on a voluntarily basis – not part of the initial type approval test program)	* FCHJU HyPactor (2014-2017)	PNR gap partially addressed but remains	*** 2015 STD action: Continue to establish <u>industrial consensus</u> 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. Once PNR is finalised, the standard should be updated.** ⇒ 2018 status STD action: ISO 17159 has progressed to the FDIS stage, which is the last stage before publication	Standardisation needs to be assessed but probably finalised. Update of the standard should be considered once the PNR gap is sufficiently addressed	PNR: N/A (finished) Standardisation: 1 year	***PNR:*** *Impact:* **Medium** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 10 years*** *Timing:* ***2020-2025*** ***Standardisation:*** *Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***current-2023***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
See above	*See above*	*See above*	*** 2015 STD action: Consider to update EN 12245 on <u>transportable cylinders</u> to reflect the latest developments in ISO/TC 58/SC3 regarding cylinder/tube volume and pressure.** ⇒ 2018 status STD action: An update of EN 12245 is being considered as a new activity is created in the work programme of CEN TC 23.	Standardisation need remains.	PNR: N/A RCS: 3-5 years	***PNR:*** *N/A* ***Standardisation:*** *Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***current-2023***	Standardization bodies, industrial and research organisations
*** 2015 PNR action: Develop equipment <u>interfaces for high pressure trailers</u> and end-users (such as refuelling stations), filling procedures and component requirements.** ⇒ 2018 status PNR action: No PNR development. Safety criteria are important as new and higher pressure trailers are being developed. A FCHJU call topic from 2017 (FCH-04-2017) included the development of a roadmap for, among others, standardisation of interfaces, however, no proposals have been made. It seems that EIGA WG11 would be a good place to start the development of criteria for connectors and interfaces.	No PNR activities ongoing	PNR activity still to be initiated		No agreement on standardised connectors and interfaces.	PNR: N/A RCS: TBC on market needs	***PNR:*** *Impact:* **Medium** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 10 years*** *Timing:* ***2020-2025*** ***Standardisation:*** *Impact:* **Medium** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 10 years*** *Timing:* ***2020-2025***	Industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
*** 2015 PNR action: Develop an <u>overarching PNR</u> 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 on <u>hydrogen storage</u>, considering its different applications and a probabilistic risk approach.** ⇒ 2018 status PNR action: An overarching PNR activity has not been initiated, however a FCHJU call topic in 2017 called for a risk assessment of the complete chain of delivering compressed H_2 with trailers, including mitigation options, a standardisation roadmap and a position paper for the ADR. No proposal was received on this call topic. Additionally, FCHJU funded in 2017 the TAHYA project which concerns the improvement of compressed storage systems and may include the lessons learned from PNR projects in terms of more robust designs.	* FCHJU TAHYA (2018-2020)	PNR activity still to be initiated			PNR: 3 years RCS: N/A	***PNR:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025*** ***Standardisation:*** ***TBC on completion of future projects***	Industrial and research organisations

4.4.1.3 Hydrogen infrastructure - refuelling

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
Hydrogen Infrastructure - Refuelling							
GENERAL							
* 2015 PNR action: 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. ⇒ 2018 status PNR action: No PNR follow-up of **refuelling protocol** development activities in HyTransfer. PNR is required regarding the acceptable maximum gas temperature at end of fill without change of tank design, the assumptions for the CHSS and the interaction between refuelling station and vehicle.	No PNR projects ongoing after the HyTRANSFER project ended.	**PNR gap changes to acceptable maximum gas temperature at end of fill**	*** 2015 STD action: Development of performance based standards for refuelling protocols outside the SAE standardization platform.** ⇒ 2018 status STD action: Regarding light duty vehicles, the SAE J2601 protocol is based on assumptions for the onboard storage equipment and the interaction between station and vehicle defined > 10 years ago. Updating of standards should therefore begin with re-assessing these assumptions. A standardisation follow-up of HyTransfer has not been initiated	Revision of J2601 on-going, regarding fuelling protocol standards for light duty vehicles, but this will still be based on the existing assumptions..	PNR: N/A (finished) RCS: 1year	***PNR:*** *Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***current-2023*** ***Standardisation:*** *Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***current-2023***	Standardization bodies, industrial and research organisations
* 2015 PNR action: 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. ⇒ 2018 status PNR action: No PNR activity for the calibration and validation of simulation models for **refuelling of vehicles with CHSS > 10kg for 700 bar and > 6 kg for 350 bar**	No PNR activities ongoing	**PNR gap changes. In order to define acceptable maximum gas temperature at end of fill, there is a need for calibration and validation of simulation models for predicting local material temperatures in the CHSS**	*** 2015 STD action: Development of performance based standards for refuelling protocols outside the SAE standardization platform.** ⇒ 2018 status STD action: Refuelling protocols are needed for medium & heavy duty vehicles (e.g. vehicles with CHSS > 10 kg for 700 bar and > 6 kg for 350 bar). The development of performance based standards are considered not within the scope of ISO TC 197.	Revision of J2601 on-going, regarding fuelling protocol standards for medium duty vehicles, but this will still be based on the existing assumptions.. Development of standards for refuelling of medium & heavy duty vehicles (e.g. buses, trains, trucks…) is required (e.g. taking into consideration the results of HyTransfer) FCH JU has put out a call (2019) for Refueling Protocols for Medium and Heavy-Duty Vehicles	PNR: call FCH JU 2019 Standardisation: to be started in relation to the PNR	***PNR:*** *Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***current-2023*** ***Standardisation:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
*** 2015 PNR action: Further develop risk assessment methodologies for failure modes of hydrogen refuelling stations to understand the consequences for on-board hydrogen storage systems.** ⇒ 2018 status PNR action: The risk assessment exercise was concluded and an annex was prepared containing the main conclusions of the outcomes of the exercise. However, the annex was not included in ISO 19880-1 as further consensus building on the methodology was required and knowledge gaps remained, e.g. regarding tank behaviour when exposed to gas temperatures > 85°C. The risk assessment is now being further developed within EIGA with the aim of publishing it as an EIGA	The risk assessment exercise is continued within EIGA.	PNR gap remains	**⇒ 2018 STD action (new): When risk assessment methodology has been concluded and finalised, consider it for uptake in relevant ISO/CEN standards (ISO 19980-1 and EN 17127)**	Update of the standard should be considered once the PNR gap is sufficiently addressed.	PNR: estimate 2 years. Standardisation: assumed in the revision cycle of ISO 19880-1 / EN 17127 (unknown) Estimate 5 years	***PNR:*** *Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***current-2023*** ***Standardisation:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025***	Standardization bodies, industrial and research organisations
			*** 2015 STD action: Development of European standards required by Alternative Fuels Infrastructure Directive.** ⇒ 2018 status STD action: CEN TC 268 WG5s working under Mandate 533 has published EN ISO 17268:2016 (connectors) and is in the process of adopting ISO/DIS 17268:2017 via the Vienna Agreement (update concerns: testing of communication hardware, evaluation of nozzle freeze-lock, evaluation of user abuse effects) Two additional standards have been published: EN 17124 (Hydrogen fuel specification and quality assurance) and EN 17127 (Outdoor hydrogen refuelling points), which are linked to the equivalent ISO documents. In the meantime, ISO TC 197 WG 24 has withdrawn ISO/TS 20100 and is developing ISO 19980-1 to replace this. ISO 14687 is also being developed, to replace the existing ISO 14687 parts 1-3, and ISO 19880-8 is close to being ready for publication.	Once relevant ISO TC 197 standardisation activities are finalised, harmonisation of: • EN 17124 with ISO 19880-1, and • EN 17127 with ISO 19980-8 and ISO 14687	PNR: N/A Standardisation: ongoing	***PNR:*****N/A** ***Standardisation:*** *Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 2 years*** *Timing:* ***current-2020***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
			*** 2015 STD action: Develop a <u>single solution for a complete qualification process</u> for European hydrogen refuelling stations (e.g. assurance of fuel quality, appropriate particle retention, legally compliant metering, compliance with refuelling protocol, legally compliant payment process, verification methods for HRS availability).** ⇒ 2018 status STD action: Standardisation actions are ongoing to address individual elements of the single qualification solution, including ISO 19880-1 and EN 17127 (FAT/SAT tests for HRS), ISO 19880-8 (quality assurance), ISO 14687 (quality), EN 17124 (quality and quality assurance), OIML R139-1 (legal metering), ISO 21087 (analytical methods). It could be considered that once these activities are finalised, an effort is performed to understand the need for integration into a single document.	Standardisation needs to be assessed once feed-in standardisation work is finalised.	PNR: ongoing Standardisation: ongoing (The feed-in standardisation activities expected to be finalised within the next 1-2 years)	***PNR:N/A*** ***Standardisation:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025***	Standardization bodies, industrial and research organisations, certification bodies
*** 2018 PNR action: EU-wide harmonised approaches / tools / methods assisting the determination of HRS safety distances.**		Development of a harmonised risk assessment methodology/tool for failure modes of hydrogen refuelling stations		ISO 19880-1 contains information on approaches currently in use internationally.	PNR: N/A Standardisation: N/A	***PNR:*** *Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***current-2023*** ***Standardisation:*** ***TBC on completion of future projects***	

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
			*** 2018 PNR action: Hydrogen refuelling in multi-fuel stations** SFGas- I WG mobility established. Workshop held at CEN/CENELEC 2/2019.	Next steps to work on aligned requirements of standards, aligned terms,common approach of risk assessment and determination of separation/safety distances	PNR: N/A Standardisation: 2019	***Standardisation:*** *Impact:* ***Medium*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***current-2023***	
COMPONENTS							
* 2015 PNR action: Continuation of PNR work in EU projects on components development. ⇒ 2018 status PNR action: FCHJU COSMHYC on innovative compressor concepts and FCHJU H2REF on refuelling system (incl. compression). No PNR activities on hydrogen components known	* H2REF (2015-2018) * FCHJU COSMHYC (2017-2019)	**New: PNR gap on hydrogen materials compatibility**	*** 2015 STD action: Identify and address gaps in standards for hydrogen refuelling components.** ⇒ 2018 status STD action: The status of the work on HRS components performed in ISO TC 197 WG19 - WG23 (the "19880-2-to-7 series) is that three activities have been deleted (dispensers, fittings and compressors), while the valve standard (ISO 19980-3) has been published, and the hose and hose assemblies standard (ISO 19880-5) is in the final stage of development towards becoming an international standard. ISO 19880 on general requirements for HRS contains general conditions for materials (hydrogen compatibility) and piping carrying hydrogen.	Standardisation gap assessed, some activities have been deleted, further developed or integrated in overarching standard. Update of standards should be considered once the PNR gap is sufficiently addressed	PNR: N/A Standardisation: 1-2 years where not already completed	***PNR:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025*** ***Standardisation:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
*** 2018 PNR action: Collection of feedback on the operation of station components and analysis of component failures**	None	Collection of data on failures of components and subsequent analysis.	*** 2015 STD action: Development of a <u>European standardization platform</u> 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).** ⇒ 2018 status STD action: Several standardisation platforms on hydrogen exist: CEN TC 268 WG 5 (H_2 technology applications), CEN/CLC JTC 6 (H_2 in energy systems), also ISO TC 197. CEN TC 268 WG5 works on the Mandate 533 to prepare EN standards for the AFID directive.	Collection and sharing of data between the standardisation committees.. Position to be reassessed after publication of hydrogen EN standards for the AFI Directive.	PNR: N/A Standardisation: N/A	***PNR:*** *Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***current-2023*** ***Standardisation:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025***	Standardization bodies, industrial and research organisations
STATIONARY HYDROGEN STORAGE							
*** 2015 PNR action: Develop PNR activities to deepen the understanding of causes for <u>fatigue</u> under shallow cycles.** ⇒ 2018 status PNR action: No PNR performed	No PNR projects have been funded after the ending of the MATHRYCE project.	PNR gap remains	*** 2015 STD action: Develop appropriate testing procedures and methodologies for <u>accelerated lifetime testing</u> based on profiles that reflect user patterns of storage means in hydrogen refuelling stations.** ⇒ 2018 status STD action: ISO TC 197 WG15 is in the process of finalising ISO 19984 as it is currently in DIS stage. The draft standard includes a definition of a shallow cycle, a test method for partial amplitude pressure cycling and a calculator method to recalculate a shallow pressure cycle life. PNR outputs confirm the calculation method provided in ISO/DIS 19984.	Update of the standard should be considered once the PNR gap is sufficiently addressed	PNR: N/A Standardisation: 1-2 years	***PNR:*** *Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***current-2023*** ***Standardisation:*** ***TBC on completion of future projects***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
HYDROGEN METERING							
*** 2015 PNR action: Development of hydrogen metering techniques to achieve consistent accuracy levels between 1% and 2%.** ⇒ 2018 status PNR action: EMPIR MetroHyVe develops a metrological framework (methodologies, standards and calibration facilities) for testing hydrogen meters to allow HRSs to calibrate their hydrogen flow meters to suitable accuracy (1%). Additionally, awaiting a fully harmonised testing protocol at EU level for HRS to enable their certification, the FCHJU has procured services to develop an intermediate metering methodology for the certification and approval of HRS as regards their ability to measure the amount of hydrogen accurately enough. ⇒ 2019 status PNR action: EMPIR NEWGASMET (2019-2022), a PRN project on flow metering of non-conventional gases including hydrogen and mixtures with natural gas aiming at developing traceable methods for the type testing and verification of flow meters that are used to measure renewable gas flows in compliance with the requirements of the Directive on the Measuring Instruments 2014/32/EU and validating the calibration methods and uncertainty budgets developed of selected flow calibration standards	* EMPIR MetroHyVe (2017-2020) * FCHJU service procurement (2017-2019) *EMPIR NEWGASMET (2019-2022)	PNR gap is being addressed and supportive verification methodologies are being developed. The development of an accurate meter (HRS are able to measure hydrogen to within a 5% margin of error approximately) is an R&D activity.	*** 2015 STD action: Development of standardised test and measurements methods to determine accuracy levels of meters (currently not in scope of ISO 19880-2).** ⇒ 2018 status STD action: OIML R 139-1 "Compressed gaseous fuel measuring systems for vehicles - Part 1: Metrological and Technical Requirements" was published in November 2018 and includes specific clauses for hydrogen. **2019 STD action:** Contribution to the standards revision work in technical committees CEN/TC 237 and OIML TC8/SC7 imprving use of gas meters hydrogen technologies - OIML TC8/SC7 about revision of OIML recommendation R137 for gas meters - WELMEC WG11 for compliance of gas meters to MID.	The aim is to have the OIML R139-1 approved for final publication by the International Committee of Legal Metrology in 2018 so that it can submitted to the International Conference on Legal Metrology in 2020 for formal sanction.	PNR: 2 years; Standardisation: under development	***PNR:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025*** ***Standardisation:*** *Impact:* ***Medium*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025***	Standardization bodies, international organisations, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
HYDROGEN CONNECTORS							
*** 2015 PNR action: Develop PNR activities to reduce <u>excessive wear and leakage</u> issues of high pressure nozzles.** ⇒ 2018 status PNR action: Research performed on nozzle freezing by Hiraki et al. in 2015. It was concluded that when moisture enters the nozzle/receptacle, the sleeve and chuck sections of the nozzle may stick due to freezing and thus the nozzle becomes impossible to disconnect. However, no hydrogen leakage or damage to the O-ring due to freezing was detected.	Engineering solutions are being developed to prevent nozzle freezing. (see e.g. source: https://cafcp.org/blog/october-2017-hydrogen-station-update-webinar-questions-answers)	PNR gap may be solved as antifreeze solutions are being developed, but this needs further assessment once these products are in the field.	*** 2015 STD action: Development of standardised test methods and preventive measures to overcome nozzle <u>freezing</u>.** ⇒ 2018 status STD action: ISO TC 197 WG 5 has almost finalised ISO 17268 on refuelling connection devices as the draft standard is currently in DIS stage and is expected to be published as a final standard in 2018. The update concerns mainly testing of communication hardware, evaluation of nozzle freeze-lock and evaluation of user abuse effects. The standard now contains a specific freeze test, which was missing in ISO 17268:2012.	Standard development for refuelling connectors is nearly finalised. It could be considered to review the standard with feedback from deployment activities on wear scenarios in order to possibly improve test criteria	PNR: N/A Standardisation: 1-2 years	***PNR:*** *TBC depending on field experience* ***Standardisation:*** *TBC depending on field experience*	Standardization bodies, industrial and research organisations
			*** 2015 STD action: Consider to (further) develop a <u>European standardization platform</u> that could facilitate connection devices to confirm to the requirements in EN ISO 17268.** ⇒ 2018 status STD action: standard **EN ISO 17268** has been published in 2016, which is referred to by the AFID and a revision is being developed by ISO TC 197	Standards exist, but currently nozzles are not being certified to the latest standard.	PNR: N/A Standardisation: 1-2 years	***PNR:*** *N/A* ***Standardisation:*** ***ITBC on completion of existing activities***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
HYDROGEN QUALITY							
*** 2015 PNR action: Development of improved metrological methods and measurement techniques for hydrogen purity analysis (i.e. by using means for concentrating and/or enriching hydrogen gas).** ⇒ 2018 status PNR action: EMPIR Hydrogen is developing optimised analytical protocols for hydrogen impurities, evaluating existing methods in view of challenged associated to individual impurities testing (e.g. CRDS technique can measure 7 impurities in theory) and developing speciation methods when necessary (e.g. for sulfur, halogenated and hydrocarbon species). EMPIR MetroHyVe is developing offline gas analysis methods, stable reference gas mixtures and metrological tools to enable the introduction of (low cost) gas analysers used for gas analysis laboratories. MetroHyVe is also validating impurities measurement instruments for online hydrogen quality monitoring. HYDRAITE is developing methods for in-line monitoring of hydrogen quality in HRS, as well as methodologies for new impurities.	* EMPIR Hydrogen (2016-2019) * EMPIR MetroHyVe (2017-2020) * FCHJU HYDRAITE (2018-2020) (follow-up FCHJU HyCORA) * U.K. Cadent study on separation/purification, including contaminations from hydrogen supply chain	PNR gap is being addressed and efforts to fill the gap are intensified.	*** 2015 STD action: Reassess PNR results to feed into revision work of hydrogen quality standards.** ⇒ 2018 status STD action: The need to develop analytical standards for hydrogen impurities was addressed in 2016 by setting up joint work group (JWG) between ISO TC 197 and ISO TC 158 in order to develop a specific standard on analytical methods for hydrogen for fuel cell vehicles. Previously, it was addressed marginally in ISO 14687-2. The JWG ISO 21087 standard is being developed:. The PNR outputs are used in this standard.	Standard development for analytical methods is ongoing and includes PNR results.	PNR: 2-3 years Standardisation: 1-2 years	***PNR:*** ***TBC on completion of projects*** ***Standardisation:*** *Impact:* ***High*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
*** 2015 PNR action: Develop risk assessment methodologies to understand the risk and consequences of <u>trespassing</u> impurity level limits.** ⇒ 2018 status PNR action: The risk assessment exercise that was developed in EIGA, and elaborated in ISO TC 197 WG28, is taken up by EMPIR Hydrogen project to further confirm and/or supplement it.	* EMPIR Hydrogen (2016-2019)	PNR gap is partially filled and efforts are ongoing to further improve it	*** 2015 STD action: Harmonise (pre-)standardization work performed at EIGA, ISO/TC 197 and SAE.** ⇒ 2018 status STD action: The development in CEN TC 268 WG5 (EN 17124) and ISO TC 197 WG27 (ISO 14687) and WG 28 ISO 19880-8 operate in parallel as the fuel quality specifications are the same. The risk assessment for the impact of hydrogen impurities initially developed in EIGA is taken up by prEN 17124 and further developed in EMPIR Hydrogen.	Further refined <u>risk assessment</u> for automotive hydrogen impurities in EMPIR Hydrogen could be used during the next revision of ISO 14687 when impurity thresholds are discussed. A better understanding of impurities that are introduced during maintenance is needed.	PNR: 2-3 years Standardisation: 1-2 years	***PNR:*** *Impact:* ***High*** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Within 10 years*** *Timing:* ***2020-2025*** ***Standardisation:*** *Impact:* ***High*** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 2 years*** *Timing:* ***current-2020***	Standardization bodies, industrial and research organisations
*** 2015 PNR action: Continue PNR activities to further understand the <u>impact of impurities</u> on fuel cell system performance under automotive conditions.** ⇒ 2018 status PNR action: FCHJU HyCora concluded that formic acid and formaldehyde impurities have a very small effect on performance and that the current thresholds in standards can be relaxed. Also the "total halogenates" impurity category should be changed. Stack tests should be preferred over single cell tests. FCHJU HyDRAITE and EMPIR Hydrogen are expanding on impurity impact testing by assessing other critical impurities.	* FCHJU HyCORA project: finalised * FCHJU HYDRAITE (2018-2020) (follow-up FCHJU HyCORA) * EMPIR Hydrogen project (2016-2019)	PNR gap is being addressed and efforts to fill the gap are intensified. Investigate the possibility to add an odorisant with no detrimental effect.	*** 2015 STD action: Reassess PNR results to feed into <u>revision</u> work of hydrogen quality standards.** ⇒ 2018 status STD action: prEN 17124 and ISO DIS 14687 have a relaxed threshold for formaldehyde impurities. Also the remark for total halogenated compounds has changed. Successful translation of PNR results to standards. Results from ongoing PNR work may be used in standards' revision cycles	Update standards with PNR results from ongoing PNR project if necessary and relevant. Once the ISO 14687 is finalised, a revision will start on the thresholds. Extend the standards to heavy duty applications (trucks, trains, ships)	PNR: 2-3 years Standardisation: 1-2 years	***PNR:*** ***TBC on completion of projects*** ***Standardisation:*** ***TBC on completion of existing activities***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
HYDROGEN QUALITY ASSURANCE							
*** 2015 PNR action: Develop <u>online measurement techniques</u> and detection apparatus for hydrogen quality assurance at refuelling stations.** ⇒ 2018 status PNR action: EMPIR MetroHyVE develops and validates three online hydrogen purity analyzers utilizing different measurement technologies which can be installed at HRS. These analyzers use traceable standards to ensure that the performance meets the criteria for implementing hydrogen quality control strategies as suggested in ISO 19880-8. In addition, FCHJU HYDRAITE develops a methodology for in-line monitoring of hydrogen quality at the HRS.	* EMPIR MetroHyVe (2017-2020) * FCHJU HYDRAITE (2018-2020)	PNR gap is being addressed and efforts to fill the gap are intensified	*** 2015 STD action: Develop an <u>analytical standard</u> dedicated to hydrogen impurities.** ⇒ 2018 status STD action: ISO TC 197 WG 28 has almost finalised ISO 19980-8 on hydrogen quality control as the FDIS is expected to be published as a final standard in May 2018. The need to develop analytical standards for hydrogen impurities was addressed in 2016 by setting up joint work group (JWG) between ISO TC 197 and ISO TC 158 in order to develop a specific standard on analytical methods for hydrogen for fuel cell vehicles. In 2018, the JWG standard developed into a Committee Draft: ISO/CD 21087.	Standard development for hydrogen quality control is nearly finalised. Standard development for analytical methods is ongoing and includes PNR results however this will not address the requirements for online quality assurance.	PNR: 2-3 years Standardisation: 1-2 years	***PNR:*** ***TBC on completion of projects*** ***Standardisation:*** *Impact:**High*** *Urgency: **Start immediately*** *Time for finalisation: **Less than 5 years*** *Timing: **current-2022***	Standardization bodies, industrial and research organisations
See above	*See above*	*See above*	*** 2015 STD action: Support ongoing standardization activities (e.g. on how to adopt European PNR work (FCH JU HyCORA project)) to develop a practical <u>implementation method</u> for hydrogen quality control.** ⇒ 2018 status STD action: ISO 19880-8 on hydrogen quality control is nearly ready for publication and FCHJU HYDRAITE is developing a methodology for in-line monitoring.	Standard development for hydrogen quality control is nearly finalised. Consider update of ISO 19880-8 based on PNR results, if necessary	Standardisation: 1-2 years	***PNR:*** *N/A* ***Standardisation:*** ***TBC on completion of existing activities***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
*** 2018 PNR action (new):** EMPIR MetroHyVe and EMPIR Hydrogen are currently participating to the development of an European Metrology Network for Energy Gases including an online virtual measurement service hub (via, among all, a website) that will list all calibration and measurement laboratories in Europe that can provide measurement services for the hydrogen industry. The network will allow end-users to easily find and access laboratories and actors answering to metrology needs for energy gases such as the physical and chemical characterisation of gas mixtures. It should be considered to expand that service hub (once established) to a recognized European Network that can propose technical and scientific solutions for metrology needs on energy gases including hydrogen (e.g. measurement virtual service hub, technical provisions, scientific collaborations, training and knowledge centre).	*See above*	*See above*	*** 2015 STD action: Development of a scheme to encourage existing gas laboratories to obtain <u>accreditation</u> for performing hydrogen purity analysis (e.g. by proficiency testing schemes)** ⇒ 2018 status STD action: It should be seen if ISO 21087 could be used as a means to enable accreditation of new laboratories. EMPIR MetroHyVe is performing dissemination activities in order to facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrument manufacturers), standard developing organisations (ISO, CEN/CENELEC) and end users. It is setting up an online virtual measurement service hub (via a website) that will list all calibration and measurement laboratories in Europe that can provide measurement services for the hydrogen industry. The hub will allow end-users to easily find and access these laboratories.	Complementary actions are taking place to enable existing and new laboratories to perform hydrogen purity analysis. This work is complemented by the development of sampling strategies (EMPIR MetroHyVe)	PNR: 2-3 years Standardisation: 1-2 years	***PNR:*** ***TBC on completion of existing activities*** ***Standardisation:*** *Urgency:* ***Start as soon as PNR is ready for implementation to standards.***	Standardization bodies, industrial and research organisations

4.4.2 Hydrogen applications

4.4.2.1 On board hydrogen storage/vehicles

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
On board hydrogen storage/vehicles							
*** 2015 PNR action: Improvement of testing methodologies and procedures for <u>mechanical impact</u> testing of hydrogen tanks (type approval)** ⇒ 2018 status PNR action: Testing for type approval does not only relate to mechanical impact, see explanation status standard. FCHJU HyPACTOR has provided recommendations for modified impact test in cylinder qualification programmes. In order to determine the impact capacity of a composite cylinder, HyPactor recommends to determine the threshold impact each cylinder design can absorb, without a reduction of burst capacity (inflexion point). Impact with higher energy than the threshold value has been demonstrated to have a significant effect on the burst capacity of the cylinder. Therefore, it is recommended for cylinder manufacturers to specify the threshold impact energy, and demonstrate by burst testing that the cylinder can still demonstrate minimum burst capacity. When no better indication is available, Hypactor proposes a formula to make a first estimate of the threshold. Cylinders that have been impacted by an energy higher than threshold energy should be rejected from further service. Hypactor has proposed an impact test program (impact test bench and impactor characteristics) to be part of type approval program.	* FCHJU HyPactor (2014-2017)	PNR gap filled	*** 2015 STD action: Harmonisation and uniformity of <u>test schemes</u> for hydrogen tank standards developed within ISO/TC 197/WG 18 (e.g. fatigue testing, failure mode considerations, bonfire testing, drop testing, safety factor determination, periodic inspection testing).** ⇒ 2018 status RCS/STD action: -Regarding Acoustic Emission tests, in 2018, a second ISO/DIS 19016.3 (Gas cylinders -Cylinders and tubes of composite construction - Modal acoustic emission (MAE) testing for periodic inspection and testing) is developed in ISO TC 58 SC4 WG15 (first DIS was registered in 2015) and is currently in balloting phase. - Regarding bonfire tests, PNR results from FireComp are integrated into the work ISO TC 58/SC3/WG 24 and are so far described as alternatives to traditional bonfire-testing of cylinders in combination with a specific Pressure Relief Device (PRD).The results and recommendations from FCHJU FireComp are referenced in ISO/TR 13086-2:2017 (ISO TC58/SC3/WG24) - ISO TC 197 WG 18 has developed ISO/DIS 19881 but PNR results have not been incorporated in the draft standard.	The second phase of the GTR 13 has started. Items relevant for the onboard hydrogen storage system that are currently being discussed are: fire test, materials, burst test, cycling test, impact test, H_2 sensors, performance-based tests for material compatibility and H_2 embrittlement, evaluation of performance-based test for long-term stress rupture, reduction of initial burst pressure from 225% to 200% NWP, etc. Investigation is ongoing on how to facilitate the reference of ISO TC 197 standards and the GTR13. The GTR phase is supposed to be finalised by the end of 2020 ([13]). Although there seemed to be initial reluctance towards using the PNR results (e.g. fire test, impact test) as part of the GTR, it is still on the agenda to be further explored. Whether the tests are fit for purpose still needs to be demonstrated. ISO 19881 needs to be re-assessed on the need to incorporate PNR results. Materials compatibility standards may need to be developed or adapted dependent on the outcome of GTR phase 2.	PNR: N/A (finished) RCS: GTR13 phase 2 finalised by 2020 Ad-hoc Task Forces on fire test, materials compatibility, burst pressure, improvement of test protocols	***PNR:*** ***TBC on completion of existing activities*** ***Standardisation (materials compatibility):*** *Impact:* **High** *Urgency:* ***Start now*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***2019-2020***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
*** 2015 PNR action: Improvement of testing methodologies and procedures for <u>thermal load</u> testing of hydrogen tanks** ⇒ 2018 status PNR action: FCHJU FireComp has proposed a new bonfire test procedure, based on two independent tests: 1) test of cylinder without protection device and 2) test of storage system with the protection device.	* FCHJU FireComp (2013-2016)	PNR gap filled			No further action required		Industrial and research organisations
*** 2015 PNR action: Development of characterisation/evaluation techniques for <u>damage quantification</u>, especially acoustic emission techniques for in-service inspection of hydrogen tank** ⇒ 2018 status PNR action: HyPACTOR recommends to use a combination of visual criteria and AE criteria for periodic inspection. Visual observation of loose fibres should lead to vessel rejection, whatever the elliptic damaged surface. When no fibre is broken, it may be possible to size an elliptic surface and when possible a depth. This elliptic surface should be compared to visual criteria of burst pressure reduction curve. Acoustic emission (AE) is better adapted to periodic inspection and calibration of AE criteria should be performed for each vessel design. An AE program is proposed to define/calibrate AE criteria.	* FCHJU HyPactor (2014-2017)	PNR gap filled, but follow up steps are needed. Qualification tests to be developed further to be applied in normal practice.		Transfer of knowledge to standardisation/regulatory bodies still missing.		*PNR/Standardisation: (N/A* *Uptake of technique not yet in place)*	Industrial and research organisations
			*** 2015 STD action: Facilitate future adoption of European standards through <u>standardisation platform</u> for hydrogen tank testing.** ⇒ not applicable , no necessity identified		PNR: N/A		Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
*** 2015 PNR action: Development of a <u>probabilistic approach</u> to determine hydrogen tank batch behaviour** ⇒ 2018 status PNR action: This is a longer term PNR action and requires further work	No PNR performed	PNR gap remains			PNR NA	***PNR:*** *Impact:* **Medium** *Urgency:* ***Start now*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***2019-2021*** ***Standardisation:*** ***TBC on completion of existing activities***	Industrial and research organisations
*** 2018 PNR action (new): <u>State of health assessment</u> of CHSS of vehicles exposed to extreme event or at end of life.** **Linked to topic above.** ⇒ 2018 status PNR action: No PNR performed	No PNR performed	PNR gap remains		May have relevance for EC vehicle regulation. Also possible link to ongoing activities on tank burst pressure at SAE and GTR phase 2. The issue of the real age or pre-damage of cylinders compared to artificial ageing has not yet been considered.	PNR NA	***PNR:*** *Impact:* **Medium** *Urgency:* ***Start now*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***2019-2022*** ***Standardisation:*** ***TBC on completion of existing activities***	Industrial and research organisations, emergency services

4.4.2.2 Fuel cells

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
Fuel cells							
Distributed generation							
*** 2015 PNR action: Improving testing methodologies for <u>performance characterisation</u> of single cells, modules and systems is ongoing (e.g. for cross-leak testing and performance testing at sub-zero temperatures).** ⇒ 2018 status PNR action: The FCHJU SOCTESQA has developed 11 generic test modules for cells and stacks in SOFC, SOEC and combined operation.	* FCHJU SOCTESQA (2014-2017)		*** 2015 STD action: Development of <u>testing methodologies</u> for stationary fuel cell systems to provide backup power, uninterrupted power supply or ancillary services to the grid.** ⇒ 2018 status STD action: Performance test methods for small stationary fuel cell systems (<10 kW) are covered by IEC 62282-3-201:2017 (Edition 2)	Standardisation gap is filled. No further action required than regular updates of the IEC 62282-3-XXX standard series		*N/A*	
			*** 2015 STD action: Development of harmonised RCS covering the <u>installation</u> of stationary fuel cell systems to the electricity grid** ⇒ 2018 status STD action: National codes apply. An overview of national regulations is provided by the FCHJU ENE.FIELD and PACE [14]	Gap is filled		*N/A*	
Reversible systems							
*** 2018 PNR action (new): Improving testing methodologies <u>for performance characterisation</u> of single cells, modules and systems is ongoing (e.g. for cross-leak testing and performance testing at sub-zero temperatures).** ⇒ 2018 status PNR action: The FCHJU SOCTESQA has developed 11 generic test modules for cells and stacks in SOFC, SOEC and combined operation.	* FCHJU SOCTESQA (2014-2017)	PNR gap addressed	*** 2018 STD action (new): Development of <u>safety, performance and installation requirements</u> for reversible fuel cells (single cell, stacks, modules, system)** ⇒ 2018 status STD action: Three standards are being developed in IEC TC 105 WG 13 on energy storage systems using fuel cell modules in reverse mode: Test procedures for PEM IEC 62282-8-102 (1) and SO IEC 62282-8-101 (2) single cell and stack performance including reversing operation as well as performance characterisation of power-to-power systems IEC 62282-8-201 (3)	Standards address performance requirements. Expand to include safety and installation requirements on system level is necessary Current standardisation action assumed to be finalised in 2019. New standardisation activities: 3 years		***PNR:*** *Impact:* **Medium** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2019-2022*** ***Standardisation:*** ***TBC on completion of existing activities***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
RAIL APPLICATIONS							
*** 2018 PNR action (new): Development of <u>safety, performance and installation requirements</u> for fuel cell system for trains**		Activities to be considered, similar as for maritime: - Bunkering (HRS, connectors, H2 quality) compatible with high flow refuelling; - FC + tanks system integration (safety and installation requirements). Storage solutions might be either CH2, LH2 or LOHC; - FC + tanks system performance testing. In addition, facilitate an impartial comparison of the performance of the FC systems for trains for the train integrators	*** 2018 STD action (new): Development of <u>safety, performance and installation requirements</u> for fuel cell system for trains** ⇒ 2018 status STD action: It is considered by OEMs that standardisation may be premature at this moment in time but regarding the high interest from many European regions, the need may arise quickly. On some occasions, EC Regulations 79/2009 and 406/2010 are used for type local approval of trains.	The gap is to set-up codes and standards to be used for referencing to regulations and for shortening the delay of national/local homologation. Recommendations from NOW study: issuing guidelines to aid permitting and the clarification of legal/regulatory requirements at national level (for example costs of infrastructure development if train operator and infrastructure provider are separate legal entities). Develop a standardisation roadmap with relevant actors involved (e.g. IEC TC 105 and UIC)	Standardisation depends on a pre-standardisation action (1.5 years estimate). Follow-up standardisation activity (3 years)	*PNR:* *Impact:* **High** *Urgency:* ***Start now*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***2019-2021*** ***Standardisation****:* *Impact:* **Medium** *Urgency:* ***Start now*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***2019-2020; 2020-2022***	Standardization bodies, international organisations, rail OEMs, train operators, FC system integrators
HEAVY DUTY ROAD VEHICLE APPLICATIONS							
PNR 2018: Bus roll-over testing GTR phase 2 is considering to include a bus roll-over test. This testing might need to be conducted in Europe, and the appropriate protocols implemented.			*** 2018 STD action (new): Review and possibly <u>update/expand existing standards</u> on fuel cell road vehicles** ⇒ 2018 status STD action: The standards developed for fuel cell vehicles in ISO TC 22 SC 37 were published in 2013 (ISO 23828:2013 (energy consumption measurement) and ISO 23273:2013 (safety)). GTR 13 phase 2 to look at including trucks, lorries and buses.	Review the necessity to update standards in ISO TC 22 SC37 regarding fuel cells. Vehicle requirements for interoperability need to be included in a standard.	*Timing Standardisation:* ***2019-2020***	***PNR:*** *Impact:**Medium*** *Urgency:* ***Start now*** *Time for finalisation:* ***Less than 3 years*** ***Standardisation****:* *Impact:* **High** *Urgency:* ***Start now*** *Time for finalisation:* ***Less than 5 years***	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
MARITIME APPLICATIONS							
*** 2018 PNR action (new): Develop an appropriate PNR roadmap/action plan to address PNR gaps in the maritime sector** ⇒ 2018 status PNR action: The European Maritime Safety Agency in its study "the use of fuel cells in shipping" has identified several major gaps for using fuel cells and hydrogen in/for waterborne applications. These gaps relate to a wide variety of areas including, bunkering of liquid and gaseous hydrogen fuel; onboard storage systems (qualification of pressure tanks, safety, usage in enclosed areas); fuel cell systems (use of LNG in high-temperature fuel cells for onboard power and heat, safe handling of hydrogen releases, ventilation requirements, piping requirements, onboard fuel reforming); ship life phases (procedures for commissioning, docking and maintenance); fuel specificities (hydrogen behaviour under shipping conditions).	* FCHJU MARANDA (2017-2021)	PNR gaps to be addressed	*** 2018 STD action (new): Develop a standardisation roadmap/actions to address standardisation gaps (see PNR gaps) in the maritime sector** ⇒ 2018 status STD action: The aspects that standards need to cover are diverse and include items like safety (e.g. fuel, ventilation, piping, risk assessment, releases, enclosed environments), performance (e.g. fuel cell system), installation (e.g. production and storage of hydrogen, LNG boil-off use, fuel cell system, ship integration), qualification methods (e.g. onboard storage system) and interoperability (e.g. bunkering).	Develop a standardisation roadmap/action plan with relevant actors involved (e.g. IEC TC 105, ISO TC 197, CEN/CLC TCs, EMSA, IMO) also considering regulatory needs. Identify standardisation work that can already be addressed.	PNR: 2-3 years Standardisation: N/A	***PNR:*** ***TBC on completion of existing activities*** ***Standardisation:*** *Impact:* **High** *Urgency:* ***Start now*** *Time for finalisation:* ***Less than 5 years*** *Timing:* ***2019-2022***	Standardization bodies, international organisations, industrial and research organisations
AVIATION APPLICATIONS							
*** PNR action (new): Hydrogen fuel cells in airborne applications** ⇒ 2018 status action: a joint EUROCAE/SAE report compiling the considerations for airborne application of hydrogen fuel cells is on going. This document provides a comprehensive analysis on the use of hydrogen as fuel. The experience gained with mature fuel cells in terrestrial applications and the handling of other gases in aviation uses, as presented herein, will help on alleviating safety concerns and on demystifying the usage of hydrogen in aviation.	* FCH 2 JU HYCARUS, FLHYSAFE, HEAVEN	PNR gaps to be addressed by projects.	*** 2018 STD action: Hydrogen fuel cells in airborne applications** ⇒ 2018 status STD action: after the publication of SAE Aerospace Information Report (AIR6464) intended to provide comprehensive reference and background information pertaining to the installation of fuel cells on-board aircraft for the purposes of supplying auxiliary power rather than using separate ground power systems and of the technical guidelines (AS6858) for the safe development, testing, integration, validation and certification of proton exchange membrane fuel cell systems, including fuel storage, fuel distribution and the integration of electrical systems into the aircraft, report compiling the considerations for airborne application of hydrogen fuel cells is on going.	Develop a standardisation roadmap/action plan with relevant actors involved (e.g. SAE, IEC TC 105, ISO TC 197, CEN/CLC TCs, EASA, FAA) also considering regulatory needs. Identify standardisation work that can already be addressed as interoperability (e.g. bunkering).	PNR: 2020 Standardisation: SAE/EUROCAE WG 80	***PNR:*** ***TBC on completion of existing activities*** ***Standardisation:*** *Impact:* **Medium** *Urgency:* ***Start: Less than 5 years*** *Timing:* ***2019-2020; 2020-2022***	Standardization bodies, international organisations, industrial and research organisations

4.4.3 Additional hydrogen system and usage PNR and standardisation actions since the 2015 report

In comparison to the 2015 report, some new challenges have been identified. These are briefly highlighted as yellow in the section 4.4.1 and 4.4.2 and expanded upon in this section.

The new challenges have been mainly identified in the area of fuel cells and cover the development of a standardisation roadmap for the development of safety, performance and installation standards for new fuel cell applications such as trains, trucks and waterborne applications. Other new challenges are identified for reversible fuel cells and state-of-health determination of the on-board hydrogen storage system after an extreme event.

1. Hydrogen and fuel cell railway applications: Safety, performance and installation standards are needed for railway applications. However, considering that there are currently only a few activities ongoing (e.g. the Coradia iLint train developed by Alstom), some OEMs consider that standardisation may still be premature time. On some occasions, EC Regulation 79/2009 and 406/2010 are used for type local approval of trains. Nevertheless the high interest of many European regions to use hydrogen powered trains either for passenger or shunting applications may lead to take actions quickly to facilitate the homologation of these trains. It is therefore suggested that a standardisation roadmap is first developed from now, with imput from all the relevant stakeholders. Once the roadmap is drafted, the standardisation actions can commence.

2. Hydrogen and fuel cell maritime applications: Standards are needed for maritime applications. It is noted that several projects developing fuel cell applications face barriers due to a lack of standards. The European Maritime Safety Agency study on the use of fuel cells in shipping has identified several major PNR and standardisation gaps for using fuel cells and hydrogen in/for waterborne applications. Considering that the International Maritime Organisation regulations do not include hydrogen and fuel cells specifically, it is worth developing a roadmap on PNR and standardisation with the relevant stakeholders, as the gaps identified are numerous. For example, the EMSA study [2] highlights gaps such as bunkering of liquid and gaseous hydrogen fuel; onboard storage systems (qualification of pressure tanks, safety, usage in enclosed areas); fuel cell systems (use of LNG in high-temperature fuel cells for onboard power and heat, safe handling of hydrogen releases, ventilation requirements, piping requirements, onboard fuel reforming); ship life phases (procedures for commissioning, docking and maintenance); fuel specificities (hydrogen behaviour under shipping conditions). Once the roadmap is drafted, the standardisation actions can commence.

3. Truck applications: With the increasing interest in using hydrogen and fuel cells in medium and heavy duty applications (e.g. Nikola, Hyundai, Toyota), the need for dedicated standards for these applications increases. Currently, ISO standards and UNECE GTR13 (R134) exist for fuel cell vehicles regarding safety, refuelling protocols, and energy consumption measurements. Relevant stakeholders should review whether these standards are sufficient, up-to-date and whether new standards should be developed.

4. Reversible fuel cell systems: Reversible systems can operate both in fuel cell and electrolysis mode. This technology is currently being demonstrated in a real operating environment (e.g. in the FCH 2 JU GrinHy project). PNR has been performed in the FCH JU project SOCTESQA regarding

performance test procedure development. Standardisation is taking place with IEC TC 105 regarding single cell and stack testing procedures for reversed operation as well as performance characterisation of power-to-power systems (IEC 62282-8 family). These standardisation activities should be expanded to include safety and installation requirements at the system level.

5. State of health determination of the on-board hydrogen storage system after an extreme event: First responders do not have the proper means available to determine the state of health of the onboard hydrogen storage system after the vehicle is involved in an extreme event, such as a crash or a fire. PNR should be performed to help these responders to assess the state of health of the system. The Annual Work Plan of the FCH 2 JU contains a call on training of first responders, which may potentially contribute towards closing this knowledge gap.

6. Setting up of a European Metrology Network: Efforts are currently ongoing to develop a European Metrology Network for Energy Gases including an online virtual measurement service hub (via a website) that will list all calibration and measurement laboratories in Europe that have the capability to provide measurement services for the hydrogen industry. The network will allow end-users to easily find and access laboratories and actors answering to metrology needs for energy gases for the physical and chemical characterisation of gas mixtures. The expansion of the service hub should be considered once established as a recognized European Network that can propose technical and scientific solutions for metrology needs on energy gases including hydrogen (e.g. measurement virtual service hub, technical provisions, scientific collaborations, training and knowledge centre).

4.4.4 Standardisation actions related to TF4

For TF4, on the topic of hydrogen quality assurance, it should be determined whether ISO 21087 could be used for enabling laboratories to perform certified measurements of hydrogen quality /composition. For "Fuel Cells – Reversible Systems", the improvement of 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). The related development of safety, performance and installation requirements for reversible fuel cells (single cell, stacks, modules, system) is necessary. Three standards are being developed in IEC TC 105 WG 13 regarding energy storage systems using fuel cell modules in reverse mode: Test procedures for PEM IEC 62282-8-102 (1) and SO IEC 62282-8-101 (2) single cell and stack performance, including reverse operation and performance characterisation of power-to-power systems IEC 62282-8-201 (3). As for fuel cells for rail applications, the development of safety, performance and installation requirements for fuel cell systems for trains has been identified as a gap. However, some OEMs consider that standardisation may be premature at this time, and it is suggested that first a standardisation roadmap be developed. In the case of fuel cells for truck applications, a review and possible update/expansion of the scope of existing standards on fuel cell road vehicles should be undertaken. The standards developed for fuel cell vehicles in ISO TC 22 SC 37 were published in 2013 (ISO 23828:2013 (energy consumption measurement) and ISO 23273:2013 (safety)). For maritime applications, an appropriate standardisation roadmap and actions to address standardisation gaps has to be developed. The aspects that standards must cover are diverse and include items like safety (e.g. fuel, ventilation, piping, risk assessment, releases, enclosed environments), performance (e.g. fuel cell system), installation (e.g. production and storage of hydrogen, LNG boil-off use, fuel cell system, ship integration), qualification methods (e.g. onboard storage system) and interoperability (e.g. bunkering).

4.4.5 Roadmap for hydrogen system and usage

As for the 2015 report, 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 fuel cells. The actions proposed for all these topics have been visualised in the Task Force 4 roadmap which include timelines (start and length of the arrow), prioritisation (red is very high priority) and impact (high impact actions are in bold) of the actions. A yellow arrow indicates that this is a new action, whereas a dotted lean arrow indicates that a PNR or standardisation action is delayed in compared to the roadmap in the 2015 report. In comparison to the 2015 roadmap, the PNR and standardisation actions are more sequentially aligned, which results in a more detailed visualisation of actions in the roadmap.

4.4.5.1 Changes in terms of prioritisation for hydrogen system and usage

In the 2015 report, many actions related to the hydrogen refuelling infrastructure received a high priority, especially in the area of protocols, metering, connectors, quality and quality assurance. Between 2016 and 2018, several PNR and standardisation activities have been initiated and further developed. This concerns all of the aforementioned areas. Consequently, some of the 2015 priorities can be re-prioritised, as metering, connectors, quality and quality assurance areas are nowadays quite well covered by PNR and/or standardisation activities. These PNR/standardisation activities are, however, still ongoing and the final results are pending, so a final assessment of the priority level should take place when these activities are complete. In terms of the roadmap, these priorities are, however, no longer marked as very high, awaiting the final results of the PNR and/or standardisation actions.

However, hydrogen refuelling infrastructure topics like the risk assessment, refuelling conditions and the development of protocols for medium and heavy duty applications are still considered as very high priority as some of these actions have not yet delivered sufficient results (risk assessment) or are yet to be started (refuelling conditions and protocols).

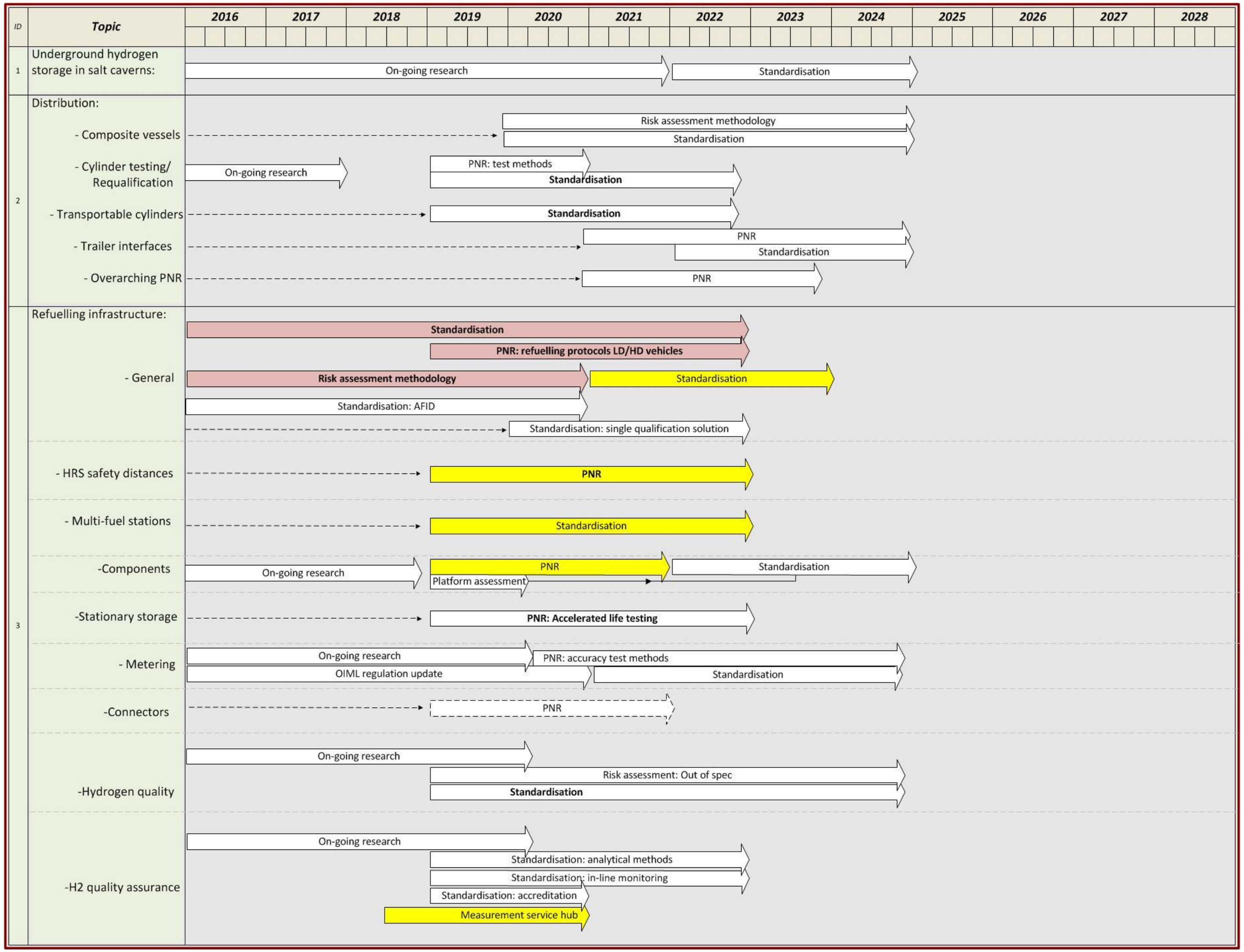

Figure 6 PNR and Standardisation actions roadmap for pure hydrogen issues, Part 1. Yellow marks new activities compared to the 2015 report, red the actions with the highest impact.

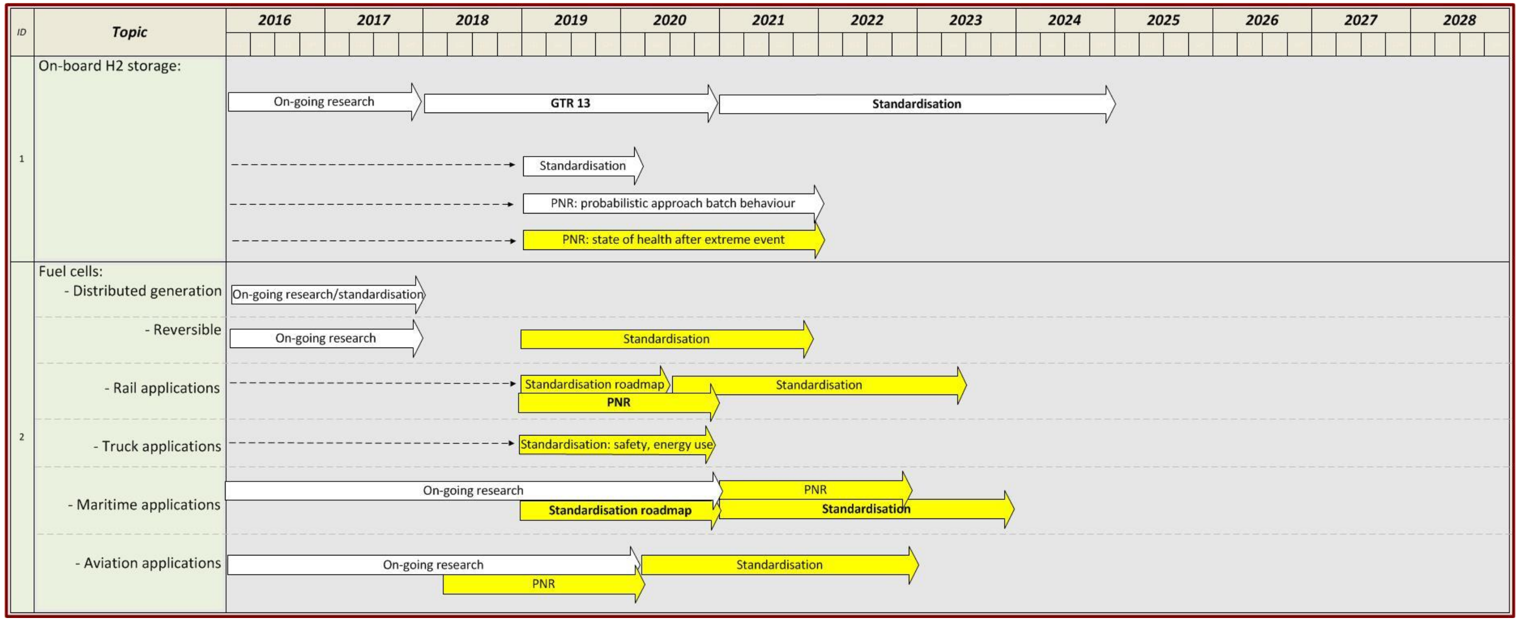

Figure 7 PNR and Standardisation actions roadmap for pure hydrogen issues, Part 2. Yellow marks new activities compared to the 2015 report, red the actions with the highest impact.

4.5 Task Force 5: Cross cutting

In the table below an update of the status of the PNR and standardisation actions within the scope of TF 5, as defined in the SFEM WG Hydrogen report of 2015, is described. The impact, urgency, time for finalisation and timing of PNR and standardisation activities are proposed.

4.5.1 Safety

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
H2 SAFETY							
*** 2015 PNR action:** **General hydrogen safety topics** (such as Spontaneous ignition in complex geometries and enclosed spaces; Numerical calculation with validated predictive tools for defined release scenarios; Mitigation and control of hazards and risks) ⇒ 2018 status PNR action: Project **HyTunnel-CS** PNR for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces. (CEN JTC6 has also identified this topic as high priority) Project **HySEA** (2015 - 2018) pre-normative research on vented deflagrations in enclosures and containers for hydrogen energy applications Project **PRESLHY** (2017-2020) pre-normative research for the safe use of cryogenic liquid hydrogen (LH2) In 2017, the FCH JU has formed the European Hydrogen Safety Panel (EHSP).	* Project HySEA * Project PreslHy * Project HyTunnel-CS	See outcome of Hydrogen Safety Priority Workshop **Project SUSANA (2013-2016)** physical and mathematical modelling of phenomena and scenarios relevant to hydrogen safety. No remaining gaps identified by project. Project **HyIndoor** (2012-2014) Pre-Normative Research on the indoor use of fuel cells and hydrogen systems identified the following remaining gaps: • comprehensive design of forced ventilation systems • the structural response of structures to internal explosions • prediction of consequences for vented explosion in realistic conditions • reliable use of CFD in risk assessment The PRESLHY project may not be able to fill all knowledge gaps for the LH2 topic.	**IEC 60079-0 / ISO 26142 / ISO 23273 / IEC 61779 / IEC 60079-10 / ISO TR 15916:2015** **ISO TR 15916:2015** HRS safety: AFID standardisation framework, mandate M533 to CEN TC268 ISO TC197 WG24 **Vehicle safety:** project TAHYA on CHSS, aims also at "*RCS activities to propose updates on GRT13 and EC79* " **ISO TR 15916:2015** **CEN/CENELEC JTC 6** Activities on tunnels and closed parking spaces going on in JTC 6.		PNR: Continuous activity Standardisation:	Impact and Urgency depends on the particular gap, in general hydrogen safety is crucial for public acceptance of the technology.	Standardization bodies, industrial and research organisations

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers Existing activities	 Recommended additional activities	Actors involved
*** 2018 PNR action: <u>Odorisation of hydrogen</u>**		The odorization of hydrogen is a safety measure to enable the detection of leaks . The e suitability of odorants, in particular sulfur free variants, should be assessed, together with performance tests to determine the effects in hydrogen applications.					
H2NG SAFETY							
*** 2015 PNR action: <u>improve knowledge on H2NG properties</u>** ⇒ 2018 status PNR action: BAM work on ATEX classification	BAM/DBI project on explosion protection for mixtures underway.	Past activities: Project **NaturalHy** (2004-2009) Preparing for the hydrogen economy by using the existing natural gas system as a catalyst. There is a need to distinguish between hydrogen and blends - Cf Hydeploy (end use) versus H21 (networks). Public perception of safety. Gaps according to Research Priority Report on Hydrogen Safety 2016 •All kinds of mitigating safety measures (TPRD, Explosion Protection Systems, etc.) have to be certified for H2/NG •Re-assessment of the ATEX Zoning should be standardized for H2/NG	**IEC 60079-0 / ISO 26142 / ISO 23273 / IEC 61779 / IEC 60079-10**	*** 2015 standardisation action** Harmonisation in the approach to determine hazardous zones defined in the ATEX directive considering the assumed leak sizes for H2NG	*PNR estimate: at least 3 years, depending on remaining gaps Standardisation actions: 3-5 years*	*Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2018*** *Timing Standardisation:* ***2019-2020***	Standardization bodies, industrial and research organisations, European Commission

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
*** 2018 PNR action: <u>Upper and lower flammability limits at SATP</u>**	Research Priority Report on Hydrogen Safety 2016 [15]	•P_{max} and dp/dt max and limit concentration for gas mixture characterization (Hydrogen H2- Natural Gas NG still in same class as NG)[9] •Flame temperatures, thermal radiation of the flame, viscosity of gas (mass flow) at SATP •Minimum safety experimental gap / Minimum Ignition Current at SATP •Flame length of H2NG mixtures					Standardization bodies, industrial and research organisations, European Commission
*** 2018 PNR action: <u>Accidental releases consequences assessment</u>**		Past activities: Project **NaturalHy** (2004-2009) Large scale tests have been conducted of H2NG flames but no criterium exists to define the scenario (jet fire or UVCE) that should be taken into account in regard to H_2 concentration and/or congestion level				*Impact :* **High** *Urgency : to be completed if rich H2NG mixtures are planned*	Standardization bodies, industrial and research organisations, European Commission
*** 2018 PNR action: <u>Ignition probability of large H2NG releases</u>**		Correlations have been derived for large NG releases ignition probability calculation. Whether these are they still valid for H2GN mixtures needs to be verified.					Industrial and research organisations

9 This work has been recently accomplished by the group of V. Schroeder, BAM and was presented at least partially at the WHEC 2016 in Zaragoza and at a DECHEMA conference in Freiburg: 15th International Symposium on Loss Prevention and Safety Promotion in the Process Industries and accompanying exhibition 5 - 8 June 2016 Konzerthaus Freiburg, Germany.

4.5.2 Hydrogen compatibility of materials

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RCS	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
Materials compatibility							
*** 2015 PNR action** **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. ⇒ 2018 status PNR action:	Past projects: NaturalHy, HIPS. Project MATHRYCE has advanced knowledge on crack rate for pure hydrogen with input to standardisation. Currently ongoing: Hydeploy, H21	GTR13 Phase 2 has identified a list of priorities including international agreement on selection criteria of H_2-compatible metals	**EN ISO 17081 / EN ISO 7539 / EN 2831:1993 / EN 2832:1993 / EN 10229:1998**	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. A standards for hydrogen compatibility with polymer materials is not yet available.		*Impact:* **High** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2018-2021*** *Timing Standardisation: t.d.c.*	Research institutes, standardization bodies, industry and testing laboratories.
*** 2015 PNR action** **Methods for evaluating compatibility of materials with hydrogen** ⇒ 2018 status PNR action:			**ASME Article KD-10 / SAE J2579 / CSA CHMC1 / CSA HPIT1 / ISO 11114-4**	Lack of experimental data, consensus on methods and metrics, and overly conservative approaches are still pending issues for the standards: ASME Article KD-10 / SAE J2579 / CSA CHMC1 / ISO 11114-4 A standard for hydrogen compatibility with polymer materials is not yet available.			
*** 2015 PNR action** **Materials selection criteria for H_2-compatibility** ⇒ 2018 status PNR action:	Project **MAtHryce** (2012 - 2015) Material testing and design recommendations for components exposed to hydrogen enhanced fatigue	Correlation between specimen and component tests for the characterisation of susceptibility to hydrogen embrittlement and enhanced fatigue. **MATHRYCE** has defined a methodology for metallic cylinders design/lifetime assessment based on lab-scale tests and taking into account hydrogen enhanced fatigue, which have been presented to ISO/TC 197, WG 15 There is a need for validation of lab experiments with full scale components testing (source: Research Priority Report on Hydrogen Safety 2016) Stainless steel compatibility to H2 is not welknown for many existing SS which might be cheaper than the currently used ones (e.g. AISI 316L).	**ISO/CD 19884**	An annex has been provided for the current draft ISO/CD 19884 standard based on the use of a hydrogen sensitivity factor to be applied to the life of a component tested under hydraulic loading. Topics such as Al-based alloys and welding are at the moment under discussions in the frame of the UN-ECE GTR13.			

4.5.3 Training and Education

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RSC	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
Training and Education							
*** 2015 PNR action** **Competency management system (CMS)** ⇒ 2018 status PNR action: No known activities				Technical Specification could be developed including schemes with the needed training and their criteria in relation to the specific discipline		*Impact:* **High** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2018*** *Timing Standardisation:* ***2019-2020***	Research, industry, training institutions, policy makers, consumer representations and standardization bodies
*** 2015 PNR action** **Training about the safety aspects of hydrogen/H2NG** ⇒ 2018 status PNR action: Addressed in various projects, but an easily accessible respository of training materials is needed.	**KNOWHY, HYACINTH, HYPROFESSIONALS, HyDeploy. HyResponse, HYFACTS.** There is often a training package in each project. The HyResponse project (2014-2016) created a European Hydrogen Safety Training Platform, which develops a tool box for European First Responders to help them assessing the status and making decisions oemergency response level in case of incident/accident on site.	Amendment of existing procedures as norm. Focus on gaps where we can take action. A database should be created, focussing on hydrogen mobility. H2NG aspects have not been addressed specifically. Current training programmes are focussed mainly on fuel cells.		Standards will only result once the outputs of these projects can be fully utilized.			
*** 2018 PNR action (new): Harmonised training for technicians**		Bus operators need to be trained in a harmonised manner, given the increased deployment of fuel cell buses.					

4.5.4 Energy policy/Regulation

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RSC	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
Legal status of power-to-gas plants and of energy storage facilities							
*** 2015 PNR action** **Clarification on legal status of PtG plants and energy storage facilities** ⇒ 2018 status PNR action: HyLAW project identified barriers related to the status of power-to-gas, such as the basic legal definition, the classification as end-user of electricity or the barriers to being supplied with renewable electricity through guarantees of origin.	Direct versus indirect connection and RED definitions. Defining P2G as indirect means of energy storage beyond just conversion to hydrogen (Sector Coupling).		Hylaw also developing advocacy position to develop policy framework on hydrogen from renewable electricity, and conversion of hydrogen to fuels, whether stationary, industrial or mobile. This is an active topic.	Specification of the methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin Definition of a hydrogen network versus a natural gas network. Standards are different, clarification needed.		*Impact:* **High** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2018***	Public authorities, policy makers, industry
Clarification of Industrial Emissions Directive							
*** 2015 PNR action** **Full survey of member states on how the directive is applied.** ⇒ 2018 status PNR action: Information available for several member states, such as France	DG Environment recently posted some guidance intended to help with interpretation of the meaning of "production in industrial quantities" within the IED Directive on their website [16].	Full survey not yet conducted				*Impact:* **High** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2018*** *Timing Standardisation:* ***2019-2020***	

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RSC	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
*** 2015 PNR action <u>Clarification of whether small scale electrolysers fall under the IED</u>**, in order to simplify the permitting process ⇒ 2018 status PNR action:	There is no clear distinction between production of hydrogen at industrial and non-industrial scale.						
RENEWABLE ENERGY DIRECTIVE							
*** 2018 PNR action: <u>Renewable Energy Directive and status of hydrogen</u>**	HyLAW project on identification of legal rules and administrative processes applicable to fuel cell and hydrogen technologies' deployment, identification of legal barriers and advocacy towards their removal.	RED II: the Directive envisages different connection possibilities for electrolysers: most important of these is that when there is a grid connection, "a reliable Union methodology" should be developed.	**Hydrogen Europe Position** Electricity for fuel production can be fully counted as renewable, if connected to the grid, but: • Can provide evidence that the respective electricity has been provided without importing electricity from the grid. If electricity has been imported from the grid: • Renewable electricity generation would have been curtailed if not consumed by the plant or • Renewable properties have been demonstrated through the use of guarantees of origin or power purchase agreements			*Impact:* **High** *Urgency:* ***Start within 1 years*** *Time for finalisation:* ***Less than 2 years*** *Timing Standardisation: see Guarantee of Origins*	

4.5.5 Certification of green hydrogen

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RSC	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
Guarantees of origin							
*** 2015 PNR action** **Clarification of whether standards should be applied at EU level or if national rules can apply.** ⇒ 2018 status PNR action: CertifHy has defined the main technical specifications of the framework of GoO, as well as a set of rules and obligations and also provided a roadmap an EU-wide implementation	Following the CERTIFHY project, stakeholders platform, consultation and implementation First GO based on Certify issued, 75 000+ CertifHy Green and Low Carbon Hydrogen GOs are available on the market now.		*** 2015 standardisation action** EU level certification scheme **NWIP CEN-CLC/JTC 6/WG 2** ***2018 Publication RED II including paragraph:** Member States or the designated competent bodies shall put in place appropriate mechanisms to ensure that guarantees of origin shall be issued, transferred and cancelled electronically and are accurate, reliable and fraud-resistant. Member States and designated competent bodies shall ensure that the requirements they impose are compliant with the standard **CEN - EN 16325.**	RED II (59) Guarantees of origin which are currently in place for renewable electricity should be extended to cover renewable gas. There is agreement that CEN/CLC/JTC 14 and CEN/CLC/JTC 14 work together on the revision of EN 16325 with the inclusion of hydrogen. A methodology is needed for guarantees of origin for renewable electricity taken from the grid. Member States shall ensure that the origin of energy produced from renewable sources can be guaranteed as such within the meaning of this Directive, in accordance with objective, transparent and non-discriminatory criteria. Member States may arrange for guarantees of origin to be issued for non-renewable energy sources.	2020	*Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2017*** *Timing Standardisation:* ***2019-2021***	Industry, consumer representatives, standardization bodies and accreditation bodies
*** 2015 PNR action** **Hydrogen products** could be differentiated (blue, green hydrogen) depending on the production path. ⇒ 2018 status PNR action: CERTIFHY green and low-carbon hydrogen							
*** 2015 PNR action** **The greenhouse gas savings calculation method** should be clarified. ⇒ 2018 status PNR action:							

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RSC	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
CERTIFICATION OF GREEN HYDROGEN							
*** 2018 PNR action (new): <u>Certification scheme will be legislation dependent, and based on the outputs of CertifHy+</u>**	The CertifHy scheme includes two different GO Labels: • CertifHy Green Hydrogen (from renewable sources and having a greenhouse gas balance below a defined threshold), and • CertifHy Low Carbon Hydrogen (having a greenhouse gas balance below a defined threshold).	CertifHy has established a European GO scheme covering the entire upstream supply chain to the production device exit gate at defined quality and providing the framework for ensuring transparent information. The CertifHy scheme is technology neutral as long as the requirement to comply with the definitions is met.	**Development ongoing for standardisation NWIP CEN-CLC/JTC 6/WG 2**	There is agreement that CEN/CLC/JTC 14 and CEN/CLC/JTC 14 work together on the revision of EN 16325 with the inclusion of hydrogen.		*Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2017*** *Timing Standardisation:* ***2018-2020***	

4.5.6 Techno-economic assessment

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RSC	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
TECHNO-ECONOMIC ASSESSMENT							
*** 2015 PNR action** **<u>exhaustive techno-economic evaluation of the cost of hydrogen injection into the natural gas grid</u>** ⇒ 2018 status PNR action: Mentioned in FCH JU Call 2018 topic, but there was no successful project. Addressed as part of a study funded by DG ENER; results expected in 2019.	Many reports are merging; commissioned both by industry and the EU both at National and EU level. FCHJU call 2018 will lead to project which develops CB analysis German assessments, Marcogaz Working Group	European level assessment of CBA	Standardisation request from CEN 2017 will feed this activity		2020+	*Impact:* **High** *Urgency:* ***Start within 5 years*** *Time for finalisation:* ***Less than 5 years*** *Timing PNR:* ***2018***	

4.5.7 Terms and definitions

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RSC	Remaining RCS gap/comments	Timeline / Roadmap identifiers: Existing activities	Timeline / Roadmap identifiers: Recommended additional activities	Actors involved
TERMS AND DEFINITIONS							
	IEA 38, projects under FCH JU - CertifyHy, Reports from IEA HIA, NREL etc.)	PNR gap analysis needed	*** 2015 standardisation action** common set of terms and definitions for H2 and H2NG ⇒ In progress, JTC6 and ongoing work IEA 38 **PWIP CEN-CLC/JTC 6/WG 1**	To be done within CEN-CLC/JTC 6/WG 1	ongoing	*Impact:* **High** *Urgency:* ***Start immediately*** *Time for finalisation:* ***Less than 5 years*** *Timing Standardisation:* ***2018-2020***	Research institutes, industry, standardization bodies , regulatory bodies and testing laboratories
			*** 2018 Standardisation action:** **Terminology** (from relevant electrical grid terminology to electrolyser terminology) CEN/CENELEC JTC6 WG1 – initial phase	Alignment of "wording" between grid operators and ancillary services providers (consistent with terminology work in other TFs) Incorporation of JRC project on electrolyser terminology	2018-2021	Impact: **High** Urgency: **Start immediately** Time for finalisation: **Less than 5 years** Timing Standardisation: **2018-2021**	e-DSO, e-TSO, Standardization bodies, industrial and research organisations

4.5.8 Circular economy - recycling and sustainability

Status PNR	Ongoing PNR activities	Remaining PNR gaps/comments	Status RSC	Remaining RCS gap/comments	Timeline / Roadmap identifiers		Actors involved
					Existing activities	Recommended additional activities	
Life Cycle Assessment							
*** 2018 PNR action (new): Impact of FCH and Power-to-gas technologies on the environment should be assessed**	Currently many FCH JU projects are performing LCA analyses. A review and gap analysis of these deliverables is being carried out by the JRC.	Not clear at this stage					Research institutes, industry
Recycling							
***2018 PNR action (new): recycling and dismantling of FCH technologies**	*project Hytechcycling	Not clear at this stage			2019		

4.5.9 Update on Cross-cutting issues of PNR and standardisation actions since the 2015 report

A short summary of the most relevant developments is provided. In comparison to the 2015 report, some new challenges have been identified. These are highlighted in yellow in the previous tables.

1. H2/H2NG safety: 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. Some knowledge gaps have been closed, in particular on the properties of H2NG. For pure hydrogen there are ongoing activities related to LH2 and hydrogen in semi-enclosed spaces, such as tunnels. At this stage it is not clear what the remaining gaps will be. For 100% hydrogen the issue of odorisation has been raised, in particular as commonly used odorants could damage PEM fuel cells.

There is ongoing work related to the characterization of the detonation sensitivity of H2NG mixtures via measurements of the induction time in shock tubes and rapid compression machines.

HYSAFE met with the JRC in 2016 and 2018 for a workshop on research priorities for hydrogen safety (RPW2016, see [15]). Much of the discussion related to pure hydrogen systems but there were a number of observations and recommendations that emerged relating to hydrogen blends, in particular concerning flammability limits.

The following list reflects the open issues identified at the RPW2016 related to the safety issues of the gas grid, mainly pointing to H_2 embrittlement and assisted corrosion (all of which are already listed in TF3):

- List of materials compatible with H2NG systems, taking into account collected data and available standardization deliverables such as the technical report ISO/TR 15916:2004 7.
- Behavior of H_2 in H2NG on plastics pipes, valves, fittings in house gas installations, storage cylinders - effect on components.
- Metering (additionally supported by the recommendations of the EC RCS strategy coordination group) and mixture concentration and homogeneity control [10].
- Influence of hydrogen on integrity of underground pore storages.
- Hydrogen-induced microbiological reactions.
- Permeation effects[11].

Regarding H2NG, the safety priority workshop 2016 called for the investigation of the basic properties such as upper and lower flammability limits, flame temperatures, thermal radiation of the flame and flame length of H2NG mixtures.

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[10] A joint working group WELMEC WG 11, CEN TC 237, FARECOGAZ, GERG and MARCOGAZ is finalizing an overview of the expected behavior of the actual meter types when renewable gases like biogas, mixture of hydrogen and natural gas-hydrogen are used.

[11] Some results have been provided by projects HyUnder and H2Store. Some additional insights might be derived from investigations of nuclear waste storage

The consequences of accidental releases of H2NG should be assessed. Large scale tests have been conducted of H2NG flames but no criterium exists to define the scenario (jet fire or UVCE) that should be taken into account in regard to H_2 concentration and/or congestion level. Also the ignition probability of large H2NG releases has not yet been fully determined. Correlations have been derived for large NG releases ignition probabilities, but whether these are still valid for H2NG mixtures needs to be verified.

2. Materials compatibility: There may be knowledge gaps for specific materials such as polymers or even metallic materials as stainless steels. Consensus on metrics and methods is also not yet available. Materials selection criteria for H_2-compatibility are considered a gap, there is a need for validation of lab experiments with full scale components testing (source: Research Priority Report on Hydrogen Safety 2016). Also, topics such as Al-based alloys and welding are at the moment under discussion in the frame of the UN-ECE GTR13.

3. Training and education: In spite of a number of past and ongoing activities, several gaps remain. The training of bus operators will soon become a critical issue with the deployment of a large number of hydrogen buses. A competency scheme could help to ensure the proper qualification of personnel.

4. Energy policy/regulation: The project HYLAW funded by the FCH 2 JU has performed a review of the relevant regulations and has identified barriers. The major legislation regarding power-to-gas is the recast RED. Recital (90)[12] notes that “Renewable liquid and gaseous transport fuels of non-biological origin are important to increase the share of renewable energy in sectors that are expected to rely on liquid fuels in the long term. To ensure that renewable fuels of non-biological origin contribute to greenhouse gas reduction, the electricity used for the fuel production should be of renewable origin […].”

Therefore, the Directive envisages different connection possibilities for electrolysers: most important of these is that when there is a grid connection, “a reliable Union methodology” should be developed. A number of factors should be included in this methodology, including demonstration of the renewable properties and other appropriate criteria through, inter-alia, possible power purchase agreements, a temporal and geographical correlation or an element of additionally (e.g.: the fuel producer is adding to the renewable deployment or to the financing of renewable energy).

This methodology should be finalised before 31 December 2021 and should be developed at European level (as a delegated act). Once the Commission, following a consultation with Member States experts and public consultation (e.g.: with industry), has adopted the act, Parliament and Council generally have two months to formulate any objections. If they do not, the delegated act enters into force. The interaction EC and Member States is needed here for clarity on possible interpretation.

A methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin needs to be developed. For the Industrial Emissions Directive

[12] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001

some new information has been made available but an EU survey and further clarification on the status of electrolysers are still missing.

5. Certification of green hydrogen: There are many ongoing activities at PNR and standardisation level. A hydrogen guarantee of origin stakeholder platform has been established and a pilot scheme will be run. The target is EU-wide deployment of the scheme. A standard for a hydrogen guarantee of origin is currently being drafted. CertifHy has established a high-quality European GO scheme covering the entire upstream supply chain to the production device exit gate at defined quality and providing the framework for ensuring transparent information. It was established and is continuously reviewed and improved by means of a multi-stakeholder dialogue. The CertifHy scheme is technology neutral as long as the requirement to comply with the definitions is met. Any technology that can provide evidence that the environmental requirements for the amount of hydrogen produced are met are included in the scope of the CertifHy scheme. In addition to designated hydrogen production technologies, the technologies producing hydrogen as by-product are included in the CertifHy scope as far as transparent information about the main product is included in the GO and the basis of the GHG emissions allocation complies with the principles of the CertifHy scheme.

6. Sustainability/circular economy: The experts emphasised the need to assess the environmental impact of FCH technologies. There are many ongoing activities on LCA, and a FCH JU project is looking into recycling/dismantling issues. The outcomes of all the LCAs already carried out should be compared and a gap analysis performed. For life cycle assessment, a common set of terms and definitions for H2 and H2NG is needed. This work is in progress, as JTC6 (PWIP CEN-CLC/TC 6/WG 1) and IEA/HIA Task 38 are looking into terminology aspects.

4.5.10 Roadmap for Cross-cutting issues

In the 2015, no roadmap specific to cross-cutting issues was provided. However, several high priority action items had been identified in the report. These issues were a clarification of the legal status of power-to-hydrogen plants, the certification of green hydrogen and a clarification of the industrial emission directive on the production of hydrogen.

The actions proposed for the topics as listed above have been visualised in the Task Force 5 roadmap and includes timelines (start and length of the arrow). The action items with the highest priorities are shown in bold. A yellow arrow indicates that this is a new action.

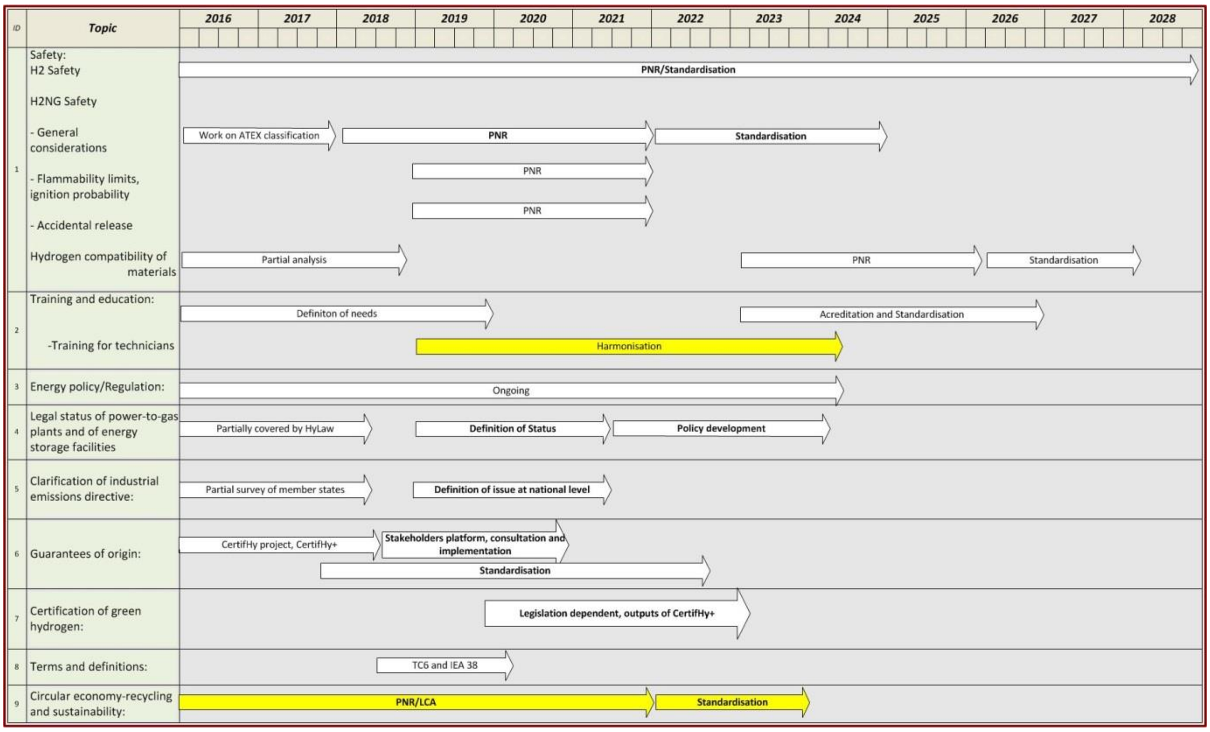

Figure 8 PNR and Standardisation actions roadmap for cross-cutting issues. Yellow marks new activities compared to the 2015 report.

5. Key near term action items

In chapter 3, priority actions have been identified based on the individual assessment per Task Force. In this chapter, an overall roadmap of the high-level priority challenges is presented and the actions needed in the near-term described. Whereas PNR typically 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

This roadmap contains all actions that are considered top priorities in the individual roadmaps. Actions are allocated priority status when it is considered that inaction would significantly hamper the uptake and deployment of hydrogen and H2NG technologies. Specifically for the H2NG technologies, the priority actions are assessed based on the expected gradual increase of hydrogen concentration in natural gas.

For **electricity grid connection and electrolyser technologies** topics, the activities related to the provision of grid services by electrolysers are considered as having high priority. The ongoing PNR activities on test procedures should feed into the appropriate standardisation work. Control strategies for integrating electrolysers with intermittent renewable energies involves the mapping of operational boundaries. There are ongoing activities, but further work is likely to be required. Future development of electrolysers should focus on up-scaling the systems to the required multi-MW level.

For the **gas grid infrastructure and end-users**, the first near term action remains the use of H2NG in natural gas vehicle steel tanks, an issue where little progess has been made since 2015. This challenge should be addressed in order to safely increase hydrogen levels above 2 vol%, either through PNR on steel tanks, or actions towards a replacement of steel tanks with composite tanks. Raising the hydrogen concentration limit above 2 vol% will also affect gas turbines and industrial processes as the highest priorities. Another topic where more activities are needed is the identification of sensitive industrial processes. Mitigation methods, if needed, are to be developed. Although research into this topic has been undertaken, the issue of hydrogen in porous rock underground gas storage facilities remains a challenge, as there are many geological and microbiological differences of these storage facilities to consider. A change from the 2015 situation is that the stakeholders identified that at concentrations of hydrogen (>5 vol%), the performance of compressors may already be affected. Grid corrosion should be considered when raising the hydrogen concentration level above 5 vol%. Although ongoing projects at national level are performing research on this topic, a broader material range should be covered for transmission lines, enabling a European perspective. In another change from the 2015 roadmap, the effect of hydrogen, and especially variable hydrogen concentrations, should be investigated further for gas engines. In general the impact of time-varying H2NG blends on the performance of end user applications should be taken into account, together with the potential impacts on safety, efficiency, lifetime and environmental performance.

For pure **hydrogen technologies**, the priority actions for PNR and standardization are targeted to facilitate the uptake of hydrogen in the transport market. The AFID provides a clear timeline regarding standardization, aimed at ensuring interoperability of connectors, filling protocols and hydrogen quality. Although many of the gaps identified in 2015 have been filled, or are receiving a sufficient level of attention, some issues on HRS remain. One of these topics is the research needed to develop refuelling protocols for medium/heavy duty vehicles. For the HRS there is still the issue of developing risk assessment methodologies. There are knowledge gaps regarding failure modes of hydrogen refuelling stations and understanding the consequences for onboard hydrogen storage systems. For fuel cell development, the medium and heavy duty transport applications will need further PNR and standardisation work. For the use of hydrogen and fuel cells for maritime and railway applications, both PNR and standards are needed. Projects are facing barriers due to a lack of standards. The recent EMSA study mentions a large number of gaps such as bunkering of liquid and gaseous hydrogen fuel, onboard storage systems and fuel cell systems.

The cross-cutting task force covers topics such as safety, societal acceptance, education and training, recycling and dismantling and energy policy. There are still knowledge gaps on H2NG properties, which would be necessary to fill if there are plans for admixture of hydrogen at large scales. A challenge already identified in 2015, the legal status of power-to-hydrogen plants has still not been sufficiently clarified. As PtH plants render a service to the energy system, the recommendation is that they should be classified and rewarded accordingly. The certification of green hydrogen and the development and use of Guarantees of Origin remain priority challenges. At policy level, further clarification of the Industrial Emission Directive on the production of hydrogen is still needed. In a change to the 2015 situation, sustainability and recycling aspects were highlighted as key areas requiring further research.

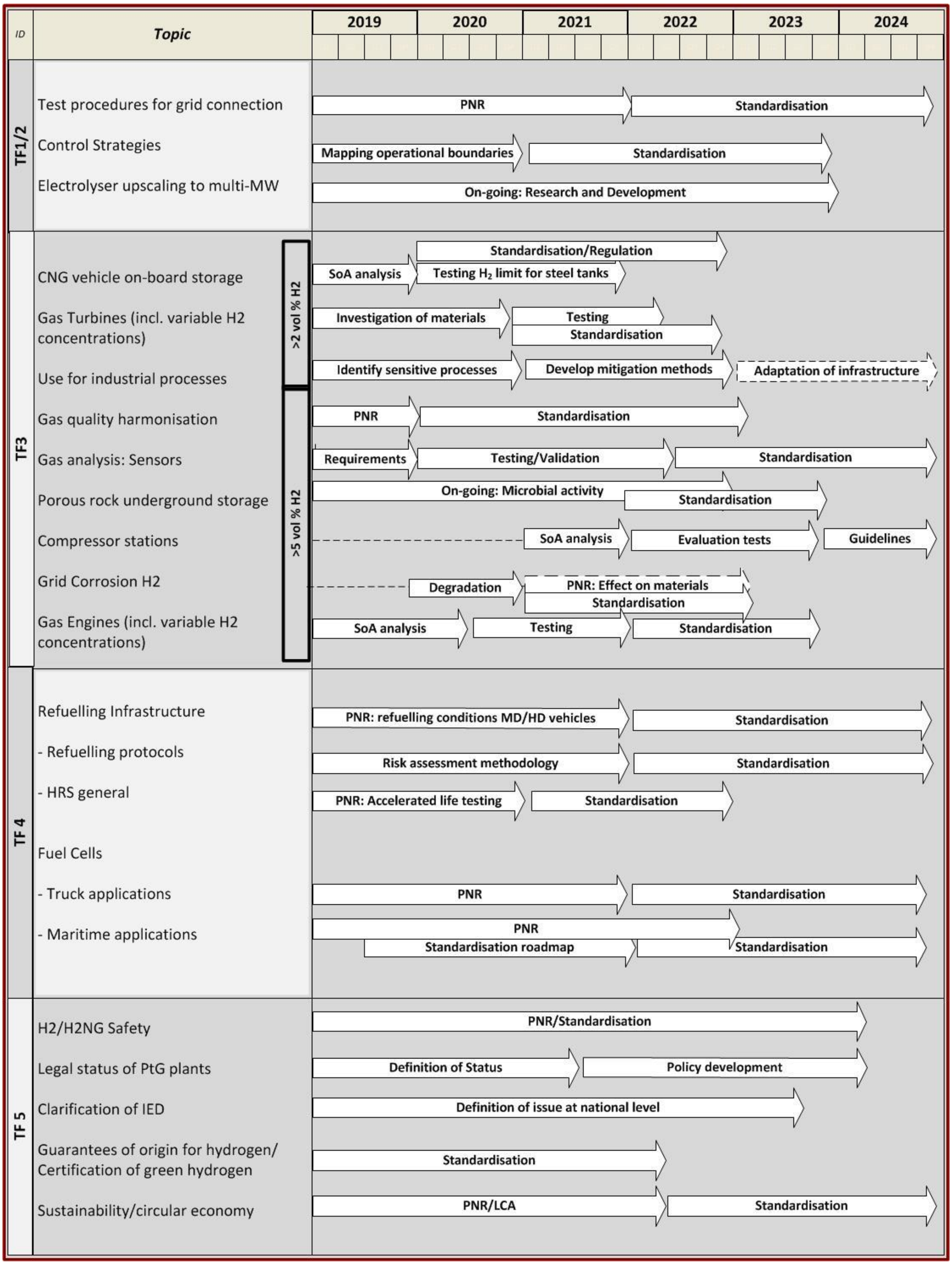

Figure 9 Key near term action items for all Task Forces

5.2 Near term standardisation 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 the table below. This table only includes items that have been identified as having high impact, for the full list of standardisation topics, please see the individual tables for each of the task forces. The full information regarding each items can be accessed via the hyperlink in the last column. Standardization actions that are identified as high priority but are already ongoing are not included in the list below.

The following color coding was used: Green - impact same as in the report 2015, Red - impact changed, Yellow - new issue

Standardization topic	Status RCS	Remaining RCS gap/comments	
CONTROL STRATEGIES			
Control strategies for integrating electrolysers with intermittent renewable energies (mapping operational boundaries)			5
NATURAL GAS QUALITY			
Natural gas quality **SFGas WG H gas quality study.** The study is to give recommendations to TC 234 for the revision of EN 16726:2015 (e.g. WI and O2) and other standards under CEN/TC 234 which may be impacted.. **⇒Topic relevance: >5 vol% H_2**	Published in 2015. SFG/WG Gas Quality Study to deliver input for revision.	EN 16726:2015 published, however, hydrogen is only mentioned in an informative annex, with no maximum level specified in the normative part. “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).” CEN/TC 234 actively prepares the inclusion of H2 in EN 16726; for this the analysis of impact on all H-gas quality parameters is in process. PNR need might be identified.	16
GAS ANALYSIS			
Gas analysis: sensors **⇒Topic relevance: >5 vol% H_2**	Safety: EN 60079-10-1:2015, IEC 60079-10-1:2015 + COR1:2015 Published. Current stage 60.60 next stage 65.31 NWIP CEN/TC 237 / ISO TR 15916:2015 Current standard for hydrogen sensor is **ISO 26142:2010.** In addition, when deploying hydrogen sensors other standards should be followed, such as, for instance, the ones related to electric components	Definition of requirements.Use of sensors for leak detection of H2/natural gas blend. Testing of sensors. The text of document 31J/253/FDIS, future edition 2 of IEC 60079-10-1, prepared by SC 31J "Classification of hazardous areas and installation requirements", of IEC/TC 31 "Equipment for explosive atmospheres" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60079-10-1:2015.	19
GRID INTEGRITY			
Sealings and connections **⇒Topic relevance: >20 vol% H_2**	EN 549 / EN 682 prEN 549 under revision.	Definition of acceptable performance	21
Grid Corrosion H_2<10% (pipeline integrity)	EN 16348 (TSO) Management system standard. Most probably no need for specific adaptation CEN/TS 15399 (DSO) prEN 15399	Material testing and developing a pipeline integrity management system for natural gas/hydrogen mixtures.	26
GRID OPERATION			
Odorisation **⇒Topic relevance: >20 vol% H_2**	ISO TR 16922 published 2013 EN ISO 13734 published 2013	Testing of different odorants are foreseen. Definition and harmonisation of performance indicators.	31, 88
Metrology/billing **⇒Topic relevance: >10 vol% H_2**			34
CNG VEHICLE ON-BOARD STORAGE			
Qualification methods for steel tanks for H2NG with hydrogen concentrations above 2 vol%	EN Regulations: Adaptation of ECE R 110, in the process of being published EN ISO 11439 / ISO/TS 15869	Standardisation: Update of ISO 15500 (15500 (Road vehicles -- Compressed natural gas (CNG) fuel system components). 11439 published 2013 / 15869:2009	35

Standardization topic	Status RCS	Remaining RCS gap/comments	
Residential appliances			
<u>Testing and Certification of appliances</u> **⇒Topic relevance: >20 vol% H_2**	EN 437, appliance harmonized standards (GAD) revision completed. Update needed to take into account communication from MS on the gases used on their territory (RAG Regulation on Gas Appliances)	Either inclusion of H2NG as gas appliance category or more likely modification of test gas. Certification actions: • Evaluation of performance • Certification of appliances for H2NG	39
<u>Adaptive combustion control</u> **⇒Topic relevance: >20 vol% H_2**	CEN/TC58 CEN/TC 48, 49, 58, 62, 106, 131, 109, 180, 244, 270, 299, 326, 399	Standardization of more flexible devices	40
<u>Combustion; incl. Investigation of suitability of burners and impact on flue gas composition (emissions)</u> **⇒Topic relevance: >10 vol% H_2**			41
<u>New gas categories including variable H_2 concentrations</u> **⇒Topic relevance: >20 vol% H_2**	Revision to be launched when Member states have provided the communication on gases used on their territory as required by GAR	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.	43
<u>Updating material specifications for metal and rubber / synthetic materials</u> **⇒Topic relevance: >20 vol% H_2**	Material specifications for metal and rubber / synthetic materials	Develop, standardise and bring more flexible devices in the market	42
Gas turbines and gas engines			
<u>Gas turbines including variable H_2 concentrations</u> Investigation of materials Operating characteristics, testing **⇒Topic relevance: >2 vol% H_2**	ISO 3977-4:2002 This standard was last reviewed and confirmed in 2017. Therefore this version remains current.		45
<u>Gas engines including variable H_2 concentrations</u> **⇒Topic relevance: >5 vol% H_2**			46
Burners			
<u>SoA analysis</u> **⇒Topic relevance: >20 vol% H_2**	ISO 13577 / ISO 13579 13577 1&3(2016),2&4(2014) 13579 Parts 1-4(2013), Part 11 (2017)		50
<u>Performance testing</u> **⇒Topic relevance: >20 vol% H_2**			51
Distribution by tube/cylinder trailers			
Develop methods for <u>cylinder testing and requalification</u>	**Continue to establish <u>industrial consensus</u> 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. Once PNR is finalised, the standard should be updated.**	2018 status STD action: ISO 17159 has progressed to the FDIS stage, which is the last stage before publication Standardisation needs to be assessed but probably finalised. Update of the standard should be considered once the PNR gap is sufficiently addressed	**54**
See above	**Consider to update EN 12245 on <u>transportable cylinders</u> to reflect the latest developments in ISO/TC 58/SC3 regarding cylinder/tube volume and pressure.**	Standardisation need remains.	**55**
HYDROGEN REFUELLING STATIONS			
<u>Refuelling protocols</u>	**Development of European standards required by <u>Alternative Fuels Infrastructure Directive.</u>**	*Once relevant ISO TC 197 standardisation activities are finalised, harmonisation of:* *EN 17124 with ISO 19880-1, and* *EN 17127 with ISO 19980-8 and ISO 14687*	**61**
HYDROGEN QUALITY (ASSURANCE)			
Develop risk assessment methodologies to understand the risk and consequences of <u>trespassing</u> impurity level limits.	**Harmonise (pre-)standardization work performed at EIGA, ISO/TC 197 and SAE.** ⇒ 2018 status STD action: The development in CEN TC 268 WG5 (EN 17124) and ISO TC 197 WG27 (ISO 14687) and WG 28 ISO 19880-8 operate in parallel as the fuel quality specifications are the same.	Further refined **<u>risk assessment</u>** for automotive hydrogen impurities in EMPIR Hydrogen could be used during the next revision of ISO 14687 when impurity thresholds are discussed. A better understanding of impurities that are introduced during maintenance is needed. The risk assessment for the impact of hydrogen impurities initially developed in EIGA is taken up by prEN 17124 and further developed in EMPIR Hydrogen.	**71**

Standardization topic	Status RCS	Remaining RCS gap/comments	
Develop online measurement techniques and detection apparatus for hydrogen quality assurance at refuelling stations.	**Develop an analytical standard dedicated to hydrogen impurities.** ⇒ 2018 status STD action: ISO TC 197 WG 28 has almost finalised ISO 19980-8 on hydrogen quality control as the FDIS is expected to be published as a final standard in May 2018. Joint work group (JWG) between ISO TC 197 and ISO TC 158 in order to develop a specific standard on analytical methods for hydrogen for fuel cell vehicles.	Standard development for hydrogen quality control is nearly finalised. Standard development for analytical methods is ongoing and includes PNR results however this will not address the requirements for online quality assurance.	*73*
Reassess PNR results to feed into revision work of hydrogen quality standards.	The need to develop analytical standards for hydrogen impurities was addressed in 2016 by setting up joint work group (JWG) between ISO TC 197 and ISO TC 158 in order to develop a specific standard on analytical methods for hydrogen for fuel cell vehicles. Previously, it was addressed marginally in ISO 14687-2. The JWG ISO 21087 standard is being developed:. The PNR outputs are used in this standard.	Standard development for analytical methods is ongoing and includes PNR results.	*71*
HYDROGEN ON-BOARD TANKS			
Improvement of testing methodologies and procedures for mechanical impact testing of hydrogen tanks (type approval) **State of health assessment of CHSS of vehicles exposed to extreme event or at end of life**	**Harmonisation and uniformity of test schemes for hydrogen tank standards developed within ISO/TC 197/WG 18 (e.g. fatigue testing, failure mode considerations, bonfire testing, drop testing, safety factor determination, periodic inspection testing).** ⇒ 2018 status RCS/STD action: -Regarding Acoustic Emission tests, bonfire tests, etc. see more information via hyperlink.	The second phase of the GTR 13 has started. ISO 19881 needs to be re-assessed on the need to incorporate PNR results. Materials compatibility standards may need to be developed or adapted dependent on the outcome of GTR phase 2. See more information via hyperlink	*76* *81*
HEAVY DUTY ROAD VEHICLE APPLICATIONS			
Review and possibly update/expand existing standards on fuel cell road vehicles	GTR 13 phase 2 to look at including trucks, lorries and buses.	Review the necessity to update standards in ISO TC 22 SC37 regarding fuel cells. Vehicle requirements for interoperability need to be included in a standard.	*86*
MARITIME APPLICATIONS			
Develop a standardisation roadmap/actions to address standardisation gaps (see PNR gaps) in the maritime sector	The aspects that standards need to cover are diverse. See meore information via the hyperlink and include items like safety (e.g. fuel,	Develop a standardisation roadmap/action plan with relevant actors involved (e.g. IEC TC 105, ISO TC 197, CEN/CLC TCs, EMSA, IMO) also considering regulatory needs. Identify standardisation work that can already be addressed.	*87*
H2NG SAFETY			
Improve knowledge on H2NG properties	**IEC 60079-0 / ISO 26142 / ISO 23273 / IEC 61779 / IEC 60079-10**	Harmonisation in the approach to determine hazardous zones defined in the ATEX directive considering the assumed leak sizes for H2NG	*89*
LEGAL STATUS OF POWER-TO-GAS PLANTS AND OF ENERGY STORAGE FACILITIES			
Clarification on legal status of PtG plants and energy storage facilities	HyLAW project identified barriers related to the status of power-to-gas. See more information via hyperlink	Specification of the methodology for assessing greenhouse gas emissions savings from renewable liquid and gaseous transport fuels of non-biological origin Definition of a hydrogen network versus a natural gas network. Standards are different, clarification needed. See more information via hyperlink.	99
GUARANTEES OF ORIGIN/ CERTIFICATION OF GREEN HYDROGEN			
Clarification of whether standards should be applied at EU level or if national rules can apply. ⇒ 2018 status PNR action: CertifHy has defined the main technical specifications of the framework of GoO	EU level certification scheme **NWIP CEN-CLC/JTC 6/WG 2** ***2018 Publication RED II including paragraph:referencing to CEN- EN 16325.**	RED II (59) Guarantees of origin which are currently in place for renewable electricity should be extended to cover renewable gas. There is agreement that CEN/CLC/JTC 14 and CEN/CLC/JTC 14 work together on the revision of EN 16325 with the inclusion of hydrogen. see more information via hyperlink	*103*
Certification scheme will be legislation dependent, and based on the outputs of CertifHy+	**Development ongoing for standardisation NWIP CEN-CLC/JTC 6/WG 2**	There is agreement that CEN/CLC/JTC 14 and CEN/CLC/JTC 14 work together on the revision of EN 16325 with the inclusion of hydrogen.	106
TERMS AND DEFINITIONS			
Common set of terms and definitions for H2 and H2NG	⇒ In progress, JTC6 and ongoing work IEA 38	To be done within CEN-CLC/JTC 6/WG 1	108
Terminology (from relevant electrical grid terminology to electrolyser terminology)	CEN/CENELEC JTC6 WG1 – initial phase	Alignment of "wording" between grid operators and ancillary services providers (consistent with terminology work in other TFs) Incorporation of JRC project on electrolyser terminology	109

6. Recommendations,next steps and future work of the platform

6.1 Recommendations

The main result of the activities of the WG is a consented, updated 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 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 continue to endorse:

- Continuation of a platform for the consideration of hydrogen in the energy system in Europe. This platform should holistically cover research, pre-normative research and standardization for Power-to-Hydrogen and all related applications, including Power-to Hydrogen-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 Next steps

The working group could, in addition to the co-operation and links already established:

- Establish a clear link with relevant DG on the specific European Directives, as mentioned under Energy policy/Regulation, which will have direct impact on the deployment of hydrogen e.g. Clean Energy Package, IED, RED II (including Guarantees of Origin);
- Strengthen the cooperation with other horizontal standardisation fora, such as CEN/Sector Forum Gas Infrastructure and CEN/Sector Forum Gas Utilisation and their joint SFGas Gas Quality Study;
- Contribute to the development of the gas package of the European Commission when relevant;
- Establish a link with and other relevant associations/initiatives on Hydrogen (for example Hydrogen Europe);
- Keep engagement/ establish new engagement of EC DGs in relation to European legislation/regulations that may impact Standardization; and exploit possibilities under the Commissions Joint Initiative on Standardisation;
- Keep and strengthen engagement of stakeholders of the natural gas infrastructure and applications, and identify and engage with new stakeholders for:
    - H2 applications in railway, maritime, airborne and heavy-duty transport, including liaison/cooperation with international organisations such as IMO and UIC;
    - Stakeholders of the electricity grid and renewable electricity;
    - Hydrogen safety related stakeholders.
- Continue the engagement with the FCH JU RCS group and if need be link with RCS activities under Mission Innovation Challenge on Renewable and Clean Hydrogen.

Possible contributions of the SFEM WG Hydrogen:

- Ensure joint information exchanges with the European gas infrastructure operators and industries on research and standardization needs related to the admixture of hydrogen to natural gas, contributing to developing a common vision. This should be in co-operation with relevant Sector Fora and TCs.
- The concerned Sector Fora and TCs should collaboratively identify the challenges related to the conversion of natural gas distribution networks for pure hydrogen, both for distribution and end-use applications.

Future work of the platform:

- Continuation of the WG as a platform for exchange and coordination on hydrogen research, pre-normative research and standardization with the aims already described in the terms of references of the WG) and in cooperation with corresponding Sector Fora, if any.
- Service as the platform for gathering expression and exchange of needs by participating stakeholders: industry, public sector, research. Members have the possibility to present relevant developments / projects. Topics for discussion during plenary meetings are based on requests / input from WG-members and from the WG MT.
- The SFEM WG Hydrogen continues to update the information gathered on PNR, research, standardization and legal frameworks. This overview will present an update on the overview and gap analyses on the state of art situation on hydrogen. It supports an overall roadmap for H2 related standardization.
- To support the development of industrial testing platforms[13] regarding P2G, dedicated to research activities, innovation and cooperation between all European Stakeholders. This will allow for modularity and the testing of several equipment items successively or simultaneously.
- Support the transfer of PNR results to standardisation work.
- Support the work related to the standardisation request in the AUWP 2017 on Power-to-Gas.

[13] The FenHYx program is intended to offer such a platform, to test in real operating conditions new equipment items and functionalities in order to accelerate the industrial-scale production of innovations. It will include key components of a high-pressure gas network, with different modules for testing gas mixes over a range of of hydrogen percentages. The stability of the mixes will be assessed on dynamic and static loops under varying conditions of temperature, pressure and flow. A land reserve will allow the development of the platform, integrating new functionalities related to downstream uses and low-pressure distribution issues

Annex: Abbreviations and Terms

Abbreviations

ACER	Gas – Agency for the Cooperation of Energy Regulators
AFI standards	Alternative Fuels Infrastructure
AFID	Alternative Fuels Infrastructure Deployment (Directive)
ATEX	ATmosphères EXplosibles
BAM	Bundesanstalt für Materialforschung
BPP	Bi-polar plate
BT	Technical board
CCMC	CEN/CENELEX Management Centre
CEA	French Atomic Energy and Alternative Energy Commission
CEN	Comité Européen de Normalisation
CEN/TC	Technical Committee within CEN
CENELEC	Comité Européen de Normalisation Électrotechnique
CertifyHy	Project: Developing a European Framework for the generation of guarantees of origin of green hydrogen
CFD	Computational Fluid-Dynamics
CNG	Compressed Natural Gas
DBI	Deutsches Brennstoff Institut
DeliverHy	Project: This project will assess the effects that can be achieved by the introduction of high capacity trailers composed of composite tanks with respect to weight, safety, energy efficiency and green-house gas emissions.
Demo4Grid	Project: Demonstration for Grid Services
DIS	Draft international standard
DLR	Deutsche Luft und Raumfahrt
DNV GL	Det Norske Veritas (Norway) and Germanischer Lloyd (Germany)
EARTO	European Association of Research and Technology Organisations
EC DG ENER	European Commission - Directorate-General for Energy
EC DG GROW	European Commission Directorate – General Internal Market, Industry, Entrepreneurship and SMEs
EC JRC	European Commission – Directorate General Joint Research Centre
EC DG RTD	European Commission - Directorate-General for Research and Innovation
ElyIntegration	Project: rid integrated Multi Megawatt High Pressure Alkaline Electrolysers for Energy Applications
EMPIR	European Metrology Programme for Innovation and Research
EMSA	European Maritime Safety Agency
ENTSOG	European Network of Transmission System Operators for Gas
FCH JU	Fuel Cells and Hydrogen Joint Undertaking (FP 7)
FCH2 JU	Fuel Cells and Hydrogen 2 Joint Undertaking (H2020)
FireComp	Project: Modelling the thermo-mechanical behaviour of high pressure vessel in composite

	materials when exposed to fire conditions
GAD	Gas Appliances Directive
GERG	Groupe Européen de recherches gazières (the european gas research group)
GoO	Guarantee of Origin
GRHYD grid	Project: Converting renewable electric power into gas
GrinHy	Project: Green Industrial Hydrogen
GTR	Global Technical Regulation
H-gas	High-calorific natural gas
H2	Hydrogen
H2 PIMS	Project: Pipeline Integrity Management for the continued use of the existing natural gas infrastructure for hydrogen
H2020	Research and innovation framework programme
H2Future	Project: European flagship project for the generation of green hydrogen from electricity from renewable energy sources.
H2-NETZ	Project: Development of innovative infrastructures to supply consumers in the hydrogen village
H2NG	Hydrogen and Natural Gas mixture
H2Store	Project: Hydrogen Underground Storage – A Feasible Way in Storing Electrical Power in Geological Media
HIPS(-NET)	Hydrogen in Pipeline System - Network
HPEM2GAS	Project: High Performance PEM Electrolyser for Cost-effective Grid Balancing Applications
HRS	Hydrogen Refuelling Stations
HSL	Health & safety laboratory U.K.
HTE	High Temperature Electrolysis
HyBalance	Project: Project that demonstrates the use of hydrogen in energy systems.
HyComp	Project: Design Requirements and Testing Procedures for Safe Hydrogen Composite Cylinders
HyCORA	Project: Hydrogen Contaminant Risk Assessment
Hydeploy	Project: HyDeploy is a pioneering hydrogen energy project to reduce UK carbon dioxide CO2 emissions
HYDRAITE	Project: Hydrogen Delivery Risk Assessment and Impurity Tolerance Evaluation
Hydrogreenn	HYDROGen Regional Energy Economy Network Northern Netherlands
HyIndoor	Project: Pre normative research on the indoor use of fuel cells and hydrogen systems
HyINTEGER	Project: Investigations on the integrity of wells and technical components exposed to highly corrosive conditions in geological hydrogen underground reservoirs.
HyLAW	Project: Hydrogen Law
HyPactor	Project: Pre-normative research on resistance to mechanical impact of composite overwrapped pressure vessels
Hypos UGS	Project: Hydrogen power storage & solutions east Germany
HYREADY	Project: Encourages the industry to ‘Be ready for Hydrogen’ by developing practical processes and procedure for the introduction of hydrogen to the grid
HySEA	Project: Improving Hydrogen Safety for Energy Applications (HySEA) through pre-normative research on vented deflagrations
Hytechcycling	Project: New technologies and strategies for fuel cells and Hydrogen Technologies in the phase of recycling and dismantling

HyTransfer	Project: Pre-Normative Research on Gaseous Hydrogen Transfer
HyUnder	Project: Assessing the potential, actors and business models of large scale underground hydrogen storage in Europe
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IED	Industrial Emissions Directive
INERIS	L'Institut national de l'environnement industriel et des risques
ISO	International Organization for Standardization
JWG	Joint Working Group
Kiwa	Keurings Instituut voor Waterleiding Artikelen
LNG	Liquefied/liquid natural gas
LTWE	Low Temperature Water Electrolysis
MAE	Modal acoustic emission
MATHRYCE	Project: Material Testing and Recommendations for Hydrogen Components under fatigue
MEGASTACK	Project: Stack design for a Megawatt scale PEM electrolyser.
MetroHyVe	Project: Metrology for hydrogen vehicles
Naturalhy	Project: Preparing for the hydrogen economy by using the existing natural gas system as a catalyst
NEN	NEderlandse Norm
NEXPEL	Project: Next-Generation PEM Electrolyser for Sustainable Hydrogen Production
NG	Natural Gas
NOVEL	Project: Novel materials and system designs for low cost, efficient and durable PEM electrolysers
NSB	National Standards Body
NWIP	New work item proposal
OEMs	Original Equipment Manufacturers
PC	Project Committee
PEM	Proton-Exchange Membrane
PGC	Process Gas Chromatographer
PIMS	Pipeline Integrity Management System
PNR	Pre-Normative Research
PRD	Pressure Relief Device
PRESLHY	Project: Pre normative Research for Safe Use of Liquid Hydrogen
PtG	Power-to-Gas
PtH	Power-to-Hydrogen
QualyGridS	Project: Standardized qualifying tests of electrolysers for grid services
RAG sun conversion	Project: Underground conversion and storage of wind and solar energy
RCS	Regulation Codes and Standards
RDI	Research Development and Innovation
RED	Renewable Energy Directive
RefHyne	Project: supply of Clean Refinery Hydrogen for Europe

RES	Renewable Energy Sources
RWS	Rijkswaterstaat
SAE	Society of Automotive Engineers
SFG	Sector Forum Gas
SGN	Scotia Gas Networks
SNG	Substitute Natural Gas12
SFEM/WG Hydrogen	Joint CEN/CENELEC Sector Forum Energy Management – Working Group Hydrogen
SoA	state-of-the-art
SOCTESQA	Project: Solid Oxide Cell and Stack Testing, Safety and Quality Assurance
SRAHG	Standardization Request Ad-hoc Group
SUSANA	Project: SUpport to SAfety ANalysis of Hydrogen and Fuel Cell Technologies
SWD	Staff working document
TAHYA	Project: Tank Hydrogen Automotive
TC	Technical Committee
TF	Taskforce
TPRD	Thermally-activated Pressure Relief Devices
TR	Technical report
UGS	Underground Gas Storage
UNECE	United Nations Economic Commission for Europe
WG	Working Group

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