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The Netherlands

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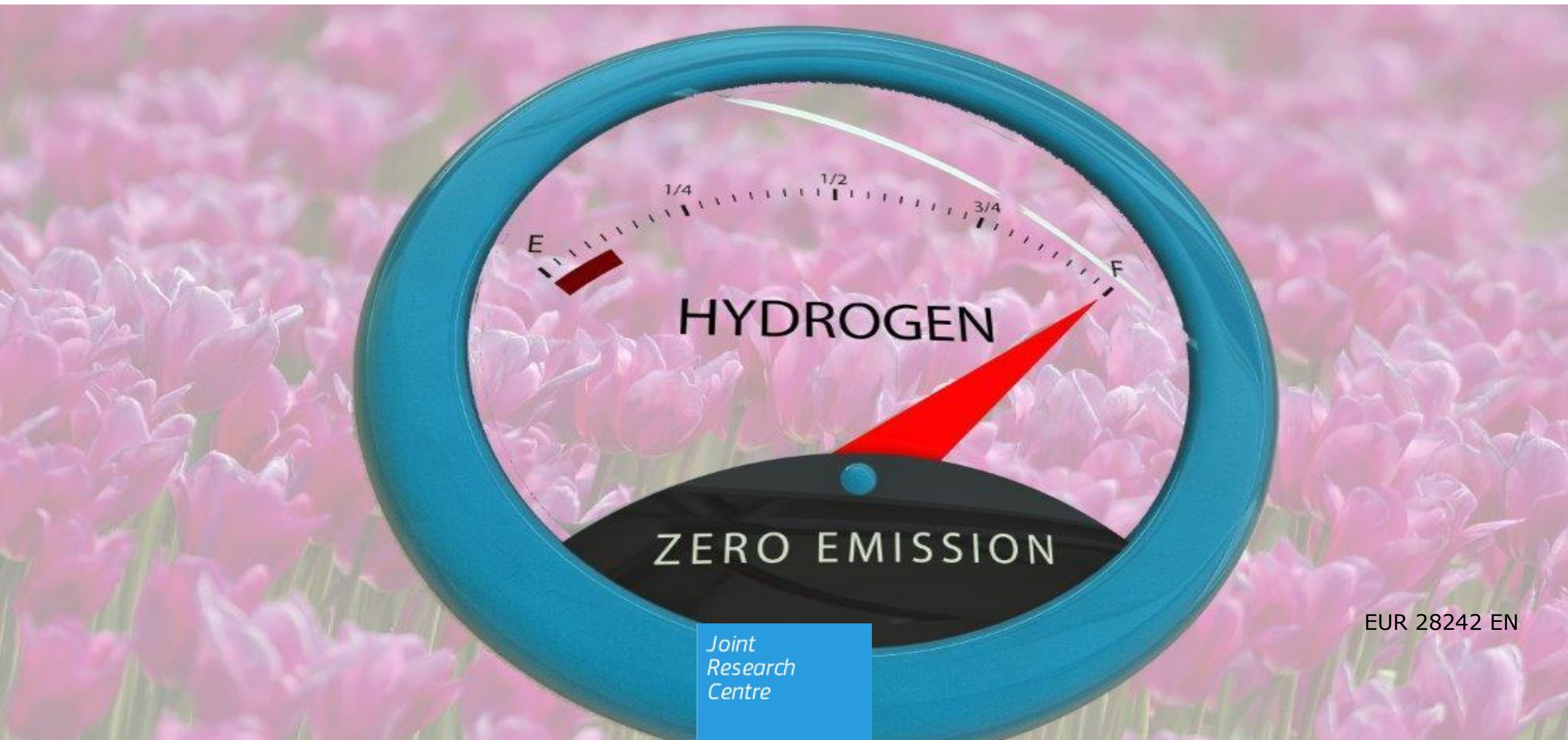

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4th International Workshop on Hydrogen Infrastructure and Transportation

Organised by EC-JRC, DoE (US), NOW (Germany) and NEDO (Japan)

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Abstract

The 4th International Workshop on Hydrogen Infrastructure and Transportation took place in Egmond aan Zee (The Netherlands) on 24-25 May 2016. The workshop was conducted by the European Commission's Joint Research Centre and supported by US DOE, NOW from Germany and NEDO from Japan.

The International Workshops on Hydrogen Infrastructure and Transportation aim at guiding and supporting industry to accelerate and facilitate the roll-out and commercialization of hydrogen refuelling stations. The 4th International Workshop has offered a forum for exchange of information through sharing experiences, best practices and progress on key and relevant issues facing hydrogen infrastructure deployment for fuel cell electric vehicles. Discussion topics included fuelling, H_2 quality and metering, as well as utilization experiences of hydrogen refuelling stations.

The series of international workshops is recognised by the main hydrogen infrastructure stakeholders as an interesting initiative because it brings together policy makers, technical experts from industry and research organisations. While participation to the workshop is upon invitation and distribution of the material presented is limited to the attendants; it is nevertheless important to make the most relevant information publicly available. Therefore this JRC Report contains a compilation of the main information shared at the 4th International Workshop on Hydrogen Infrastructure and Transportation so that it can be used as reference material.

The workshop was divided into topical sessions. The first session covered General Country/Region Overviews on policy initiatives, R&D, demonstration and deployment, investments and funding, etc. regarding hydrogen and fuel cell infrastructure. The other sessions aimed at discussing technical topics considered critical for the hydrogen infrastructure. In this report the most relevant information of each of the countries' overviews and the outcomes the four technical sessions are summarised.

1 Introduction

The International Workshops on Hydrogen Infrastructure and Transportation aim at guiding and supporting industry to accelerate and facilitate the roll-out and commercialization of hydrogen refuelling stations around the globe. The initiative started in Berlin (Germany) in 2013, followed by Torrance Los Angeles (US) in 2014 and Tokyo (Japan) in 2015.

The 4th International Workshop on Hydrogen Infrastructure and Transportation took place in Egmond aan Zee (The Netherlands) on May, 24th and 25th 2016. The workshop was conducted by the European Commission's Joint Research Centre and supported by the US Department of Energy (DOE), the German National Organisation Hydrogen and Fuel Cell Technology (NOW) and the New Energy Development Organisation (NEDO) from Japan.

The workshop has offered a forum for international exchange of information through sharing experiences, best practices and progress on key and relevant issues facing hydrogen infrastructure deployment for fuel cell electric vehicles. Discussion topics included fuelling, H_2 quality and metering, as well as utilization experiences of Hydrogen Refuelling Stations (HRSs).

Participation to the workshop was upon invitation of NOW, DOE and NEDO of their respective industry, academia, research organisations and government representatives. Furthermore the European Commission has taken care that representatives from key European countries and players involved in hydrogen deployment activities, such as the Fuel Cell and Hydrogen Joint Undertaking, were present as well. Moreover representatives from PR China and South Korea have been invited for the first time. The total number of participants were 58 out of which 16 delegates from Germany, 9 delegates from US, 9 delegates from Japan, 3 from Norway, 1 attendant from Finland, 1 from Belgium, 3 delegates from The Netherlands, 3 from UK, 3 from France, 1 delegate from PR China, 2 from South Korea, 1 representative from the FCH-JU and 6 participants from the European Commission Joint Research Centre. The participants list can be found in Annex 1.

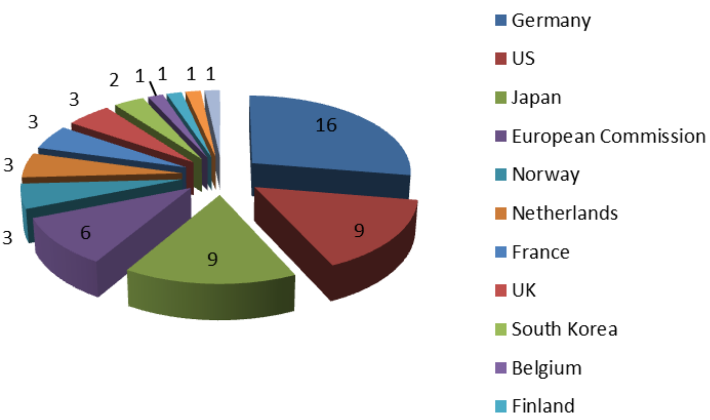

Figure 1 Country/Region distribution of participants to the 4th Int. Workshop on Hydrogen Infrastructure and Transportation

The workshop was divided into topical sessions. The first session covered General Country/Region Overviews on policy initiatives, R&D, demonstration and deployment, investments and funding, etc. regarding hydrogen and fuel cell infrastructure. The other sessions aimed at discussing technical topics considered critical for the hydrogen infrastructure: H_2 Fuelling, H_2 Quality, H_2 Metering, and Utilization Experience of 70 MPa HRS. The final agenda of the workshop can be found in Annex 2.

Figure 2 Group picture of the attendants to the 4th Int. Workshop on Hydrogen Infrastructure and Transportation

Each country/region group has been requested to contribute to the general session with a presentation on their Country activities and when appropriate to present the progress, achievements and complexities on the topics addressed in the technical sessions. Presentations are confidential and have only been distributed to the workshop attendants. Nevertheless it has been agreed to make the main outcomes of the workshop available in a public report.

The most relevant information of each of the countries' overviews and the outcomes the four technical sessions are summarised in this report. The first chapter is dedicated to the Countries Overview, the second to the H_2 Fuelling, the third to H_2 Quality; the fourth to H_2 Metering and, finally, the fifth chapter is dedicated to the Utilization Experience of 70 MPa hydrogen refuelling stations.

2 Country/Region Updates

The objective of this session was to provide an overview of the national and or regional activities to promote and accelerate the deployment of hydrogen refuelling infrastructure. Each country/region invited to the workshop has been requested to make a presentation describing the following topics:

- New Policy Initiatives on Hydrogen and Fuel Cell
- Hydrogen and Fuel Cell R&D Update
- Demonstration and Deployments Update
- Events and Solicitations
- Investments: Government and Collaborative Hydrogen and Fuel Cell Funding
- Update on actions from the previous workshops

The most relevant information provided by the different countries/region is summarised in the following sections.

2.1 Germany

- The German *eMobility* funding programme was announced on April 27th, 2016. It will promote electric vehicle deployment by providing a buyer's premium of 4000 EUR for BEVs and 3000 EUR for PHEVs. The total budget for buyers' premium is 1.2 billion EUR until 2019. There is also a 300 MEUR budget for infrastructure out of which 200 million is for AC-charging. Other measures will include no taxation on electric charging at workplaces and the introduction of 20% electric vehicles in the federal government fleet by 2017.
- The Federal Ministry of Transport and Digital Infrastructure (BMVI) leads the preparation of the National Policy Framework for Germany (with support from NOW) required by the Alternative Fuel Infrastructure Directive (AFID) EU 2014/94. Key elements are: approximately 400 HRS for 2023 and definition of funding schemes for these HRSs.
- Germany is working on making non-electrified railways zero emissions and is considering hydrogen for that purpose. First prototypes of fuel cell powered rail vehicles, built by ALSTOM, are expected in 2016. Demonstration is envisaged in 2018. BMVI allocated funding is 7.9 MEUR.
- The H2 Mobility Congress was held on April 12th 2016. It demonstrates that hydrogen as electricity based clean fuel in transport is present on the German agenda. https://www.now-gmbh.de/en/news/press/hydrogen-as-an-electricity-based-clean-fuel-in-transport
- The National Innovation Program Hydrogen and Fuel Cell Technology will be continued until end of 2025 (NIP-2) to support further research and development and to establish mobility by hydrogen and fuel cells in the market. The NIP 2 budget (2016-2025) will be increased compared to NIP 1 and at least 161 MEUR will be allocated for the program between 2016 and 2018. NIP-2 will focus on R&D to reduce cost of technology and on market activation (a new funding guideline for market activation is in preparation).
- The Clean Energy Partnership (CEP) will continue with changed focus to support the industry with technical issues as H_2 quality and metering.

- *H2mobility Germany* is a joint venture for establishing hydrogen refuelling infrastructure (planning, building, operation, maintenance of HRSs), covering as well hydrogen production and sales. Total investment is now at 350 MEUR. Its stakeholders Linde, Air Liquide, Daimler, Shell, and Total are committed to roll out the German HRS network (26 HRS stations are in development as of May 2016 and 400 are planned by 2023).
- NOW has a formal Memorandum of Understanding with CATARC – China Automotive Technology Research Center. FCEV infrastructure is included in this MoU.
- Reinhold Wurster coordinates the German research project *50 HRS programme*. This project analyses a number of country approaches to hydrogen technology research and development. The 50 HRS programme will identify key players for hydrogen research in Europe, USA and Japan and their common concerns (e.g. causes of HRS downtime, understanding challenges…) by collecting data from all around the world.
- H2mobility plans to have 100 stations in place by 2019. As of June 15th there will be ground broken on the first station of this 100 for unconditional ramp-up. The next 300 stations are dependent on the number of hydrogen cars deployed.

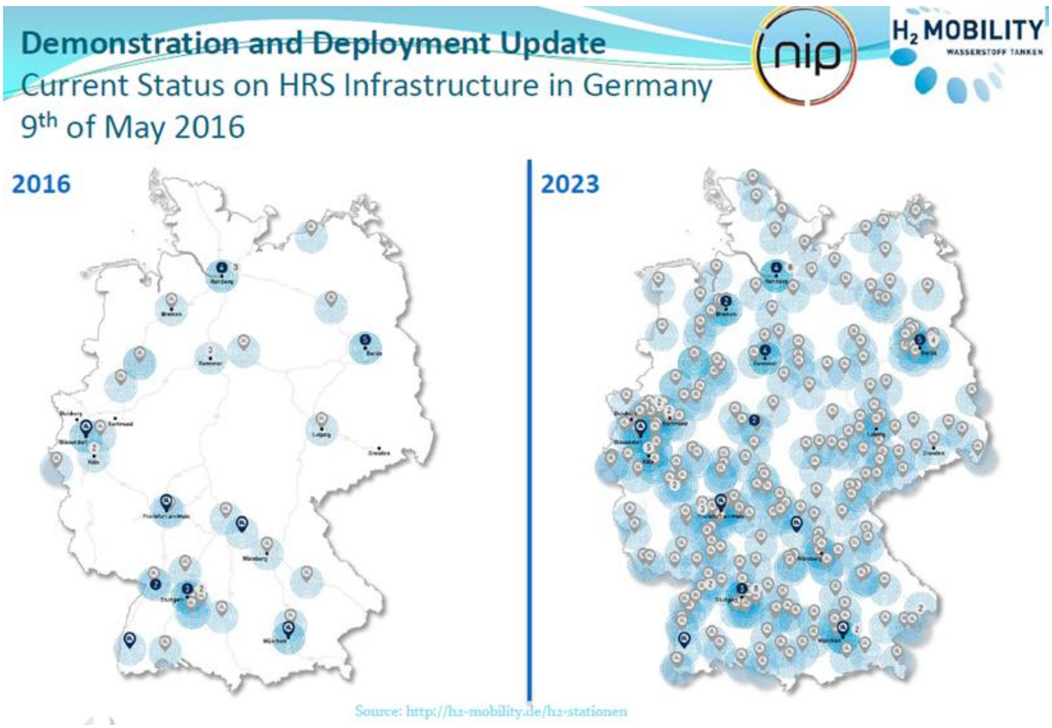

Figure 3 HRS deployment plan in Germany

2.2 Japan

- Japan has revised its *Strategic Roadmap for H&FC* which now is extended to the period 2020 – 2040. It is divided in 3 Phases: Phase 1 "installation of the fuel cell" aims at further decreasing the costs of fuel cells till 2030. Phase 2 "H_2 supply and mass production" is dedicated to reduce the costs of hydrogen and to enhance the supply chain in Japan. By 2030 Japan expects that it will need to import hydrogen from overseas and foresees to have full scale H_2 plants for power generation. Phase 3 "CO2-free H_2 production" targets obtaining carbon free hydrogen through renewables and CCS by 2040. Japan expects to spend 1 trillion JPY by 2030 and roughly 8 trillion JPY by 2050.
- The new Strategic Roadmap has as well revised targets for FCEV and HRS. New targets for FCEV are 40000 FCEVs by 2020, 200000 by 2025, 800000 by 2030 and for refuelling stations 160 by 2020 and 320 by 2025.
- Concerning status for FCEV, Toyota released the Mirai in December 2014 and in October 2015 announced its FCV sales plan that envisages 3000 cars in the global market in 2020 or later. Toyota has sold (on order) 3,500 Mirais so far and 573 are on the road today. Mirai price is at present 65 kEUR. In March 2016, Honda has released the Clarity Fuel Cell at a price of 67 kEUR.
- Japan plans to build 100 HRS in the four most populated areas. As of March 2016, already 78 are open (about 20 are mobile stations which cover 27 locations) and the budget is secured for 81 stations. The plan is to cover the 4 major cities by 2020, then to have connected areas by 2030 and by 2040 have nationwide coverage. The price of hydrogen at the pump is 8.9-9.6 USD/kg and is fixed for the commercial stations.
- METI provides support for capex and opex: 9.5 billion JPY subsidies for residential FC, 6.2 billion JPY for HRS and 15 billion JPY for vehicles. Moreover 2.8 billion JPY is allocated for building the H_2 production chain (in the late 2020).

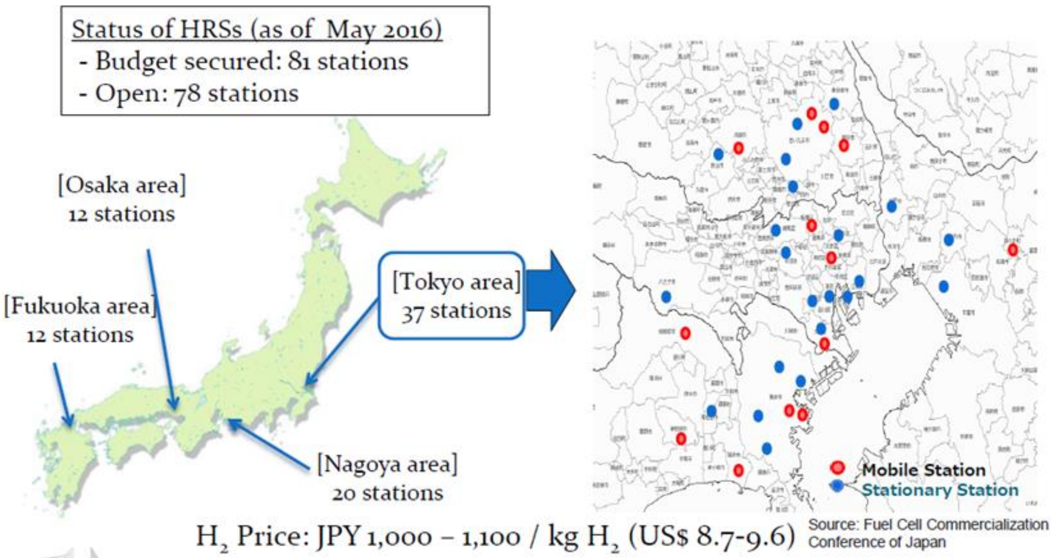

Figure 4 HRS Deployment in Japan

- NEDO foresees 100 buses (under preparation) for the 2020 Olympics. Toyota is developing busses at 70MPa and 35 MPa busses from other manufacturers are accepted as well.
- NEDO's research programme is oriented to PEFC for transport (full-fledged deployment by 2025) and SOFC for industry (market introduction in 2017). For HRS the target is to reduce refuelling station cost by half by 2020 (from currently 3 million EUR including the installation costs).
- HySUT (NEDO R&D programme) funds the development of an 875 bar hose with longer life, the development of vessels for stationary storage (300 litres) at 875 bar and also the development of type 5 composite cylinders at an affordable price.

2.2.1 The new HySUT structure

Part of the funding for the installation of the fuelling stations in Japan comes from the automakers. HySUT has been renamed into *Association of Hydrogen Supply and Utilization Technology*. So from 1st April HySUT it will do more than research and can now fund installation of stations. HySUT works on technology development for fuel quality guidelines and metering and is also working on hydrogen safety (safety control database) and reliability including future technologies. HySUT activities cover training and education too. Finally HySuT is covering the HRS support program (opex funding). The HySUT organigram has not changed.

The plan is that HySUT will be the future organization for hydrogen technology (like JARI for automotive).

2.3 United States of America

- The DoE Hydrogen and Fuel Cell Program's mission is to enable widespread commercialization of H_2 and fuel cells technologies. Priorities for 2017 are on fuel cell R&D (USD 35 M) and hydrogen fuel R&D (USD 44.5 M), followed by safety, codes and standards (USD 10 M) and technology validation (USD 7M). Budget is also foreseen in 2017 for Technology Acceleration (combination of manufacturing R&D, technology validation and market transformation).
- Current H_2 price is USD 13-16 gasoline gallon equivalent (gge), the target is USD 7/gge in the 2020 early market. The target price is based on analysis which takes into account the current gasoline prices.
- Hydrogen production infrastructure mostly consists of centralized production facilities; there are 9 liquefaction plants in North America and 1600 miles pipelines. Current production is 10 M metric tons/year. Renewable H_2 a USD 4 per gge cost target to be competitive with gasoline is the long-term target.
- There are 23 open retail HRSs in California (definition of open retail: similar to a conventional gas station with payment via credit card). More than 30 open HRS are expected by end of 2016.
- There is no direct Federal Government funding for commercial HRS construction. The state of California has provided USD 100 million with a goal to have 100 stations by 2023. More than 12 stations have been planned in the north-eastern US through industry funding.
- Federal Initiatives: the Federal tax credit has been extended to December 2016 and states can have their own additional tax credits as well. The federal tax credit for HRS infrastructure is 30% of the cost, not exceeding USD 30000. Eight states (California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island & Vermont) have signed the Memorandum of Understanding "3.3 million ZEV by 2025" which includes hydrogen fuel cell vehicles.
- H2USA is a public-private collaboration co-launched by DOE and industry in 2013 and now has more than 50 partners. H2FIRST (the Hydrogen Fuelling Infrastructure Research and Station Technology project) is a DOE project led by national labs (NREL and Sandia) to help accelerate infrastructure rollout and to provide support to H2USA. They have developed the Hydrogen Station Equipment Performance (HyStEP) testing device to validate station performance (thereby accelerating station acceptance and avoiding the need for individual-OEM validation at every station). The device has been validated by Mercedes, Hyundai and Toyota and was delivered to California in December 2015.
- The U.S. notes that station reliability have improved however compressors and dispensers continue to be the leading cause of unplanned maintenance. It is calculated that this "infant mortality failures" end after approximately 2000 refuelling (5000 kg of H_2 dispensed). DOE tracks over 3,000 infrastructure maintenance events thus far through a database at NREL, with no attribution as to organization, to promote information sharing.

- DOE has launched H2Tools.org, through Pacific Northwest National Laboratory (PNNL), as a one-stop 'portal' to provide information on hydrogen, including safety and training material. The material is available at no cost and Japan has already translated some of the first responder information. Discussions are under way with China, Korea, and other countries interested in translating information.
- The Safety Panel which was launched by DOE several years ago is comprised of technical experts managed by PNNL to provide feedback on safety related to hydrogen and fuel cell technologies. More information about the safety panel can be found here: https://h2tools.org/hsp
- The U.S. Congress has set National Hydrogen day on October, the 8th (H_2 [10.08]) http://www.fchea.org/h2fcday/ with outreach events across government and industry throughout the country.

2.4 Scandinavia

In Scandinavia there are 70 FCEVs and 17 stations in operation with another 14 stations planned, see Figure 5.

- Denmark has 9 stations in operation; the amount of hydrogen dispensed is rising with 10 tons delivered so far in 2016 for 600 refuellings. All of the hydrogen is produced from water electrolysis. The stations are all available 24/7 and the average network reliability is 98%. Such a reliability figure was questioned by the audience. It has been concluded that a common definition of HRS reliability must be established to enable proper comparison between reliability networks in different countries.
- Sweden has at present 3 stations in operation, funded by EU programmes, and 8 FCEVs on the road. It is planned to have another 4 HRS in place in spring 2017 and to put in operation the first taxi fleet in Scandinavia in mid-2016. All the hydrogen is 100% renewable.
- Sweden has put a strong focus on biofuels, and the audience wondered about the possibility of a Swedish national policy framework plan for AFID not including hydrogen infrastructure. The presenter was unable to confirm this.
- Norway has 27 FCEVs and 5 FC buses and a network of 5 HRS (4 for cars and 1 for busses). A national hydrogen strategy will be launched in 2016, and there are strong signals from the national government on support schemes for rollout of hydrogen infrastructure. With large incentives for zero emissions vehicles, ZEV, Norway has currently more than 75000 BEVs on the road and a third of all cars sold in Norway are plug-in vehicles; there is on-going work to secure incentives for FCEVs until 50000 FCEVs are on the road.
- The Norwegian stations are operated by HYOP with the exception of the hydrogen station at the Rosenholm bus garage owned by Air Liquide and operated on a contract with Ruter. NEL and Uno-X have signed a letter of intent to build 20 HRS by 2020 (3 new stations established during 2016).
- Finland has 2 HRS in operation and one FCEV. Iceland is planning 2-3 HRS by 2017 - 2018.

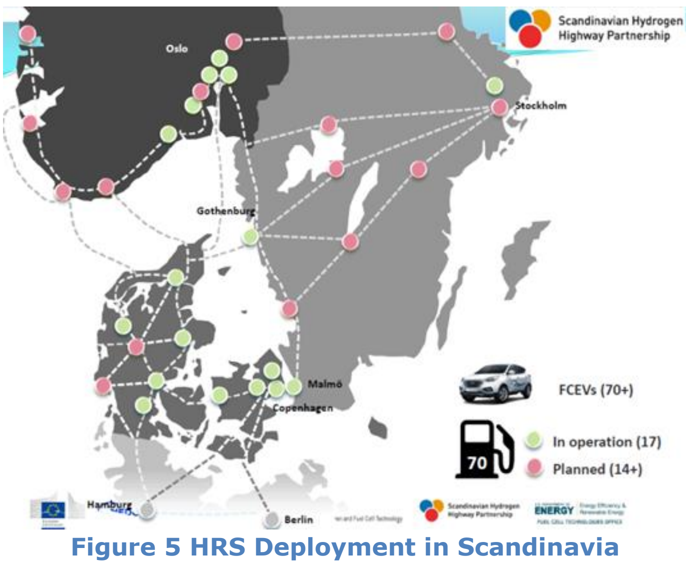

Figure 5 HRS Deployment in Scandinavia

2.5 European Commission

– The *European Energy Union* is the leading policy. It focusses on establishing secure, sustainable, competitive, affordable energy for every European. This means:

  1. Energy security,
  2. Internal energy market
  3. Energy efficiency
  4. Transition to a long lasting low carbon society
  5. Energy union for research innovation and competitiveness

  The European Energy Union contains the 5 above guiding directions, 15 concrete actions and 43 initiatives with an end date of 2019. Six of the actions are directly relevant to hydrogen.

– Under the *EU Integrated Strategic Energy Technology Plan* C(2015)6317, the Action 8 – Strengthen market take-up of renewable fuels includes FC&H.

– The *Renewable Energy Directive II (RED II)*, expected at end 2016, identifies how a binding target of 27% renewables by 2030 will be achieved. It will also cover how to drive the update of RES in transport and therefore this is relevant to pure hydrogen but also power-to X and CCU.

– The *Transport Decarbonisation* strategy has been published in summer 2016. This is not a legislative document it is a communication. It proposes new CO2 targets for cars and vans post-2020 and outlines measures in support of the AFI including HRS. The Strategic Transport Research and Innovation agenda, STRIA (communication by the European Commission) will be issued at the end of 2016.

– Also relevant to hydrogen although not on transport:

  - The New Electricity Market Design Directive, to be issued at end 2016, creates conditions helping RES integration including storage, for which hydrogen can play a role. This is legislative document.
  - In the communication Strategy for Heating and Cooling (published in February 2016) fuel cells are mentioned for their potential to reduce carbon footprint and fossil fuel import dependence.

– The main legislative document regarding hydrogen infrastructure is the *Alternative Fuel Infrastructure Directive* (Directive 2014/94/EU). By 18 November 2016 all Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive. This applies to the larger European Economic Area (therefore includes Scandinavia). Also before this date the Member States must submit their National Policy Framework (NPF). The evaluation of NPFs (by the Commission) will be done taking into account the objectives of EU-wide mobility, reduction of oil dependence, economic growth, and greenhouse gas emissions.

  Those member states which have decided to include publically accessible hydrogen refuelling points in their NPFs shall ensure that, by 31 December 2025, an appropriate number of such points are available and that the HRS network includes, where appropriate, cross-border links. Moreover Member States shall ensure that hydrogen refuelling points accessible to the public deployed or renewed as from 18 November 2017 comply with the technical specifications set out in point 2 of Annex II of the AFID.

- So far those that will include hydrogen are Germany, Austria, the Czech Republic, Belgium, Latvia, and Italy. Romania will not include it. Others are still undecided.
- The Commission shall be empowered to adopt delegated acts to update the references to the standards referred to in the technical specifications set out in point 2 of Annex II where those standards are replaced by new versions adopted by the relevant standardisation organisations.
- Mandate M/533 requests the European Standardisation bodies CEN- CENELEC to draft European standards for alternative fuel infrastructure in particular to address interoperability. The CEN TC 268 – WG 5 deals with this for hydrogen supply.
- Article 7 of AFID focuses on user information. It covers labelling for all fuels and requirement to display the cost compared with a relevant unit price. If a common methodology for alternative fuel unit price comparison is not provided the Commission will be empowered to adopt one by means of implementing acts. It is expected that this is the path that will be required and therefore the EC, the Member States and stakeholders have already started discussing this.
- The Sustainable Transport Forum (STF) is established to assist the Commission with implementing the Union's activities and programmes aimed at fostering the deployment of AFI and provide a platform for structural dialogue. It includes the Member States' authorities responsible for the deployment of alternative fuels, public and private organisation involved in the subject, experts and observers (international organisations, EFTA and Candidate Countries). http://ec.europa.eu/tramsport/themes/urban/cpt/stf_en.htm

– Relevant EU research and innovation activities on hydrogen are carried out under the umbrella of the FCH-JU/FCH2 JU. The total FCH JU support amounts to date to 240 M€ for 42 projects and 185 M€ for demos (excluding the results from the 2015 call). Funded projects relevant to this workshop scope are: *HyTransfer* – fuelling protocol development and validation of practical approach for temperature control during fast transfers, *HyCora* – hydrogen contaminant risk assessment, *HyAC* – metering and *Phaedrus* – Hardware.

– The *FCH2 JU RCS Strategy Coordination Group* has to implement three main tasks in agreement with the Industry Group (Hydrogen Europe) and the Research Grouping (N-ERGHY): 1) Identification and prioritization of RCS needs of strategic importance for the EU; 2) Definition of the strategy to be put in place to pursue the priority RCS issues and 3) identification of PNR activities to support the RCS priorities. To be noted that the RCS Strategy Coordination Group will not draft standards and will not duplicate any existing work.

2.6 The Netherlands

- In 2013, the NL *Energy Agreement for Sustainable Growth*, which includes transport as well, stipulated that by 2035 all new cars are to be ZEV.
- The Dutch vision and roadmaps on sustainable fuels considers: a) transition to electric propulsion of light duty vehicles, busses and trucks, if promising and b) a roadmap for 20 publicly accessible HRS by 2020 and 2000 cars, 100 city buses and a few hundred logistic vehicles.
- Established in 2015-2016, the National Hydrogen Platform for public-private cooperates (at BENELUX level) on barriers identification, priority setting and coordination of actions and new initiatives. It has 4 tasks forces:
    1. Sustainable hydrogen economy - production and delivery and use
    2. HRS and market development for mobility
    3. Buses
    4. Vans, trucks and special vehicles
- The Netherlands is working on the basis of agreements and public-private green deals; as the "*green deal for zero-emission for public bus transport in 2030*", the "*green deal on zero-emission logistic vehicles*" and the "*green deal on hydrogen*" that is being elaborated in 2016.
- The PGS 35 "*Hydrogen installations for delivery of hydrogen to road vehicles"* is part of a publication series on dangerous substances. It brings together all applicable standards and guidelines, for competent authorities and operators, applicable for the design, building and operation of HRSs and it includes a document to facilitate permitting of HRS. The PGS 35 has been translated into English and is available at: http://www.publicatiereeksgevaarlijkestoffen.nl/publicaties/PGS35.html.
- At international level the Netherlands participates in CEN/CENELEC and ISO activities and is concerned with identification of knowledge gaps and implementation of hydrogen laws and regulations.
- At present there are 23 cars on the Dutch roads; among them the Netherlands' Secretary of State has a chauffeured hydrogen car, there are a taxi in Rotterdam and a road-assistance vehicle of the ANWB. As for busses 12 are planned and 3 are already decided. In addition the Netherlands has 1 garbage truck in operation and 2 more featuring a FC range extender are planned. The development and demonstration of a 40 ton hydrogen truck is also planned.
- Two hydrogen refuelling stations are in operation in the Netherlands; both of them are 700 and 350 bar. The station in Rhoon (Rotterdam) is operated by Air Liquide and its hydrogen is supplied through pipeline. The second located in Helmond is operated by WaterstofNet and the hydrogen is produced by electrolysis (60 kg/day). Three more HRSs are decided for 2017; another 7 are in preparation and 5 more under investigation. These HRSs are built within the framework of regional initiatives, the TEN-T, the FCH-JU and the EIB (under discussion).
- The Netherlands is granting strong fiscal incentives for zero emission cars which include FCEVs. There is also no excise duty on hydrogen (yet). Moreover there are fiscal incentives for business investment in environmentally friendly technology and products.

2.7 France

- Hydrogen is now on the French Government Agenda. Industry and Government have agreed on 2020-2030 targets which include the goal for 2030 of 600 refuelling stations (70MPa) and 800000 vehicles. In March 2016 an inter-ministerial report on the hydrogen energy sector was published; the report acknowledges an acceleration of innovations and progress in the field, in particular for logistics and captive fleets. The report recommends the Government to structure and give political support to the hydrogen sector by building a roadmap and adapted governance. Moreover commitment from industry has been expressed on energy storage using hydrogen.
- There are 12 HRS in operation in France: 5 are private and 7 are public (but there is a contract in place; they are not retail). The main areas are Grenoble, Lyon, Paris, and Low Normandy, as shown in Figure 6. The plan is to have, with funds from the FCH2 JU and the TEN-T, 1000 cars and 100 stations by 2020. Currently France has almost 100 cars but most of them are range extenders as the Kangoo ZE-H2. France has as well two demonstration fuel cell ships.
- Within the project "*hype*" a taxi fleet with 5 FCEV and one HRS have been deployed in Paris for the COP-21 in early December 2015. The plan is to enlarge the fleet to 70 FCEV by the end of 2016. FCEV taxis are being well received by the public in Paris. There are also BEVs (Teslas) under testing, however they have the challenge of recharging in contrast to the FCEVs and therefore the taxi drivers prefer the FCEVs because of fast fuelling.
- In France the hydrogen introduction strategy focusses in a first instance on a cluster model and range extender vehicles (low pressure station and 20 refuellings per day). The goal is to have small size stations in place by 2026 and just make them bigger as 2030 approaches. In this way the financial risk of the first investment is minimised.
- A call for proposals called "*Hydrogen in the territories*" was launched in May 2016 to fund large scale demonstrations projects. The projects selected will be announced before end October 2016. The call includes metropolitan areas, rural areas with potential for RES, isolated territories with grid issues (islands, Corsica, Martinique), logistic platforms, and airport and harbour zones.
- R&D activities are mostly carried out with funding from the FCH-JU; France is part of project consortia dealing with on-board storage (*HyPactor*, *FireComp*, *Copernic*), with HRS infrastructure (*HyTransfer*), with hydrogen quality (*HyCora*) and with fuel cell as power units for non-essential aircraft application (*HYCARUS "Hydrogen cells for airbone usage"*, www.hycarus.eu).

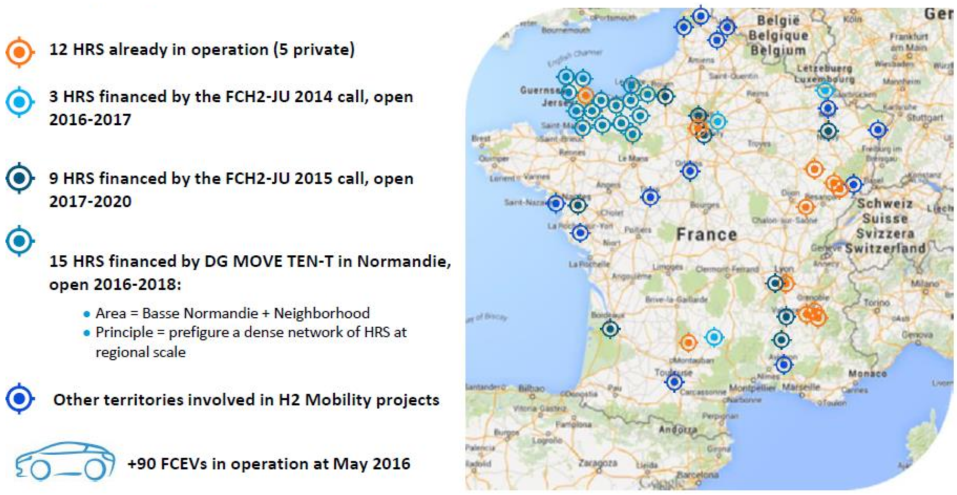

Figure 6 Deployment of FCVs and HRS in France

2.8 United Kingdom

- The *UKH2Mobility* project started in January 2012 with 10 organizations and 3 government departments to support the introduction of hydrogen as a transport fuel by developing and implementing a strategy that will help to decarbonise road transport, create economic growth, diversify energy supply and improve local environments. The UK H2Mobility project is a private-public partnership, primarily funded by its industry participants with contribution from the UK Government. There are currently 12 industry parties together with the FCH-JU and three UK Government Departments (the Department for Business for Innovation and Skills, the Department for Transport and the Department for Energy and Climate Change) as well as Transport for Scotland, Greater London Authority, and the Welsh Government. In its first phase of work, UK H2Mobility has developed a roadmap for the introduction of vehicles and hydrogen refuelling stations from 2015 onwards. Currently in the second phase of the project, the consortium is developing a coordinated business plan.

  According to UK H2Mobility it is estimated that by 2030 1.6 million FCEV and 1150 HRSs will be required for national coverage. The target is to produce 51% of hydrogen by electrolysis by 2030. This will generate 1.3 billion GBP benefit to the UK economy by switching from imported fuels to domestic hydrogen. At shorter term, by 2020, 65 HRSs (80 kg/day electrolysis based) could provide basic initial coverage. Hydrogen refuelling infrastructure will be developed following a cluster approach with a focus on a 25-30 mile radius of London. This is where the majority of the population and the money are. Historically there have been some other projects around the UK: e.g. Aberdeen, Sheffield etc. and there is an expectation that some additional HRSs may go in there. It is also expected that some of the other larger cities will start deploying HRSs by 2020.
- A total of 600 million pounds is allocated for decarbonisation of transport (increased in November 2015 from the 500 million pounds initially established). It is not clear how much of that is specifically for hydrogen infrastructure.
- In October 2014 the Office for Low Emission Vehicles (OLEV) announced 7.5 million pounds toward establishing 15 HRS and FCEV fleets under the *Hydrogen Transport Advancement program – HyTAP*. In Feb 2015 the OLEV announced a HRS infrastructure grant scheme with 5.5 million pound allocated. Seven projects were just started in 2015, delivering 12 HRS.
- The Teddington HRS, the first of those 12 stations to be built, was opened in May 2016. It is an on-site electrolysis station with an ionic compressor and gas storage (600 kg/day) for both 700 and 350 bar dispensers. A second station will be opening in East London during 2016. A service station near the M25 at Cobham has included hydrogen dispenser and plans to open in August 2016. There should be 15 HRS in operation by the end of 2016.
- There is a preference to co-locate HRS with existing petrol stations and there are requirements for this outlined in the UK Blue Book. This should help speeding the approval. This is very challenging from footprint, permitting and consumer basis. One of the preferred locations is on the sides of busy highways.

- The *H2ME* project funded by the FCH-JU will put two more stations in to operation in UK and will upgrade another one (www.h2me.eu).
- The H2Mobility analysis determined that initially HRS sized for 80 kg/day with an upgrade later to 400 kg/day as the market expands makes more sense than investing in oversized infrastructure. The compressor that is being installed at these 80 kg/day stations is capable for 600 kg/day; however the limiting factor is the hydrogen production that will require the development of high current density electrolysers. There is as well the need of reducing the parasitic electricity needs especially for cooling and thermal management of the electrolysers. The price for hydrogen at the pump in UK is £10 /kg.
- At present UK is waiting for a new Government funding strategy (probably later in 2016) to clarify the path forward from 2017 to 2020 to reach the 65 HRS target. Finally an OLEV announcement is awaited on the implementation of the AFID and the technical issues that this may create.

2.9 People's Republic of China

- The Chinese Government has released policy mandates to encourage hydrogen and fuel cells technologies: the "National Development Reform Commission" and the "National Administration" released the "*Energy Technology Revolution & Innovation Initiative (2016-2030)*" and the "*Energy Technology Innovation oriented Roadmap*" in April 2016. With these mandates China expects that hydrogen production, storage and commercialization, and fuel cell wide applications can be deployed by 2025.
- In 2015 the Ministry of Industry and Information Technology released "*China Manufacturing 2025*". One of its development strategies is to achieve engineering and industrialization of FCEV core technologies. The goal is to improve performance (targeting an equivalent performance to ICVs by 2030) and reduce cost to 22 million CNY/ kilowatt. In the frame of this initiative China will set up a "New Energy Vehicle Technology Innovation and Demonstration Fund" specifically for manufacturing of FCEVs in China.

  In addition several local governments like Yunfu and Yutong and SAIC Motor Corporation Ltd. are investing in FCEV demonstration and hydrogen supply chains projects.
- A subsidy scheme for FCEV by the Ministry of Finance is in place for the period 2016-2020. It comprises 31000 USD for fuel cell passenger cars, 46000 USD for fuel light duty busses and vans and 77000 USD for fuel cell heavy duty busses and trucks. There are also subsidies for HRS. At present FCEVs and BEVs do not need to go to the lottery to register a vehicle in Beijing and Shanghai. Under the new policy development China would like to include benefits like fast lane use permit for FCEV.
- China Central Government will allocate more than 100 million EUR in hydrogen, fuel cells and FCEV R&D and demonstration in the period 2016-2020. At present there is on-going R&D on fuel cells containing precious metal-free nano-catalysts and on FC durability improvements. There are as well running projects on FC power trains, on FC vehicles and on hydrogen generation and storage. Research activities on on-board hydrogen storage and filling technologies and hydrogen standards are carried out at the Tongi University.

- A new project will be launched at the end of this year for "*Accelerating the Development and Commercialization of FCEVs in China*". It is a 4 year project from 2016-2020 with focus on FCEV production and application, H2 production and refuelling, policy and regulatory frameworks for FCEVs and HRS, education and outreach activities and also a FCEV technology capacity development program. There will be an international call for proposals for participating in this project.
- China has been running several fuel cell vehicles demonstration projects since 2006. FC busses provided services in 2008 Olympic Games and in 2010 World Expo. This has originated data from 12 FC buses that have been in intermittent operation for the last 2 years and have a cumulative total of 300000 km. In March 2014 Shanghai Automotive Industry Corporation launched the "*New Energy Vehicle Journey 2014*". Among seven new energy vehicles, 2 Roewe FC cars were test driven along 25 cities, as Beijing, Shanghai, Lhasa, etc. These cars were operated for more than 10000 km under different climate conditions.
- In China, there are currently 4 HRS in place and 3 more are planned. The Table 1 shows a breakdown of fuel cell vehicles and HRS in China.

Table 1 Deployment of fuel cell vehicles and HRS in China

City	Bus	Car	Delivery Van	Delivery Truck	Hydrogen Station	Hydrogen resource	Total
Shanghai	16	41	30	0	1	Industrial by-product gas	87
Beijing	10	0	0	5	1(1 more built next year)	Natural gas reforming +electrolysis	15
Zhengzhou	3	0	0	0	1	Industrial by-product gas	3
Foshan	2	0	0	0	1(more built soon)	Industrial by-product gas	2
Yancheng	5	0	0	0	Under planning	Industrial by-product gas	5
Total	36	41	30	5	4		**112**

- At present there is a restriction in China on the use of type 4 tanks (plastic liner) for hydrogen on-board storage. The China Central Government is now realising the importance of high pressure tanks and it seems to be an opportunity in the coming years for allowing type 4 tanks in the Chinese market. However it will take time to revise the current regulations.

3 Hydrogen refuelling

At present the commonly used hydrogen vehicle refuelling protocol is the one established in the SAE J2601 [1]. Under the "hydrogen refuelling" subject participants to the Workshop elaborated on the adoption of SAE J2601 in their countries, the validation of the fuelling protocol, the field test methods and equipment used to certify HRS compliance with SAE J2601 and the number of stations SAE J2601-compliant, the amount of SAE fillings in relation to station use and the occurrence of non-SAE fillings. Other topics as the use of non-SAE fuelling protocols or the research development and demonstration efforts to address issues in relation with hydrogen refuelling were discussed as well.

The main outcomes are summarised in following:

SAE J2601-2014 is widely adopted. In Japan JPEC-S0003 is the fuelling protocol standard and it refers to SAE J2601 but it is modified for the Japanese regulation (i.e. not to exceed 82 MPa). The high pressure gas safety act refers to JPEC-S0003 and is paired with the Guidelines for Fuelling Performance Validation (similar as CSA HGV 4.3). JPEC-S0003 includes specific safety requirements as, for example, duplicity of temperature and pressure sensors, and additional performance requirements.

In the US, California requires HRS to comply with SAE J2601-2014; and the stations built in the previous years must be upgraded to at least comply with the SAE J2601-2010. California does not have currently a HRS certification process codified in law.

Concerning validation of HRS's compliance with SAE J2601-2014 each country has a different approach. The 2014 version of J2601 includes new features for the top-off and the fall back options for refuelling. A new test series is being developed in Germany: safety related functions and station performance are subjects for validation through a list of 36 tests. In Japan there are 9 tests to validate station fuelling performance according to the Guideline and it takes 3 days to do all the testing. Validation of fuelling performance is the responsibility of the HRS constructor. At present Japan has validated 67 stations and another 12 were tested by Toyota with the Mirai. In the US the CSA HGV 4.3 includes field tests on faults detection, critical data communication and fuelling protocol performance for checking station compliance with SAE J2601-2014.

Similarly each country has developed its own HRS certification field test method and equipment: in Germany CEP has already one test device in operation that is used for both HRS factory acceptance test and on-site acceptance tests; Japan has the HySUT Hydrogen Dispenser Testing Apparatus (HDTA) and in USA the HyStEP (Hydrogen Station Equipment Performance) device developed by H2FIRST (Sandia/NREL) is used.

The certification of HRSs is judged to be a crucial item that needs to be internationally harmonised. An appropriate certification test assures compliance with standards without any need of OEMs to perform instrumented vehicle tests to confirm that the station meets their requirements. Activities to harmonize the HRS validation tests with those described in ISO 19880 are on-going.

The activities of ISO/TC 197/WG24 on drafting ISO 19880-1 were presented in this session. ISO 19880-1 "Gaseous hydrogen — Fuelling stations — Part 1: General requirements" covers the whole hydrogen station and includes on-site production, delivery, compression, precooling device and gaseous hydrogen dispensers as well as the electrical safety and the fuelling protocol. HRS acceptance testing comprises both factory (FAT) and on-site (SAT) tests. Capacity tests are considered part of the FAT, though some tests (e.g. precooling capacity) are as well included in the SAT. There are requirements for on-site field tests to be performed before HRS normal operation and then periodical evaluations (e.g. each year verification of safety relevant programmable logic controller, PLC). The WG24 has combined the data they have from US, Germany and Japan to make the guidelines for the minimum SAT; and the piping and instrumentation diagrams for the HyStEP and the HySUT validation devices will be included in the ISO 19880-1 document should anyone wish to build a device. A third party will need to be identified country by country if they wish to have the "certification paperwork"; in the US that would be an AHJ. The idea is to have harmonized acceptance tests, equivalent to the CSA HGV 4.3.

In the 2016 version of JPEC-S0003 a new category is included for fuel cell bus refuelling (70 MPa, 10 to 35 Kg H2 tank and non-high flow). In addition Japan would like to develop a fuelling protocol for small volume tanks (0.5 to 1 kg H2) for motorcycles and a non-precooling protocol for 350 bar fuelling for forklifts. In the same line the next steps for SAE J2601 revisions will expand the fuelling protocol to cover medium duty application and small compressed hydrogen storage systems and will develop guidelines and a protocol for higher fuel delivery temperature applications (e.g. non-precooled residential and service fuelling) In addition it will ensure compatibility between all possible protocol interactions (e.g. emergency roadside refuelling and commercial HRS).

The fuelling protocol "MC method" is an alternative considered by Japan and USA and it will be part of the 2016 version of SAE J2601. Japan is as well developing another protocol based on the Monde formula in which the vehicle tank temperature is estimated as a function of the hydrogen mass flow rate and temperature measured at the HRS. In the EU pre-normative research to optimise the refuelling process is carried out within the FCH-JU funded project HyTransfer (www.hytransfer.eu). With a total budget of 3.1M€ the project will be finished in December 2016. HyTransfer proposes a new approach in which the 85 °C temperature limit is applied to the tank materials rather than to the gas and so the cooling needs are reduced while still enabling 3 minutes or less for vehicle re-fuelling. Results of 83 tests carried out at the JRC and at Air Liquide show that the current limit and ramps are conservative and there is room for optimization. The final report will be issued in 2017 and will include the computational fluid dynamic modelling results and thermodynamic model, the validation of the new approach on a vehicle test bench and techno-economic analysis.

At the Joint Research Centre's "*Gas Tank Testing Facility (GasTeF)*" pre-normative research is oriented to assess safety and performance of high-pressure hydrogen (and natural gas) storage tanks. For example the way that the hydrogen flows into the tanks is studied to determine its effect on the tank lining temperatures. The JRC findings are reported in publicly available scientific literature. Furthermore, in 2016, a number of tests have been performed in GASTEF upon request of ISO/TC 197/WG24 in support to the risk assessment and to improve understanding of the effects of "out of bound fuelling".

4 Hydrogen Quality

The assurance of the quality of the hydrogen delivered in hydrogen refuelling stations is a critical item as it affects the performance of the fuel cell in a vehicle. In the session hydrogen quality the participants shared experiences on the methods available for the determination of hydrogen impurities and the test results and provided an update on the R&D efforts and the guidelines, codes and standards applicable in their countries, to address hydrogen fuel quality assurance.

In this session the activities of ISO/TC 197/WG28 dealing with hydrogen quality verification in the draft ISO 19880-8 were presented[1]. The ISO 19880-8 "Gaseous hydrogen — Fuelling stations — Part 8: Hydrogen Quality Control" specifies the protocol for ensuring the quality of the gaseous hydrogen at hydrogen distribution bases and hydrogen fuelling stations for PEM fuel cells for road vehicles (only this application). The first edition of ISO19880-8 is aiming to achieve the H2 specifications of ISO 14687-2:2012 [2] (WG28 does not touch specifications) guiding the ways of quality control for the whole supply hydrogen chain for the FCEV application. It is envisaged to have the international standard completed in 2017. In Europe the AFID requires to have a European standard defining the hydrogen quality requirements, so the EC has given mandate to CEN TC268 for the preparation of this standard (which resulted in the creation of the CEN TC 268 WG 5). The WG 5 gave mandate to EIGA to prepare a draft for H2 quality specification based on ISO 14687-2 (and ISO 19880-8) and to initiate discussion with OEMs and stakeholders to have a European position.

The hydrogen purity specification is a matter of concern; in the 2012 update of ISO 14687-2 the purity requirement was dropped from 99.99% to 99.97%. Specifically the allowed helium has increased. The 99.999% purity for delivered hydrogen is based on quality control; and so process control is an important part of the ISO 14687-2. The question is whether the hydrogen fuel specifications should be changed since such 99.999% purity is actually difficult to certify. The current specifications are based on 10 years of gathering technical data across countries. It is also argued that the current specifications are a challenge for recent developments such as lower catalyst loading and higher current density for smaller FC units.

In Germany the CEP uses a sampling system developed in collaboration with Daimler. Samples are taken during a normal fuelling (a FCEV is required) and there is no need for technical support from the HRS operators. The results of the test campaigns performed in 2013 and 2014 show that particles are one of the major issues. A CEP project is on-going (30 months approximately duration and 2.5 M€ costs) to set up a reference laboratory in Germany (HyLaB) offering ISO 14687 compliant testing services. HyLAB will develop processes to produce and reproduce gas reference mixtures and will also develop and establish appropriate analytical methods with different equipment from ZBT and ZSW (for example test to the 4 ppb sulphur). The laboratory will be in charge of sampling all CEP-stations every 6 months, performing analysis according to ISO and identifying contamination sources. German Regulatory bodies are not yet involved in the quality sampling project. Costs for 5.0 analyses are approx. 300-800 EUR whereas costs

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[1] Clarification of the Working Group responsibilities for H2 quality for FCEV: ISO/TC 197/WG27 is in charge of the specification of contaminant thresholds levels (discussed in ISO 14687-2), whereas WG28 is in charge of the hydrogen quality control (discussed in ISO 19880-8). In ISO/TC 158/WG7 the analytical methods for each impurity constituent in FCEV hydrogen are discussed.
ISO/TC 197/WG24 is in charge of clauses (7.3 & 7.4 "hydrogen quality") in ISO 19880-1.

for a full ISO-analysis are approx. 2.700 EUR. A CEP common practice is to measure the hydrogen 5.0 quality on the delivery truck, checking the 6 most important species but not all the cross species as prescribed by ISO 14687-2. There is no laboratory in Europe with capabilities to perform particles test according to SAE J2719 [3].

From the 81 stations planned in Japan 40 are off-site hydrogen production, 14 on-site and 27 are mobile refuelling stations. So far all commercial HRS in Japan satisfy ISO 14687-2. In Japan the Guideline mandates checking once per year (though water and oxygen are checked at every maintenance). It is expected that the station owner will take care of the H2 quality assurance without check from the Japanese government.

In USA, SAE J2719 is the law in force in California. In 2013, the California Energy Commission (CEC) Program Opportunity Notice (PON) requested purity checks at HRS commissioning, every 6 months and after a major maintenance event. The new California stations under the current grant funding opportunity will perform sampling on a 3 months interval. One SAE J2719 self-sampling (no particulates) test costs USD ~4000. The sampling procedure is done according to ASTM D7606 (gaseous sampling) and ASTM D7650 (particulates).

A US DOE project is on-going at Los Alamos National Laboratory to develop an in-line device to measure impurities in the fuel stream at HRS. The results obtained with the prototype are promising (e.g. response to 50 ppm CO) and the next step will be the testing at SAE/ISO levels. Also in Los Alamos a parametric study is being carried out to determine impurities tolerance under more realistic operating conditions.

In Europe, the objectives of the FCH-JU funded project HYCORA-"Hydrogen Contaminant Risk Assessment" are to reduce cost of hydrogen fuel quality assurance for HRS and to provide recommendations for revision of ISO 14687-2:2012. The HyCORA approach is based on a quantitative risk model which takes into account probabilities of fuel cell impurities related incidents in FCEV daily operation/refuelling in order to estimate, for a given time interval, the number of contaminants-caused incidents and the costs associated to them.

The JRC Report "EU Harmonised Test Protocols for PEMFC MEA Testing in Single Cell Configuration for Automotive Applications" presents a methodology to enable a fair comparative assessment of the performance of MEA under representative FCEV operating conditions (fluctuations, stressors tests, load cycles and degradation). The test protocols have been agreed with automotive OEMs and research organisations (no gas suppliers) participating in FCH-JU funded projects. The aim is not to substitute any testing protocol/procedure currently existing in the different industries, but to establish a common test protocol. The final goal is to reach international harmonisation rather than just an European protocol. To be able to reliably determine the effect of hydrogen impurities on FC performance, the use of harmonised test protocols is considered necessary.

5 Hydrogen Metering

The accurate measurement of the hydrogen dispensed in refuelling stations (at 70 MPa pressure and -40 °C) is an important topic. In the session "hydrogen metering" discussions were held on the performance of existing equipment (accuracy, measuring method, calibration, etc.), the applicable regulations and standards, devices to certify metering at HRS and R&D activities to address performance gaps.

In Germany, an allowable tolerance of 1% to 1.5% is prescribed based on *OIML R 139 - Compressed gaseous fuel measuring systems for vehicles*. The hydrogen refuelling station design, the dispenser and the location of the measurement devices play a role for achieving this tolerance. Using a reference measurement system designed by Linde deviations of 2-2.5% and 5-8% at the station have been identified. This shows that at present it is not technically possible to reach the required accuracy, therefore derogation has been asked for the existing HRS to exceptionally allow for higher tolerances. In Japan, *JIS B 8576 0 - Hydrogen metering system for motor vehicles* has been published in May 2016. The standard considers accuracy classes (Table 2) and makes reference to OIML (R-139) and OIML R117. For JIS B 8576 0 technical aspects (e.g. pressurisation loss, measuring method, etc.), the FCCJ (Fuel Cell Commercialization Conference of Japan) voluntary guideline established in 2014 is preferentially adopted.

Table 2 JIS B 8576: Hydrogen metering system for motor vehicles

Accuracy class	Maximum permissible error (MPE)	MPE in service (Maintenance)
2	1.5 %	2.0 %
3	2.0 %	3.0 %
5	4.0 %	5.0 %
10	8.0 %	10.0 %

In USA the required specifications and accuracy tolerances for hydrogen dispensers are listed in the *National Institute of Standards and Technology (NIST) Handbook 44 Section 3.39 - Hydrogen Gas-Measuring Devices -Tentative Code*. Existing hydrogen dispensing technology cannot routinely meet the accuracy tolerances (1.5% when certified, 2% at maintenance or in-use annual check). In 2014, California modified, amended, and made specific sections of NIST HB 44 through rulemaking to establish attainable California specifications and accuracy tolerances for hydrogen gas measuring devices as shown in Table 3.

Table 3 California's accuracy classes for hydrogen gas measuring devices

New Accuracy Classes Adopted 2014	Acceptance Tolerance	Maintenance Tolerance
3.0 installed before 2020	2.0%	3.0%
5.0% installed before 2020	4.0%	5.0%
10.0% installed before 2018	5.0%	10.0%

Results from the Hydrogen California Type Evaluation program show that after testing 16 HRS (more than 200 fills) none met NIST 1.5/2.0% Accuracy Class; 4 dual H35/H70 stations were awarded Certificates of Approvals 5.0/4% and 5.0/4% accuracy class/acceptance tolerance and another 2 got temporary use permits.

According to product information many flow meters are suitable for hydrogen station operation and can be calibrated; in practice, however, this may not be the case. A study by the Fraunhofer Institute for Solar Energy Systems reviews the state of art for measurement of quantities of hydrogen and the accuracy and availability of the current methods. It also contains simulation of different scenarios and a standard HRS-design as well as evaluation of results of on-field measurements. The study is not yet published but in summary it concludes that metering performance depends on boundary conditions such as starting pressure at the vehicle, starting pressure at the HRS, refuelling amount, ambient temperature, etc. and that the measurement result is not always accurate. Accuracy is much better for large amounts of dispensed hydrogen than for small amounts but this highly depends on the ambient temperature.

In Germany fuel stations need to re-check their metering devices every 2 years; in the case of hydrogen stations since the PTB– the German national weights and measures office -does not have a device to check hydrogen flow metering equipment, suppliers must check themselves every two years. In the near future CEP will discuss with PTB to set-up a metering device that can easily be calibrated.

Japan uses a test apparatus developed by Tatsuno based on the gravimetric method for certification of HRS metering performance. Tests were carried out at all commercial HRSs, and it is found that for 1 kg H2 dispensed the accuracy ranges from +/- 8% while for 4 kg the measurement is within +/-4%. The frequency of calibration in Japan will be 1-2 year in the beginning stage.

In USA type evaluation of retail hydrogen fuel dispensers is conducted using the Hydrogen Field Standard (HFS) designed and constructed by NREL. Field tests are designed to determine: (1) Conformance to one of the adopted accuracy classes specified in the regulation; (2) Fill-to-fill repeatability, accuracy, and precision; (3) dispenser performance during interrupt and emergency stop simulations; (4) compliance to advertising, labelling, and method of sale requirements. Moreover in the frame of the on-going US DOE H2First validation project a laboratory gravimetric hydrogen measurement device has been built to test commercially available high pressure hydrogen flow meters. The project will assess the performance of three flow meters (2 Coriolis meters and one turbine meter) against NIST Handbook 44 requirements. At present pre-testing of the system is carried out and the next step is testing the three mass flow meters.

Hydrogen mass metering equipment is still scarce and expensive: in Germany a meter costs 9000-12000 EUR, in US the cost is close to USD 15000. The target price is 3000-5000 EUR.

Regarding R&D, California has no budget or plans for research on metering. It is expected that the temporary accuracy classes will help encourage stakeholders to pursue meter technology improvements. The temporary accuracy classes sunset in 2018 (10%) and 2020 (5%, 3%). By this time, possibly, new meters with improved accuracy and ability to deliver accurately the Minimum Measured Quantity[2] (MMQ) may be nearing market release. However, the U.S. is interested in developing a more compact, portable, affordable, hydrogen field standard device (gravimetric and/or flow meter) for use by multiple state and local jurisdictions. Along with this there are needs for increased training and awareness (especially at local government level) on hydrogen metering challenges.

Japan suggests carrying out research to address the effect of leak check and pulsed-discontinued flow and depressurization losses on meter performance. Furthermore it is recognised that at present there is no solution to account for the hydrogen that is left in the dispenser hose after a fuelling; which currently it is not considered.

[2] The Minimum Measured Quantity means the smallest quantity specified by the manufacturer for which a Coriolis metering assembly is capable of measuring within the applicable prescribed limit of error.

6 Hydrogen Refuelling Station Utilisation Experience

In this session the different participant countries presented an overview of operational experiences of 70 MPa hydrogen refuelling stations.

6.1 Germany

There are 18 public stations in Germany and another 23 under construction. Their availability is tracked by the CEP. In the past "availability" was defined as the time that the station was open; now the CEP has established a new definition based on the availability for the customer (Was the HRS available when the customer needed it?) so that maintenance is included in outage. In addition a new performance indicator was introduced: "successful full filling at first try".

For the monitoring of the German HRSs the CEP has set-up an automatic Hydrogen Info Terminal (HIT) system that provides signals "in-operation" or "out-of-operation" for each dispenser of all the stations. The status changes are transmitted via GSM/GPRS to a web-portal (central information port) that provides HRS's status logging and processed data. Live information on availability of HRSs can be checked at www.h2station.info

The CEP also introduced a new remote-controlled energy data collection system, which is successfully in operation since September 2015 at 2 stations. The system can be applied to an already built station. A framework agreement is signed for delivering 50 systems with CEP default configuration and 20 systems have already been ordered in February 2016. The hardware of such system costs 1500 EUR and the estimated operational costs are 20 EUR/month.

A comparative survey for user friendliness of two different refuelling systems (WEH and Walther) has been carried out in January and February 2016 in Hamburg with a sample of 15 first time users (of different gender, age, education and qualification/job). It was noted that all users were having troubles using both systems for one or another reason; e.g. play is to loose, no indication on whether the nozzle is properly seated or not, no clear indication on the direction to tighten/untighten, too low location of the card reader. As a result of this study some recommendations for optimising the refuelling system are made:

1. Reduce play of the fixed nozzle and communicate that nozzle has been arrested correctly (to avoid nozzle falling down),
2. Indicate direction of use of the nozzle, mark it with colours,
3. Increase flexibility of the hose to avoid nozzle pop-off,
4. Optimise the position of the card reader in the dispenser, communicate more precisely and provide feed-back,
5. Install information display (e.g. leak test in process, refuelling in process, expected filling level, and "Station is ready for a complete refuelling in a few minutes. A partial refuelling is immediately possible" or "the station cannot guarantee a complete refuelling at the moment") and a service hot-line.

Finally the freezing of the nozzle is not any more an issue in Germany and the nozzle pop-off due to the stiffness of the hose is not very frequent.

6.2 Japan

Iwatani operates 15 HRSs and 4 mobile stations. The Shiba-Park hydrogen refuelling station located in a very central location near Tokyo Tower) was presented as an example. It is attached to the first retail Toyota Mirai shop in Tokyo and the station has also a "Seven Eleven" shop built-in. Main characteristics of Shiba-Park are:

1. Liquid H2 supply, 1.5 tonnes (24000 litre) storage and 300 litre Type III ground storage for the compressed gas,
2. 2300 refuellings performed up to May 2016 in compliance with the protocol JPECS0003 (2012),
3. Design philosophy is "no leakage" (tightly built, compressor in steel container with steel wall), "no accumulation" (no roof) and "no ignition" (gas and fire detectors and fire protection walls at the border of the station),
4. Vehicle is refuelled by a licensed operator (after 6 month training) and not by the user,
5. General foot-print of the site is 1000 m^2. 8 meter safety distances are required. This can be reduced if there is a wall; the liquid hydrogen equipment does have it and the set-back distance is 2.5 m,
6. Cost of the station 460 million JPY (USD 4.2 M),
7. Duration of HRS construction 15 months.

Different standards for qualification of materials and equipment in HRSs are applicable in the different countries, see Table 4. This constitutes a barrier for the deployment of hydrogen infrastructure. Necessary compliance with more strict Japanese safety regulations makes the cost in Japan significantly higher than elsewhere, for example compressor costs are 1.3 million JPY while in Europe it would be 0.8 million JPY.

Table 4 Qualification Standards for Equipment and Materials in HRS

	Europe	US	Japan
Station	VdTÜV 514	State Fire Code, State Electrical Code	High Pressure Gas Safety Law, Article 7.3
Gas conditioning unit	PED 97/23/EG	ASME BPVC, TEMA	Designated Equipment Inspection Regulations
Compressor unit	Machinery Directive 2006/42/EG	NFPA 2	Security Regulation for General High Pressure Gas Article 7-3
Material	AD 2000 EN 13480	ASME	Illustration standard Article 9
Bank control valves	PED 97/23/EG ATEX 94/9/EG	-	Illustration Standard Article 9
High pressure Buffer storage	PED 97/23/EG	ASME BPVC Division III	Designated Equipment Inspection Regulations
Electric	ATEX 94/9/EG	NFPA 70 (NEC)	TIIS

6.3 United States of America

In California there are two hydrogen refuelling stations operated by Shell: Torrance and Newport Beach. Torrance opened in 2010; the hydrogen is supplied by a pipeline. It has a capacity of 50 kg/day and the utilization is currently 70%. Newport Beach was opened in 2012, hydrogen is produced by on-site reforming and with a capacity of 100 kg/day the utilization is just 10%. Shell also operates 3 HRSs in Germany: Berlin (liquid H_2 supply, capacity 100 kg/day and <5% utilization), Hamburg I (gaseous H_2 supply, capacity 70 kg/day and <5% utilization) and Hamburg II (PEM electrolysis H_2 production, capacity 80 kg/day and still to determine utilization). Here below some operative experiences:

1. Liquid hydrogen stations are the most reliable. Setback distance requirements for liquid hydrogen stations may be an issue. However, the FCH-JU project *IDEALHY* on large scale liquefaction concluded that liquefaction energy requirement could be halved (from 13 kWh/kg H_2 at present to 6 kWh/kg H_2). .
2. Forecourt hydrogen production by steam methane reforming enables low cost H_2 supply but the station footprint is a concern and reformer performance at low utilisation need to be optimised.
3. In the case of trucked-in gaseous hydrogen supply a faster transfer of H_2 from the truck into the station ground storage is needed. For H2 supply in 500 bar trailers (in U.S.) standards are needed for the safe delivery to the 200 bar storage.
4. Compressors at the station are performing fairly well, however cost and reliability of compression needs to be improved. Innovative methods such as electrochemical compression or liquid-hydrogen thermal compression are being studied.
5. Dispensers are expensive and not optimised for hydrogen. Shell is currently working on a programme with a design engineering company to develop an "iconic dispenser" that will exceed the expectations of FCEV users.
6. Assurance of appropriate hydrogen fuel quality is crucial for HRSs credibility. An affordable hydrogen quality monitoring system capable of on-line and multi-species analysis at part-per-billion level is needed.

6.4 Scandinavia (Norway)

In Norway there are 5 hydrogen refuelling stations, the hydrogen is produced by on-site electrolysis in two, is trucked-in in another two and is supplied by pipeline in the other one. Three of the stations are being expanded to supply higher quantities of hydrogen. They are operated under the HYOP brand since 4 years. Some technical issues found are related to:

All the HRS uses piston compressors; they work better and better as the operator gets to know them. To reduce station down-time the first-line maintenance is done by HYOP personnel and since all the HRS have the same compressor design, in case of maintenance, a swap from a less used location is possible.

In the past, two HRS in Norway had 35 and 70 MPa refuelling hoses on the same dispenser (now the 35 MPa hose is removed after the last 35 MPa FCEV left Norway). The use of a 35 MPa hose for refuelling a 70 MPa car with 45 MPa in the tank has caused station shut-down.

The pipeline station has an on-line hydrogen analysis for oxygen and moisture. The other 4 stations undergo periodic sampling and external analysis: hydrogen from electrolysis is of good enough quality and for the stations with trucked-in supply the hydrogen is checked by the manufacturer before shipping. Hyundai has stated that the fitness of the fuel cells of the cars operating in Norway is as good as that of fuel cells operated under laboratory conditions.

Cooling equipment may create many issues and if the cooling fails the station is down, nevertheless attention given to hydrogen cooling system is not as much as for other hydrogen equipment.

In Norway HRS up-time varied from 10 to 99%, the 10% corresponding to a costly repair. The average filling amount is now 3.3 kg; for Hyundai and Toyota FCEVs it is expected to be around 4 kg. No car has been immobilised due to lack of hydrogen supply at the HRS; however the key question is what would happen for 100 customers per day. To guarantee high HRS's up-time requires having a stock of spare parts, however this is expensive and implies elevated cost in the demonstration-phase. It is important to associate with suppliers giving a rapid response for which standardisation of components is certainly of help.

Norway has experienced, similarly to the other countries, user interface troubles regarding connecting /disconnecting couplings and lack of communication with the customer. In addition, in Scandinavia freezing of the nozzle can be a problem under certain atmospheric conditions as it can take several minutes to loosen it.

Some lessons learnt are:

1. A hydrogen station is a complex processing unit,
2. Need to be on-line to prevent faults from happening,
3. Need a back-up station not too far away,
4. Need stock of critical replacement parts,
5. Need speedy logistics for replacements and repairs
6. Appreciate patient customers, but do not expect many of them in the years to come.

6.5 European Union

The European Union contribution to this session was made by the programme office of the FCH-JU, with an overview of EU projects and initiatives on hydrogen infrastructure deployment.

Grouping the existing H2Mobility initiatives will create the start of a European hydrogen network: France, Germany, Scandinavia, and United Kingdom have in place advanced FCEV and HRS programmes. Similar initiatives are starting or running in Austria, Belgium, Finland, Netherlands and Switzerland. At present 49 stations and 150 range extender vehicles in EU are under the H2 mobility.

From 2020, the H2Mobility initiatives will allow nationwide driving in the first-mover countries and start expanding into neighbouring countries along TEN-T Corridors, taking learning from the early deployment centres.

The investment in EU on hydrogen infrastructure comprises: 112 million EUR provided by the FCH JU to fund 7 HRS infrastructure projects, 38 million EUR from Connecting Europe Facility (CEF) for funding in 5 projects plus the additional contribution from Member States national budgets.

Main issues to be addressed at short term are: metering accuracy, reliability, standardised payment forms and harmonisation of the different permitting procedures across Europe.

6.6 Belgium

As there is no fuelling network in Belgium yet, the presenter elaborated on the business (development) case for Belgium.

FCEVs need a network of hydrogen refuelling stations. The main issue is the small number of cars meaning low utilization: Toyota only planned 10 cars this year, 5 in 2017, 5 in 2018. Hyundai can supply, but demand is still low.

Multi-fuel stations will increase visibility of hydrogen. Scalable station may reduce the first-player investment.

Green H2 provides a good message to customers; however hydrogen production by electrolysis suffers from high electricity costs at distribution level.

From the perspective of a (small) business developer, the comparison of compressors (capacities, features and prices) is important. The cost of the compressor determines the investment for a HRS. Compressor reliability and service level must be taken into account, too.

7 Conclusions

The International Workshops on Hydrogen Infrastructure and Transportation aim at guiding and supporting industry to accelerate and facilitate the roll-out and commercialization of hydrogen refuelling stations.

The 4th International Workshop on Hydrogen Infrastructure and Transportation took place in Egmond aan Zee (The Netherlands) on May, 24th and 25th 2016. The workshop was conducted by the European Commission's Joint Research Centre and supported by US DOE, NOW from Germany and NEDO from Japan.

The workshops in this series are recognised by the main hydrogen infrastructure stakeholders to be an interesting initiative as they bring together policy makers, research organisations, industry and technical experts. While participation to the workshop is upon invitation and distribution of the material presented is limited to the attendants, it is indeed important to make the most relevant information publicly available. Therefore, this report compiles the most relevant items discussed during the two days of the workshop.

The workshop was structured into topical sessions. The first session provided general Country/Region overviews on policy initiatives, R&D, demonstration and deployment, investments and funding regarding hydrogen and fuel cell infrastructure. The other sessions aimed at discussing technical topics considered critical for the hydrogen infrastructure: H2 Fuelling, H2 Quality, H2 Metering, and Utilization Experience of 70 MPa HRS. The objective of the workshop was not to agree on general conclusions but to share knowledge and expertise. Nevertheless some concluding remarks on items that according to the participants require special attention and follow up are summarised below.

- Certification of HRSs needs to be internationally harmonised. An appropriate certification test assuring compliance with standards without any need of OEMs to perform instrumented vehicle tests to confirm that a HRS meets their requirements is desirable.
- Sharing data from hydrogen fuelling and hydrogen quality (www.H2protocol.com) is important in support to standardisation efforts.
- It is important to clearly define quality targets for the hydrogen fuel. Guidelines, Recommended Practices for the quality control are needed to achieve the targeted quality.
- Round robins to show reproducibility and allow validation of analytical methods through regular testing and comparing/sharing between demo projects are desired.
- At present it is not technically possible to reach an appropriate accuracy for mass flow metering. Development of fit-for-purpose hydrogen metering systems should be encouraged.
- It will be helpful to develop, at international level, an affordable, easily in-field deployable hydrogen metering testing apparatus (gravimetric and/or flow meter).
- Address the effect of leak check and pulsed-discontinued flow and depressurization losses in HRSs meter performance. Identify a solution to account for the hydrogen that is left in the dispenser hose after a fuelling.

- Training and awareness increase at local government levels on hydrogen infrastructure challenges (metering, safety, expensive equipment…).
- A common definition of HRS reliability must be established to enable proper comparison between networks in the different countries.
- At present costs associated to HRS equipment are high, on the one hand because their specific technical/safety requirements and the low volume production. On the other because back-up capacity and redundancy are required to guarantee HRS availability due to lack of suppliers and/or lack of rapid response capacity from suppliers.
- International harmonisation of HRS equipment and material qualification standards is desirable.
- There is a need for reducing parasitic electricity requirements for HRS with electrolysers, especially for cooling and thermal management.
- HRS refuelling equipment (nozzle, pay-systems, communication and information displayed in the system) can be made more user-friendly.

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[3] SAE International, SAE J2719 - Hydrogen Fuel Quality for Fuel Cell Vehicles, November 2015
[4] Tsotridis G, Pilenga A, De Marco G and Malkow T., EU Harmonised Test Protocols for PEMFC MEA Testing in Single Cell Configuration for Automotive Applications, EUR 27632, Publications Office of the European Union, doi: 10.2790/342959 (print) 10.2790/54653 (online), 2015.

List of abbreviations and definitions

AFI (AFID): Alternative Fuel Infrastructure Directive; refers to Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure

BEV: Battery Electric Vehicle

CCS: Carbon Capture and Storage

CCU: Carbon Capture and Use

CEP: Clean Energy Partnership (Germany)

EC: European Commission

EFTA: European Free Trade Association

EIB: European Investment Bank

FAT: Factory Acceptance Test

FCCJ: Fuel Cell Commercialization Conference of Japan

FCEV: Fuel Cell Electric Vehicle

FCH-JU: European Fuel Cell and Hydrogen Joint Undertaking; www.**fch**.europa.eu/

HRS: Hydrogen Refuelling Station

H&FC: Hydrogen and Fuel Cells

ICV: Internal combustion vehicle

MEA: Membrane Electrode Assembly

NPF: National Policy Framework as described in Article 3 of the Directive 2014/94/EU. Each Member State shall adopt a national policy framework for the development of the market as regards alternative fuels in the transport sector and the deployment of the relevant infrastructure.

OEM: Original Equipment Manufacturer

PEM: Proton Exchange Membrane

PHEV: Plug-in Hybrid Electric Vehicle

PLC: Programmable Logic Controller

PNR: Pre-normative Research

ppm: part per million

ppb: part per billion

RCS: Regulations, Codes and Standards

RES: Renewable Energy Source

SAT: Site Acceptance Test

STF: Sustainable Transport Forum

TEN-T: Trans-European Transport Network;
http://ec.europa.eu/transport/themes/infrastructure/index_en.htm

ZEV: Zero Emissions Vehicle

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Annex 1: List of Participants

4th International Workshop on Hydrogen Infrastructure & Transportation

24 - 25 May, 2016 The Netherlands

LIST of PARTICIPANTS

Name	Surname	Affiliation	Country
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Georgios	Tsotridis	European Commission	
Michel	Honselaar	European Commission	
Francesco	Dolci	European Commission	

Annex 2: Agenda

Date	**Workshop: May 24 (Tue) - 25 (Wed), 2016** **JRC-Petten site visit: May 26 (Th), 2016**
Location	**Hotel Zuiderduin – Egmond aan Zee** *Zeeweg 52, NL-1931 VL Egmond aan Zee, The Netherlands*
Organizers	European Commission, U.S. DOE (U.S.), NOW (Germany), NEDO (Japan)

Day 1: 24th May

08:30 – 08:45 Registration

08:45 – 09:00 Welcome by the European Commission

09:00 – 12:15 General Country Overview

- Germany
- Japan & HySUT
- USA
- Scandinavia
- EU

12:15 – 13:00 Lunch Break

13:00 – 15:15 General Country Overview (cont.)

- The Netherlands
- UK
- France
- China
- Korea

15:15 – 15:30 Coffee Break

15:30 – 18:00 Session 1: H_2 Fueling

- Germany
- Japan
- USA
- ISO WG24
- Scandinavia
- EU

Day 2: 25th May

9:00 – 11:00 Session 2: H_2 Quality

- Germany
- Japan
- USA
- Scandinavia
- EU
- EU HyCora Project

11:00 – 12:15 Session 3: H_2 Metering

- Germany
- Japan
- USA
- Scandinavia

12:15 – 13:00 Lunch Break

13:00 – 15:15 Session 4: Utilization Experience of 70 MPa HRS

- Germany
- Japan
- USA
- Scandinavia
- EU FCH-JU
- Belgium

15:15 – 15:30 Coffee Break

15: 30– 16:30 Session Summary

Day 3: 26th May Visit to JRC-Petten Facilities

09:30 Bus transport to JRC-Petten from Hotel Zuiderduin

10:00 – 12:00 Visit to JRC-Petten H_2 Test Facilities

12:00 Bus transport to Alkmaar Train Station and Hotel Zuiderduin

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