Workshop

"Putting Science into Standards: Power-to-Hydrogen and HCNG"
EARTO, the European Standards Organisations and the European Commission's Joint Research Centre

JRC Petten, The Netherlands, 21-22 October 2014

FINAL REPORT

SUMMARY AND MAIN OUTCOMES
The Joint Research Centre (JRC) of the European Commission, together with the European Association of Research and Technology Organisations (EARTO), the European Standards Organisations (ESO) CEN and CENELEC, and the European Commission Directorate-General Enterprise and Industry (ENTR) have launched an initiative, within the context of the European Forum on Science and Industry, to bring the scientific and standardization communities closer together.

The second, and very successful workshop in a series entitled “Putting Science into Standards” was held at the Institute for Energy and Transport of the JRC in Petten on 21.-22.10.2014.

The workshop focused on Power to Hydrogen (P2H) and Hydrogen Compressed Natural Gas (HCNG) which represent a promising and major contribution to the challenging management of increased integration of intermittent renewable energy sources in the overall energy system.

This workshop focused on four topics:
- Power-to-hydrogen by electrolysis;
- Admixture of hydrogen to the natural gas grid;
- Impact of HCNG blends on materials and on the performance in end-use applications;
- The provision of ancillary services in support of the electricity grid.

65 experts from research, industry, standardization and policy participated to the workshop.

The workshop offered a platform to exchange ideas on technologies, policy and standardization issues. The participation of major stakeholders from both industry and research to this event proved fruitful in moving towards consensus on the relevant technical issues involved, and at identifying a common way forward to increase the maturity and market visibility of P2H components and systems. Other outcomes include a clarification of expectations of industry of where and how policy and standardization can contribute to a competitive development of P2H and related issues. The workshop outcomes will be used to devise a roadmap on "Opportunities for Power to Hydrogen and HCNG" by CEN/CENELEC, outlining the next steps of standardization activities.

The presentations of the workshop can be downloaded from:

This report provides a summary of the workshop and highlights the main results.
Electrolysis is a well-known process and has been applied in industry for more than a century for several purposes (e.g. production of chlorine). Alkaline electrolysis is most mature and has reached satisfactory lifetime during steady-state operation. In order to satisfy the requirements of intermittent operation, an optimisation of alkaline electrolyser is needed. PEM electrolyser are intrinsically well suited to dynamic operation regimes, but are at the moment a developing technology and less mature in terms of durability. The currently still high costs of PEM electrolyser are in part related to the materials used (e.g. titanium current collectors and noble metal catalyst) and research efforts are ongoing to decrease total costs. Solid oxide electrolyser are in a R&D stage, but offer promising efficiencies.

Future energy systems with growing RES penetration will need to become more flexible, require more energy storage capacities, and will need more interaction between natural gas and electricity grids. Electrolyser technology seems well suited for facilitating intermittent energy storage and flexible operations, but as such requires further tailoring towards specific needs regarding operational management (e.g. link with electricity generation forecasts with start-up/shut-down constraints of the electrolyser, number of electrolyser modules to operate), operational flexibility (e.g. material robustness, thermal/fluidic management, modular designs, low standby consumption, quick start up and cold starts) and dimensioning/optimisation (e.g. efficiency, thermal optimisation). So in order to better position hydrogen as a means of storing intermittent renewable energy, new specifications, boundary conditions, scenarios and business cases need to be defined to facilitate technology adaption and improvement.

First demonstration projects with PEM electrolyser are ongoing and provide operational feedback to technology providers and system operators, but long-term performance characteristics still need to be understood, knowledge gaps need to be identified and addressed and potential business cases need to be assessed. Currently, the number of positive business cases is limited and a stable and supportive regulatory framework is required to enable industry to invest in significant production capabilities in order to bring the costs of electrolyser down to competitive levels. Such a framework should allow the development and integration of (new players in) the new value-chain. For example, this new value-chain could include system operators or developers/suppliers of balance-of-plant components of the energy storage system (storage tanks, transformers, gas pipeline connectors, gas mixers, storage field control and injectors).

**Research topics:**
- Define and propose R&D approaches and roadmap on cell, stack, electrolyser system and energy system level
- Hydrogen safety and sensing
- State of health indicators and monitoring
- Operational strategies for cells, stacks and systems
- BOP components performance validation under new operating strategies
- Smart energy management
- Co-electrolysis (CO2 → CO)

**Standardization topics:**
- Terminology and definitions
- Measurement and verification (at start of operation and over time)
- Performance measurement and control
- Requirements for testing and performance validation of components and systems
- Safety of the system and its components
- Power grid interface (hardware and software)
- Interoperability (including storage)
- Definition of "green hydrogen"

**Other topics:**
- Need for large scale demonstration driven by industry to specify and assess performance (e.g. KPIs: efficiency, durability, dynamics) feasibility
- Exchange of knowledge among demonstration projects to identify the gaps
- Need to involve all relevant stakeholders
SESSION 2: INJECTION/ADMIXTURE OF H2 TO THE NG GRID: COMPATIBILITY, INTEROPERABILITY AND SAFETY

Electrolysers produce hydrogen from electricity from renewable energy sources (RES), which can then be either used directly as a chemical feedstock, as a fuel for transport, be fed into the natural gas grid, or be converted back to electricity during periods of large demands. A high share of RES may also necessitate large scale storage of energy, where hydrogen can play a key role, either by utilizing the existing natural gas grid or by storing hydrogen in salt caverns or other suitable geological formations. When injected into the natural gas grid, the storage capacity of hydrogen is very large (although the composition of the resulting gas mixture has not yet been estimated). Hydrogen can also offer storage capacity over long periods of time, beyond what be offered by other storage options. The admixture of hydrogen into the natural gas grid can be part of an integrated energy system, with roles for both natural gas, hydrogen and hydrogen natural gas mixtures (HCNG), facilitating the integration of fluctuating renewable energy sources.

In order to determine a safe hydrogen concentration limit for admixture in the natural gas grid, several research and standardization issues have been identified. A strong knowledge base of the hydrogen tolerance of the gas grid has already been established within several European or national projects and studies. In NaturalHy it was found that no materials related showstoppers have been identified in the pipeline system, and case by case consideration of the limits of hydrogen addition to the gas grid was recommended. Further investigations have been made in other projects and studies. The current consensus seems to be that most parts of the natural gas system can tolerate mixtures of up to 10% by volume hydrogen. However, several areas need further investigation in order to understand the hydrogen tolerance e.g., cavern storage, surface facilities, storage tanks, gas flow monitors and gas analysis instruments. Depending on national or local conditions, the allowable limit may vary. A common, European wide understanding about how much hydrogen can be added to the overall gas network system is therefore necessary. There is also a need to provide guidance to TSO’s and DSO’s for injection of hydrogen in the natural gas networks in order to ensure operational safety.

Public support (regulations, market, funding) may be required to identify all necessary changes to the gas grid. As safety is a key principle of the gas industry, focus should be placed on the establishment of sound engineering practices.

Barriers identified include a fragmented and compartmentalized industry and insufficient collaboration between network operators. As the level of integration needed and number of technologies involved are high, long timescales before commercialization are expected. Therefore a directed rather than market-led approach to setting the innovation agenda has been proposed by members of industry. The access to existing networks for demonstration projects should be incentivised. In general an energy network based focus (rather than separating electricity and gas) should be taken as further integration is expected in the future.

**Research topics:**
- Effect of transient and non-homogeneous gas compositions
- Assess corrosion of the grid as a function of hydrogen concentration (impact on grid safety)
- Hydrogen embrittlement
- Pre-mixing for transmission grids
- Sensors for monitoring concentration
- Adaptation of gas analysis methods
- Effect on compressor stations
- Porous rock underground storage
- Economic evaluation of the P2G routes

**Pre-normative research topics:**
- Safety issues regarding change to the lower flammability limit and necessity of odorization
- Flow behaviour of HCNG
- Ensure safety of P2H taking into account the irregular usage frequencies of electrolyser, storage facilities and infrastructure, related to the intermittency of RES.

**Standardization topics:**
Several Technical Committees (TCs) were identified where further input for establishing limits for H2 concentration is still needed. The maximum hydrogen content has been discussed in several of the TCs, but setting a clear limit is currently viewed as premature. A harmonisation of existing and future standards with

**SESSION 3: USE OF HCNG FOR RE-POWERING, MOBILITY, HEAT**

The injection of hydrogen in the natural gas grid will affect all the gas users. This implies that all appliances that currently use natural gas (about 200 million in Europe) will be affected by the addition of hydrogen in the grid, since the gas mixture properties will change. Due to regulations for emissions and efficiency, most appliances function within a limited fuel composition range. Therefore, a compromise has to be reached to limit impact. Compensation systems for gas quality fluctuations have to be included in all appliances and end user installations need to be certified for HCNG. For the near future, scenarios however indicate that the share of hydrogen may be small, not exceeding 2% in Germany in 2025. Locally the hydrogen concentration could be up to 5 times higher, depending on local production volumes. This variability of hydrogen concentration is another issue to be addressed, possibly via standardization.

Hydrogen can be a very effective storage medium, which is extremely important for the evolution of the energy system towards decarbonisation, with high shares of intermittent energy sources. Synthetic natural gas using renewable H2 and CO2 from bio-methanation plants is another interesting proposition, especially for the transport sector. Thus hydrogen can alternatively be used both after its transformation into SNG in combustion engines or directly in FCEV. However both options require production infrastructure of higher efficiency and lower cost than at present.

Determining requirements for admixing hydrogen into the natural gas grid and for the end-users depending on it go hand in hand and as such should be approached from a system perspective. It was discussed that a minimum threshold for no or limited action would be around 2%. Mixing up to 5% could also be possible but this is to be further investigated and could be a driver for innovation for appliances. According to current understanding, a hydrogen concentration limit up to 20% poses some challenges with regards to end-use appliances and gas analysis methods. Further research is needed to address end-user concerns regarding process control, emissions and safety. Public acceptance relies on the proper identification and assessment of risks.

**Research topics:**
- Transport (CNG cars): address the tank issue, i.e. extend the limit for hydrogen in natural gas beyond 2% (current international norm) to up to 10%, focusing on materials issues; improved and new materials for the future
- Transport - adapt combustion systems (combustion control) for gas engines to higher hydrogen content, to ensure same lifetime, although according to industry, this is not a major issue
- Transport - Develop cost efficient measurement systems for CNG filling stations
- Power generation and CHP: Adapt combustion systems of gas turbines (to address the increased combustion velocity), gas engines (with adaptive controls for fluctuating hydrogen concentration) and fuel cells for CHP (with adaptive controls for reforming), while ensuring that performance does not deteriorate
- Industry - heating systems: Understand / predict off-gas composition and combustion attributes, e.g. flame characteristics, NOx formation; and develop adaptive combustion controls
- Industry - thermochemistry processing appliances: assess the impact on chemical process stability and produced metal quality; develop gas composition measurement systems and adaptive controls in these processes
- Residential heating - Adaptive combustion controls including identification of combustion quality (combustion systems) and feed gas quality (fuel processors)

**Pre-normative research topics:**
- A main bottleneck to HCNG has been identified, the ability of CNG vehicle tanks to accept higher hydrogen concentrations. Research should determine whether the current 2% limit can be increased.
- Assess explosion venting protective systems
- Determine basic HCNG safety data
Standardization topics:
Standardization needs to ensure the safety of HCNG use by considering the specific properties of hydrogen and NG blends and address all associated risks.
- All end user installations need to be certified for HCNG regarding their compatibility with flame stability and hydrogen embrittlement
- Assumed leak size needs to be addressed which in turn affects the size of explosive atmosphere (ATEX) zone and ventilation needs
- The ATEX zoning needs to be reassessed
- Detection devices and mitigating safety measures need to be certified
- Need for a wide composition range for natural gas (to support security of supply by allowing various gas sources into the network), but equipment manufacturers need a narrow composition range to develop appliances
- Test procedures are needed for adaptive measurement controls to cope with fluctuating gas composition and hence varying gas quality

Session 4: Standardization aspects for provision of ancillary services

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

In the UK but also elsewhere in Europe, wind curtailment is a growing problem for operators of high voltage electricity grids. The financial penalties for wind curtailment are increasing. In the UK alone, around 19 M£ was spent between 2010 and 2012 for wind curtailment. Absorbing otherwise curtailed wind energy via electrolysers could provide a means to prevent curtailment. In the UK alone, a total of 725 M£ was paid for balancing services in 2010-2011 and this amount is expected to rise to 1,900-5,900 M£ per annum in 2020.

Grid stabilisation services for frequency control are typically distinguished on response time: frequency containment (or primary reserve), frequency restoration (or secondary reserve) and frequency replacement reserves (or tertiary reserves). Service payments are typically made on the basis of availability (MW/h) and utilisation rate (MWh). For the ancillary service market, PEM and alkaline electrolysers have good ramp rates and respond well to a change in power settings and could therefore, in principle, provide all reserve functions, both negative (absorbing power from the grid) and positive (lowering power demand by decreasing production while being operational). As PEM electrolysers respond faster to changes in power settings than alkaline electrolysers, PEM electrolysers are in principle better suited for the primary reserve market. Alkaline as well as PEM electrolysers could provide services to the secondary reserve market. Using electrolysers for grid balancing is in a sense demand response management. The Energy Efficiency Directive requires that Member States promote the use of demand response for balancing services. So far only 5 Member States have created regulatory and contractual structures that support aggregated demand response. Another area where electrolysers could play a role is for voltage regulation as an ancillary service as the electrolyser contains AC/DC converters and as such can absorb reactive power.

Pre-normative research topics:
- Pre-normative research into and development of measurement methods and test procedures for electrolyser performance dedicated to the needs of ancillary service requirements
Standardization topics:
- Performance requirements and standards for electrolysers (e.g. initial response time, total response time, ramp rate), including the measurement methods and test procedures for electrolyser performance (such as efficiency in dynamic, intermittent operation), that would allow grid operators or third parties to assess capabilities as ancillary service provider, covering, among others, frequency and voltage control requirements of grid operators
- Interconnection standards to allow physical connection of and communication between the electrolyser and the grid control systems

Other topics:
- Identification of main needs for grid operators regarding assessment criteria for ancillary services providers
- Investigation among grid operators to understand nearby and future trends in the field of ancillary services, e.g. in bid blocks, quality remuneration, service stacking

**OUTCOME - PROPOSAL TO DEVELOP A CEN/CENELEC WORKING GROUP ON HYDROGEN ENERGY**

As an outcome of the workshop, it was proposed to gather all relevant actors and stakeholders in a CEN/CENELEC working group on hydrogen energy to be established. The mandate of the WG is to develop a roadmap identifying opportunities for power-to-hydrogen and HCNG and topics for standardization based on the outcome of the workshop. Items to cover include, but are not limited to: mapping of initiatives and needs and gaps, prioritisation of topics, identification of existing technical committees where priorities could be addressed, identification of ISO activities relevant to the EU context, identification of areas of cooperation between regulations and standardization, identification of research, development and innovation needs, recommendations for new work item proposals. This activity will address the "multi-dimensional" puzzle that is the future energy landscape: as multiple technology options and many stakeholders, as well as different sectors are involved, a platform to enable communication could be of great value. In order to ensure success of the working group, it is necessary to involve all stakeholders (research, industry) from all sectors (suppliers and end-users) and to put a particular focus on green hydrogen produced from renewable energies.

A call for experts to join this activity is expected in 2015. An overview of the timeline and possible activities of the working group are depicted below.