Getting metrology fit for the hydrogen economy

Menne Schakel, Marcel Workamp, Jacoline Boonman, and Erik Smits, VSL National Metrology Institute, Netherlands, argue that lack of fit-for-purpose hydrogen measurement standards could potentially turn metrology into the bottleneck of the hydrogen economy.

In today's world, annual natural gas consumption stands at about 4000 billion m^3, valued at US$300 billion in 2021. It is gradually being replaced by renewable energy gases, such as green hydrogen produced from decarbonised, renewable energy. Reliable trading of large amounts of hydrogen requires accurate calibration of measurement equipment. This is made possible by accurate measurement standards developed and maintained by national metrology institutes such as VSL. While they are in place for the energy system based on natural gas, a huge effort is needed to ensure appropriate reference measurement standards for the hydrogen economy. As the shift towards a decarbonised economy takes place today, actions for getting metrology fit for the future have to be taken now.

Hydrogen economy

Against the background of decarbonisation of the energy system, dedicated hydrogen gas networks are currently under development in various countries and regions. The European Hydrogen Backbone unites energy infrastructure operators in a mission towards an integrated pan-European hydrogen gas infrastructure. A hydrogen gas network offers noteworthy benefits:

- It offers the highly needed storage capacity for renewable energy produced when wind and solar energy are abundant and cannot be handled by the electricity grid.

- An integrated gas grid enables the transfer of energy efficiently, to places where it is needed and when it is needed.

- Long-haul energy transport can connect regions of production to regions of end-use in similar fashion as liquefied natural gas is currently integrating natural gas infrastructure across the globe.

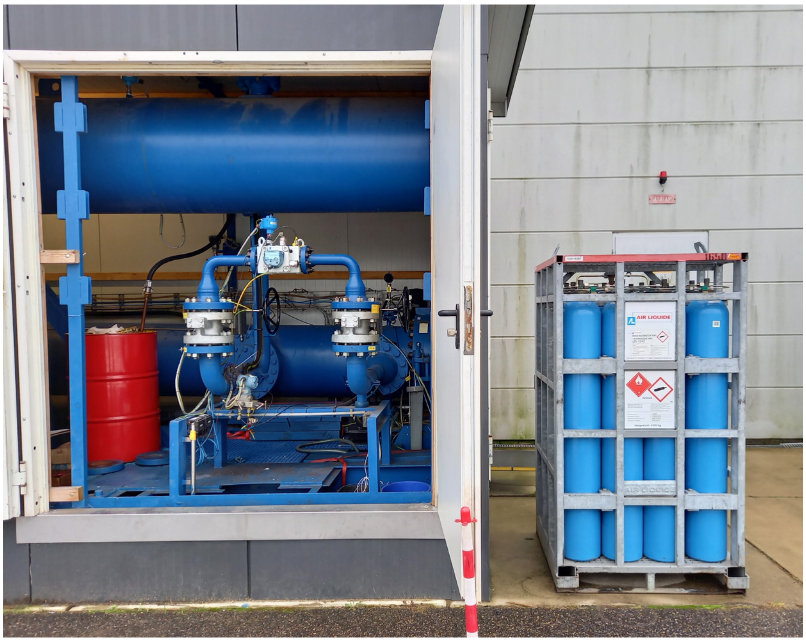

Figure 1. **VSL's primary standard for the calibration of natural gas flowmeters on the left (see also Table 1), hydrogen cylinder bundle on the right. The primary standard was modified to the use of HENG in addition to natural gas.**

Table 1. **Typical natural gas flow calibration and measurement capabilities showing the lowest calibration uncertainties for gas flowmeter calibration. The coverage factor $k = 2$ indicates a coverage probability of approximately 95% (as applicable to a normal distribution)**

Traceability level	Flowrate m³/h	Pressure range bar(a)	Calibration uncertainty ($k = 2$) %
Primary Standard (VSL)	5 – 200	4 – 64	0.06
Secondary Standard (VSL)	200 - 2000	4 – 64	0.10 – 0.12
Working standards (gas flowmeter calibration facility)	Up to 65 000	4 – 64	0.15 and above

The hydrogen backbones that are currently under development make use of existing gas grid pipelines, illustrating their projected crucial role in the future energy supply system. In the short-term, mixing of hydrogen with natural gas (hydrogen enriched natural gas: HENG) is already taking place as economies are transitioning towards a fully decarbonised energy system.

Accuracy and fiscal risk

In today's natural gas based energy system, several calibration facilities enable to calibrate large flowmeters used in the transmission of natural gas through the gas network. These facilities are in place to avoid systematic errors of the flowmeters so that financial risk during natural gas trading by pipeline operators is minimised. A systematic error in the flowmeter of 1 % leads to the same impact in the amount of money invoiced. To minimise the impact and to support fair and reliable trade the accuracy of gas flowmeters, measuring the amount of traded gas should be proven by calibration with the actual gas.

Typical achievable calibration uncertainties for the calibration of natural gas flowmeters are listed in Table 1. The primary standard gas flowrates are limited by the nature of the installation. Consequently, calibration uncertainties are higher for larger flowrates as they build up from the primary level. VSL is in possession of a high pressure natural gas flow primary standard which it developed and maintained, using decades of experience, to achieve the lowest uncertainties as indicated in the Table 1. Natural gas transmission system operators require uncertainties at levels indicated in Table 1. A crucial component in achieving the lowest uncertainties is to perform intercomparisons with primary standards of independent, partnering national institutes in Europe. Preferably the partners in intercomparisons have comparable and low uncertainties. The intercomparisons guarantee that the systematic measurement errors lay within the claimed measurement uncertainties of the different institutes.

It is currently not possible to calibrate gas flowmeters measuring hydrogen with ranges and calibration uncertainties as listed in Table 1, since the primary level is lacking. Time is needed to develop metrological standards for the hydrogen economy with similar ranges and calibration uncertainties as is currently in place for the natural gas based energy system. Development efforts have to be undertaken such as developing dedicated hydrogen gas flow standards, performing intercomparisons, and proving validity of calibration results as established over time. Without the hydrogen standards, larger errors of hydrogen gas flowmeters may occur when they measure the amount of transferred hydrogen. For illustrational purposes, a systematic error of 0.5% is taken on the total amount of annually traded natural gas, currently at 900 billion m^3 according to the Energy Institute's latest statistical review of world energy. The corresponding monetary equivalent, taking the natural gas price at €11/mmBtu (about 1 kJ) and setting its heating value at 47 000 Btu/kg, is estimated at €2 billion each year. In a hydrogen economy without suitable metrological standards, such costs may be paid on an annual basis and will eventually be charged to the end-users (consumers) of the hydrogen energy, obviously posing a severe financial risk. A further risk exists that lack of public trust in measured values poses a hurdle to the adoption of clean hydrogen as an alternative to natural gas.

Pan-European hydrogen metrology research

Significant progress in the metrology of hydrogen is made in the European metrology community, in close interaction with industry. A number of European research projects under EURAMET (the European Association of National Metrology Institutes) funding programs, have tackled challenges in hydrogen flow metrology. Significant progress was made:

- Understanding the effects of hydrogen and HENG on the performance (and longevity) of gas flowmeters in varying applications.

- VSL's primary standard for high pressure natural gas flow (the first realisation of the unit "m^3/h") was used successfully, for the first time, with HENG. It resulted in the first calibrations of gas meters with HENG establishing a direct traceability to the SI-unit 'meter' at pressures relevant to the gas grid. This standard will be compared to similar standard(s) across Europe, which is key to ensuring the quality of the provided reference values.

Further development towards a hydrogen primary standard for the calibration of gas grid flowmeters is needed. It is only partly undertaken as part of ongoing metrology research projects. The primary standard is needed to provide a direct link to the SI units of measurement under the conditions in which the gas flowmeter is operating in. Flow calibration facilities for pure hydrogen exist (for domestic gas meter to transmission pipeline gas meter calibration). Their links to the primary level SI units of measurements usually includes assumptions or models to predict a (reference) meter's performance on pure hydrogen while being calibrated with so-called surrogate or alternative gases. With a dedicated hydrogen primary standard, less models and/or assumptions are needed. A gas flowmeter calibration from a dedicated hydrogen primary standard will improve trust in measurements, and bring it to the level of trust as it currently exists for natural gas.

Metrology readiness for the hydrogen economy

VSL – the National Metrology Institute of the Netherlands – is working relentlessly with its partners and the government of the Netherlands, to meet the pressing metrology challenges of the hydrogen economy. The hydrogen economy is already being rolled-out, necessitating action today. Ensuring fit-for-purpose hydrogen measurement standards is a complex task, needing large investments. Measurement standards are serving all stakeholders in industry and the wider society. Without them, calibration facilities can't be made traceable to the SI units of measurement. Pipeline operators need them to minimise their financial risk and make correct invoices. Governments need them for tax purposes. Consumers need them for fair billing. Operators and citizens need them for safe handling of equipment.

Lack of fit-for-purpose hydrogen measurement standards can potentially turn metrology into the bottleneck of the hydrogen economy. Trust in measurement values leads to reliable billing and safe use of hydrogen. Lack of trust can lead to slower adoption of renewable hydrogen than needed for meeting energy transition targets. It can further lead to a larger measurement uncertainty, and concomitant financial risk, than what is technically conceivable. The current situation for LNG can serve as an example. It's significance is evidenced from its share in all globally traded natural gas which currently stands at about 59% according to the Energy Institute's latest statistical review of world energy. VSL's LNG calibration facility led to improved calibration of LNG flowmeters and composition measurement systems from the direct and complete link to the SI units of measurement. This link is established with the LNG primary standards embedded in the calibration facility. Yet, LNG measurements are not as accurate as they could be as the industry is reluctant to make the investments needed to upscale their measurement capabilities. In large LNG transfer systems determination of LNG quantity is typically done through volume measurement of tanks versus usage of calibrated LNG flowmeters. As a result, relatively large measurement uncertainties and concomitant exposure to financial risks are occurring in the day-to-day practice of LNG trading. The resulting costs are eventually paid by the end user, who takes the brunt of bad measurement in the chain.

VSL invites all parties to team up and ensure that large scale hydrogen transport measurement will be made possible within the required accuracies and proven by traceable calibrations as exists for natural gas, today. As stated above, the development of new, fit-for-purpose standards needs time. We need to act today to get metrology fit for the hydrogen economy already being implemented. Without action today, (financial) risk will be carried by the hydrogen pipeline operators tomorrow.