MefHySto
Metrology for Advanced Hydrogen Storage Solutions

Deliverable D2

Trials of rapid response analysis of key impurities in hydrogen from electrolysis

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EMPIR EURAMET

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Executive Summary

This report describes the use of the online gas analysers, whose validation is described in the Metrology for Advanced Hydrogen Storage Solutions (MefHySto 19ENG03) D1 "*Report on the development of new metrology for the measurement of key impurities in hydrogen (water vapour and oxygen) produced from PEM water electrolysers, with fast response times of a few or tens of seconds*", to make quality measurements of the hydrogen produced by a number of laboratory-based and industrial electrolysers available to the project partners.

Demonstrations of measurements of key impurities (including water vapour and oxygen) in hydrogen generated from electrolysis (i.e. power-to-gas), were made in-situ. Where possible, the trial conditions simulated rapid changes representative of fluctuations in electrical grid supply (i.e. rapidly imposed transient use periods (0–100 %, 200 % peak).

This report presents the hydrogen quality measurement results and discusses the findings.

1.1 Test protocol for laboratory and field trials. (NPL, CEA)

Test protocols for laboratory and field trials of the online gas analyser instruments previously characterised in the project as reported in D1 were developed.

The aim was for tests to be carried out under ideal laboratory conditions and under simulated field conditions on the commercial electrolysers at NPL and CEA. Where possible the test protocols included trial conditions to simulate rapid changes representative of fluctuations in electrical grid supply (i.e. rapidly imposed transient use periods (0–100 %, 200 % peak).

The test protocol for NPL is described in section 1.2.2 and for CEA in section 1.3.2.

1.2 Laboratory trials of hydrogen quality measurements using online gas analysers with previous NMI characterisation (NPL, CEA)

1.2.1 NPL electrolyser measurement set-up

To simulate use in a hydrogen energy storage system the measurement equipment under test was connected on a branch between a hydrogen generator (PEMWE type, Hogen S Series 2 S40, Proton OnSite) and a buffer tank (20 L water volume cylinder with liquid and gas connections, Luxfer Cylinders) feeding a fuel cell test stand (Greenlight Innovation, Canada) operating a short-stack fuel cell (anonymized) as shown in Figure 1. All connections in the system are made from untreated ¼ inch 316L stainless steel tubing and Swagelok™ compression fittings. All instruments were connected in parallel and tested simultaneously. Two instruments were tested at supply line pressure and five at atmospheric pressure. The flow through each sensor was set to 0.5 NLPM using rotameters (Omega) and needle valves (Swagelok™).

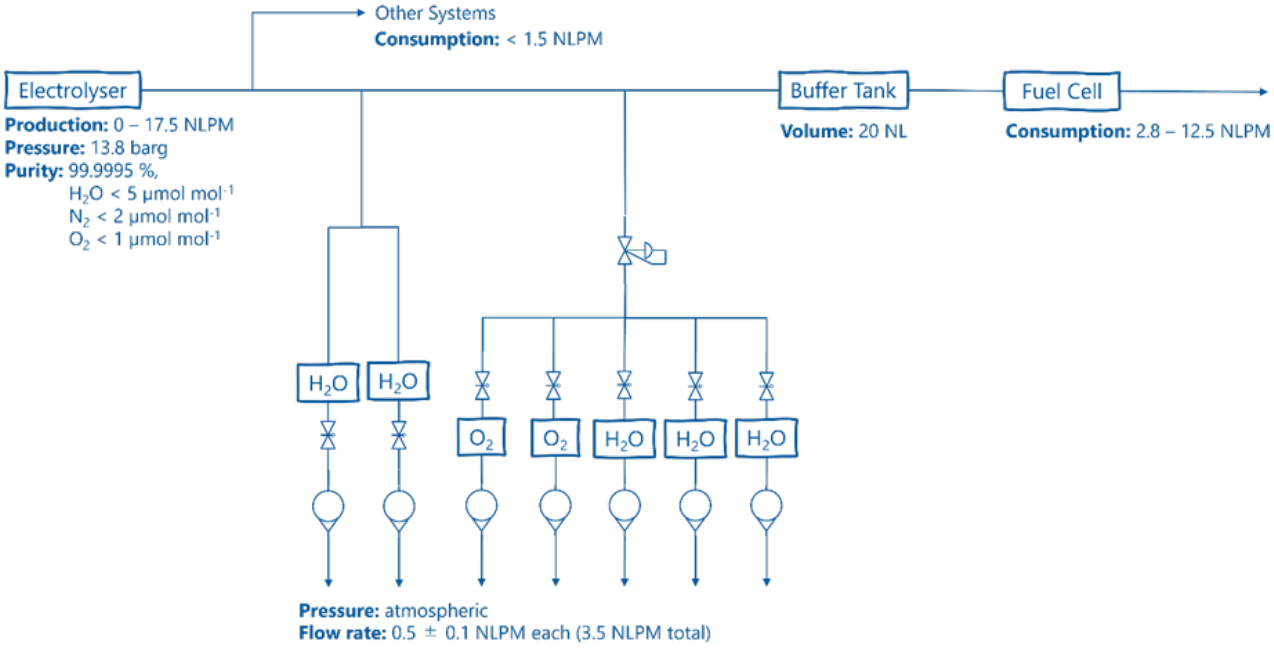

Figure 1 : Schematic showing the layout of the system used to test the sensors at NPL in simulated conditions between a hydrogen supply and storage tank feeding a fuel cell test station.

1.2.2 NPL laboratory electrolyser hydrogen quality measurement test protocol

Data was logged from each sensor simultaneously while the operating behaviour of the system was modified. As the hydrogen generator produced hydrogen on demand to maintain a constant outlet pressure, the behaviour of the system was modified by changing the hydrogen demand of the fuel cell and buffer tank. This was accomplished by changing the applied current density and by isolating the inlet of the buffer tank. During the testing the operating state of the hydrogen generator was monitored and logged to enable correlation between the rate of hydrogen generation and the water and oxygen levels recorded by the sensors.

It's not possible to directly control the load on the electrolyser in the hydrogen generator, ruling out use of standardised electrolyser test protocols such as those developed in the EU's QualyGridS project (and currently being adapted to a standard by ISO/TC197/WG32) instead the fuel cell load must be controlled. Widely adopted fuel cell drive cycles aim to evaluate the durability of fuel cells for automotive or combined heat and power applications [**1**], [**2**], rather than generate transients on a reasonable time scale, so three new transient drive cycles were defined as shown in Table 3 in Appendix – A – Drive Cycles. Theoretical hydrogen consumption for each applied drive cycle is shown in Figure 2, note that as the fuel cell is operated in dead-end mode in addition to the stoichiometric consumption of hydrogen presented in these plots there is an intermittent purge for 0.2 s every 30 s which increases the consumption rate, but which is ignored here as it's challenging to calculate purge rate accurately [**3**] and the impact on the total hydrogen utilization was previously found to be < 1 % of the maximum flow rate used here. The dwell-time at each step is 10 min to enable the slower responding sensors to reach equilibrium. Also note that there is a significant, but constant, consumption of hydrogen by the sensors and other processes in the laboratory.

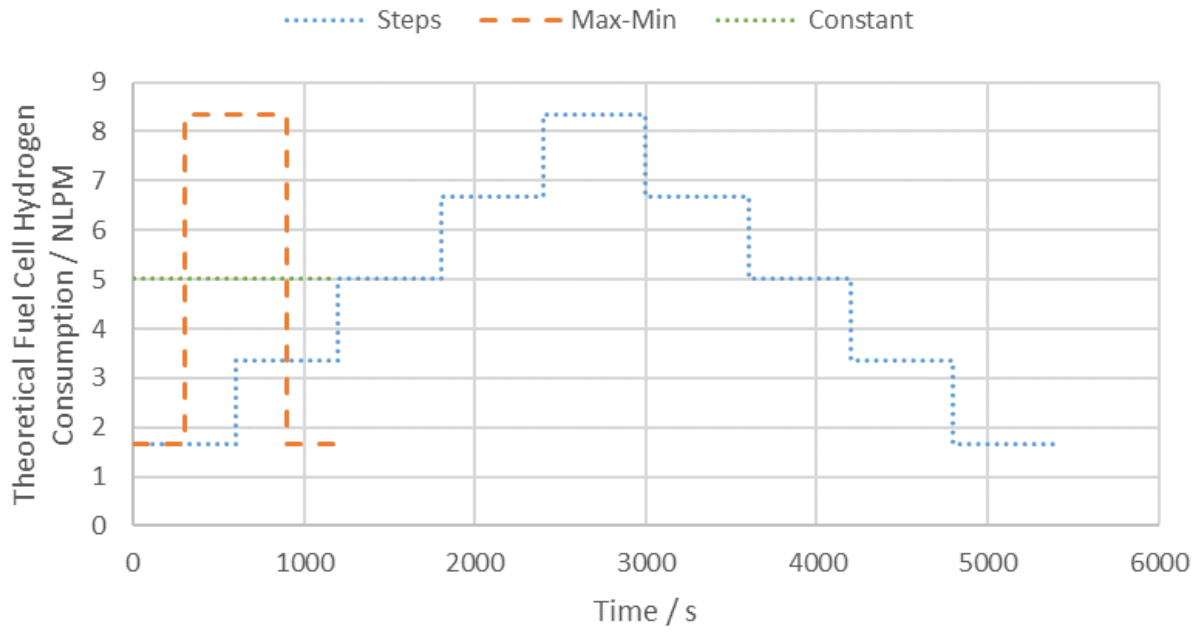

Figure 2 : Theoretical hydrogen consumption from the fuel cell based on the three applied drive cycles assuming a 10 cell stack, maximum current of 120 A with a stoichiometry of 1, operating between 20 and 100% of maximum load. Note that hydrogen consumption for purges is ignored.

The following protocol was applied:

- Operated at constant 60 % load (~ 5.0 NLPM hydrogen use) for > 72 h to dry down the system.
- Ran each of the drive cycles constantly for 12 h in sequence (this corresponds to 8 cycles of the Steps cycle followed by 32 of each of the Max-Min and Constant cycles).
- While operating at constant 60 % load, closed the inlet of the buffer tank for 30 min, then opened the inlet of the buffer tank for 30 min, repeated 3 times.

1.2.3 CEA laboratory electrolyser in H2 Platform hydrogen quality measurement set-up / method

The SENEPY H2 Platform at CEA is equipped with a commercial PEMWE Electrolyser HOGEN from PROTON (see Figure 3). The main technical specifications are:

- Maximum H_2 production : 530 Nl/h (500 Nl/h as maximum set point in SENEPY)
- 10 cell-stack (around 130-140 cm² as active area)
- No internal H_2 purifier
- Drying by two zeolite units (regenerated with dry H_2 bypass by alternative operation)
- Asymmetrical stack operation: atmospheric pressure at the anode (O_2) / 01.5 MPa (15 bar) abs at the cathode (H_2, 200 psig)
- Gas analysis for %H_2 in O_2 by catharometer equipment but not really precise (drifts in time due to “wet gas”)

Figure 3 : HOGEN S20 Electrolyser installed on SENEPY Platform

Regarding gas quality for the HOGEN S20, PROTON specifies a purity of H_2 at 99.9995% with H_2O < 5 ppm, N_2 < 2 ppm and O_2 < 1 ppm without any other compounds detectable.

The humidity measurement was carried out with a DMT152 sensor from Vaisala with customized range from -100 to 0°C for dew-point (frost-point) temperature with a manufacturer’s specified accuracy of ± 2°C in our humidity range. The humidity sensor was placed at electrolyser H_2 outlet after a pressure regulator at low pressure (between 0.1 and 0.13 MPa (1.0 and 1.3) bar abs) in a dedicated measurement chamber close to pressure and temperature sensors as well as flowmeter. The sensor was still under the validity of manufacturer’s factory calibration but the humidity sensor was also calibrated in hydrogen by NPL with their humidity standards after the measurement campaign, which

confirmed that it met the manufacturer's specifications for accuracy of ±2 °C. The values in ppmv (per volume) are calculated via the Sonntag formula [**4**].

In this test campaign, the first step consisted in flushing and drying the H_2 pipes on the platform for several hours until the humidity level remains stable (frost point below -85°C) at 70% of H_2 maximum production before any specific humidity measurements.

First, increasing and decreasing current steps (between minimum and maximum stack operation, 10 min per step) were applied progressively. The impact of fast transitions between minimum and maximum electrolysis current (47 A / 140 A, 10 min per step) was also studied. Finally, a steady-state phase at 70% of maximum production (100 A) was applied before shutting-down the equipment.

The corresponding results are presented in section 1.3.2.

1.3 Results of trials of hydrogen quality measurements using online gas analysers (NPL, CEA)

1.3.1 NPL laboratory-based electrolyser hydrogen quality measurement results

The current load of the NPL laboratory-based fuel cell was varied in steps of % of maximum load (120 A) as described in Table 3 in Appendix A and shown below in Figure 4.

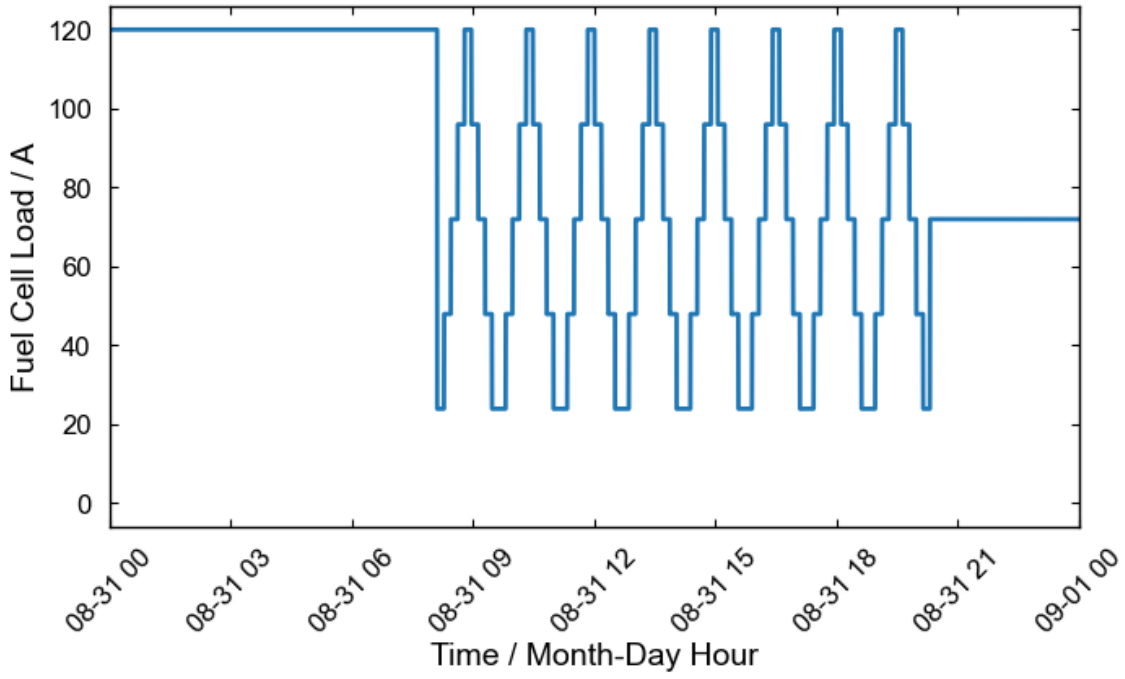

Figure 4 : Load value of electrolyser and flow rate against time for NPL laboratory based electrolyser testing

Figure 5 and Figure 6 show changes in the oxygen concentration measured in the hydrogen produced by the electrolyser when the current load is varied during the test profile for Instrument A and Instrument B respectively. An increase in the current load resulted in a higher oxygen concentration being measured.

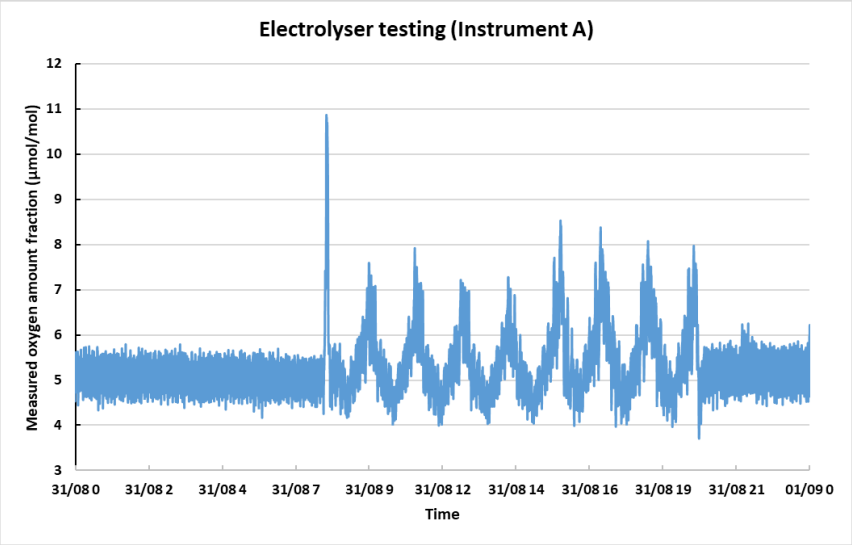

Figure 5 : Quality measurements of NPL electrolyser hydrogen during test profile – oxygen concentration analyser results

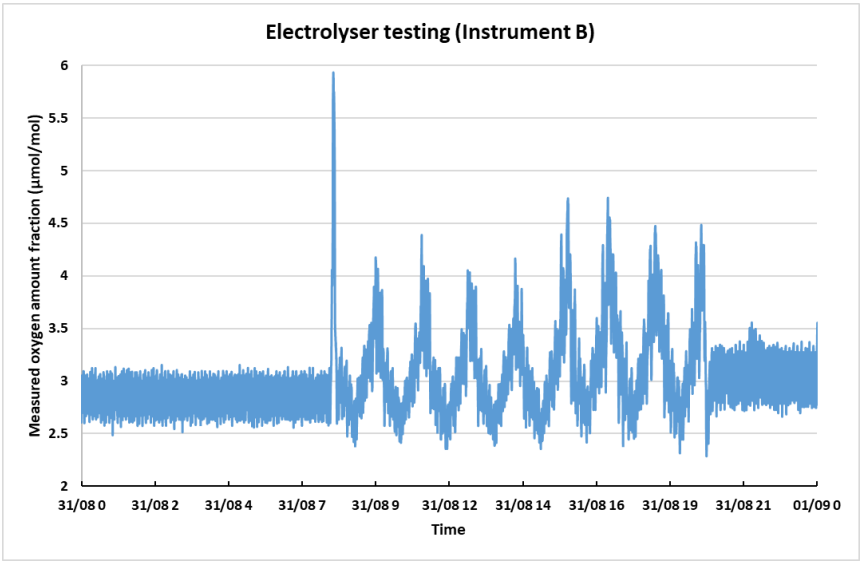

Figure 6 : Quality measurements of NPL electrolyser hydrogen during test profile – oxygen concentration analyser results

Dew-point temperature measurements made of the Hogen electrolyser hydrogen at 1.35 MPa gauge pressure are shown in Figure 7. The measurements are corrected for errors found during NPL calibrations. The measurements of instruments G and H display variations in the water dew-point temperature measured when the current load of the electrolyser is varied during the test profile. An increase in the current load resulted in a lower dew-point temperature being measured as can be seen from the results of Instrument G plotted in Figure 9.

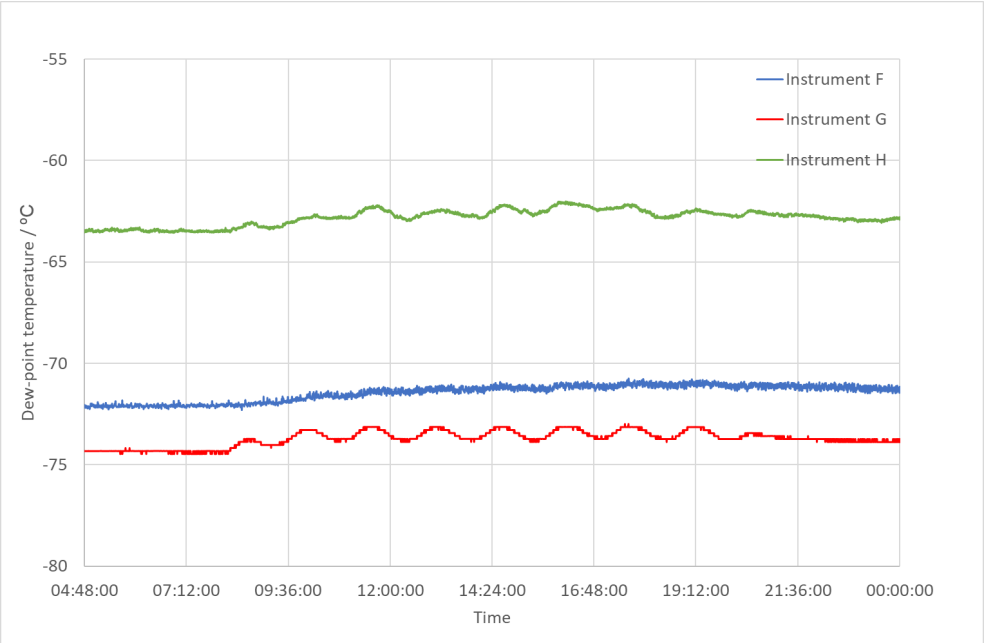

Figure 7 : Quality measurements of NPL electrolyser hydrogen during test profile – water vapour analyser results from instruments measuring at approximately 13.5 barg

Converting these dew-point temperature values to water vapour amount fraction gives values < 1 µmol mol^{-1}. In the measurements of the slower responding Instrument F, humidity fluctuations due to the electrolyser load profile changing were barely noticeable compared to the measurements of the faster responding instruments G and H.

Dew-point temperature measurements made of the Hogen electrolyser hydrogen at atmospheric pressure are shown in Figure 8. The measurements are corrected for errors found during NPL calibrations. The measurements of instrument E display variations in the water dew-point temperature measured when the current load of the electrolyser is varied during the test profile. An increase in the current load resulted in a lower dew-point temperature being measured as can be seen from the results of Instrument E plotted in Figure 9. Converting the dew-point temperature measurements of Instrument E to water vapour amount fraction gives values of approximately 1 µmol mol^{-1}.

The measurements of instrument B appear to have bottomed out at a minimum value of -100 ºC and show no response to the variations in electrolyser current load. As the fastest responding instrument tested in the project this was surprising but at this point in the project re-calibration found significant drift in the measurement error towards under-reading since the initial calibration results of instrument B. It was not possible to accurately correct these measurements as the instrument had reached the bottom of its measurement range.

The results in Figure 9 for instruments E and G show how the measured dew-point temperature varied with the step change profile of the load current. The measurements of both instruments showed increased dew-point temperatures when the load value current decreases. The measured values of Instrument E can be seen to respond faster to the load value current changes in the test profile which is to be expected as this instrument as shown to have a faster response time than Instrument G in the work reported in D1 Section 2.4.1.

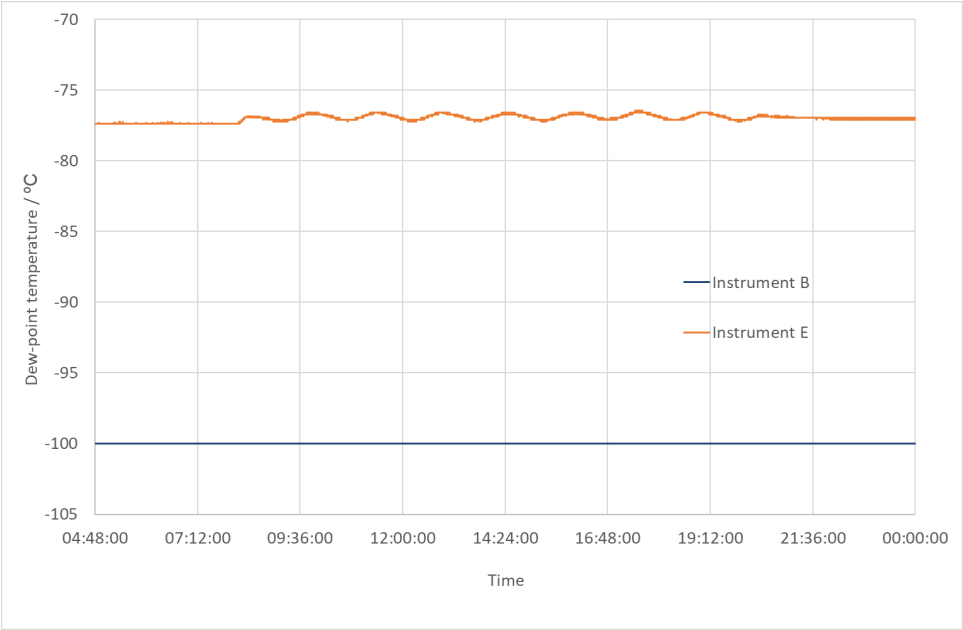

Figure 8 : Quality measurements of NPL electrolyser hydrogen during test profile – water vapour analyser results from instruments measuring at atmospheric pressure

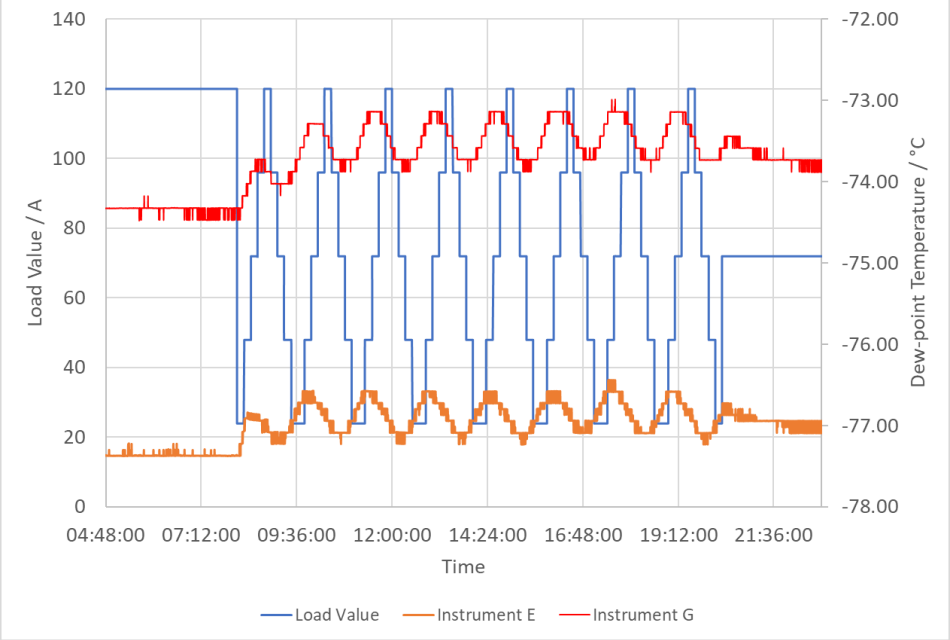

Figure 9 : Quality measurements with instruments E and G of NPL electrolyser hydrogen plotted with fuel cell load value profile

Overall, the water content measurements at both pressures confirmed that the hydrogen quality from the NPL laboratory-based electrolyser met its specified water content level of < 5 µmol mol^{-1}.

1.3.2 CEA laboratory electrolyser hydrogen quality measurement results on SENEPY Platform

The detailed operating phases are listed in Table 1 and an overview of the test is presented in Figure 10. The dew point measured initially is already below -65°C (< 5 µmol mol^{-1}, corresponding to the HOGEN specifications) and progressively decreases. After 20 hours of drying, the humidity level reaches -80°C (*ca*. 0.5 µmol mol^{-1}) and continue to drop slowly down to -88°C (*ca*. 0.1 µmol mol^{-1}).

Table 1: Detailed operation phases for the humidity measurement campaign

	Time	H2 production	Stack Electrolysis current	Description
		[%]	[A]	
1	~41h	70	100	Pipe flushing and drying
2	~1h	100	140	Max. power test
3	~10min	50	71	Intermediate load
4	~2h	~ 25 (minimum flowrate allowed)	47	Stabilisation at minimum current (33% of maximum current)
5	~10min	40	57	Polarisation curve test
6	~10min	60	85	
7	~10min	80	113	
8	~10min	100	140	
9	~10min	80	113	
10	~10min	60	85	
11	~10min	40	57	
12	~30min	~ 25	47	Stabilisation at minimum current (33% of maximum flowrate)
13	~10min	100	140	Minimum/Maximum Current tests
14	~10min	~ 25	47	
15	~10min	100	140	
16	~10min	~ 25	47	
17	~10min	100	140	
18	~30min	~ 25	47	Stabilisation at minimum current (33% of maximum current)
19	~17h	70	100	Test at intermediate current (70% of maximum current)
20	~10h	~ 25	47	Stabilisation at minimum current before shut-down

The humidity variation during current cycles are presented in detail in Figure 11. Some pressure variations at high electrolysis current can be observed due to the pressure regulator and the pressure drop within the H_2 gas network. The humidity value is influenced by the electrolysis current. The higher the current, the drier the H_2 gas: at minimum current the dew point reaches *ca*. -86°C and -94°C for the maximum current during the maximum current step. We can observe some delay in the humidity sensor response probably due to the volume buffer between the electrolyser and the sensor.

These humidity variations are also observed during minimum/maximum current cycles but to a lesser extent between -86 and -92°C as dew point which corresponds to a concentration of water between 0.2 (considering 0.1 barg at minimum H_2 flowrate) and 0.03/0.04 µmol mol^{-1} (considering 0.1/0.3 barg for the maximum current). For information, taking the H_2 pressure into consideration for the calculation is in the same range of the measurement precision of the humidity sensor (± 2°C).

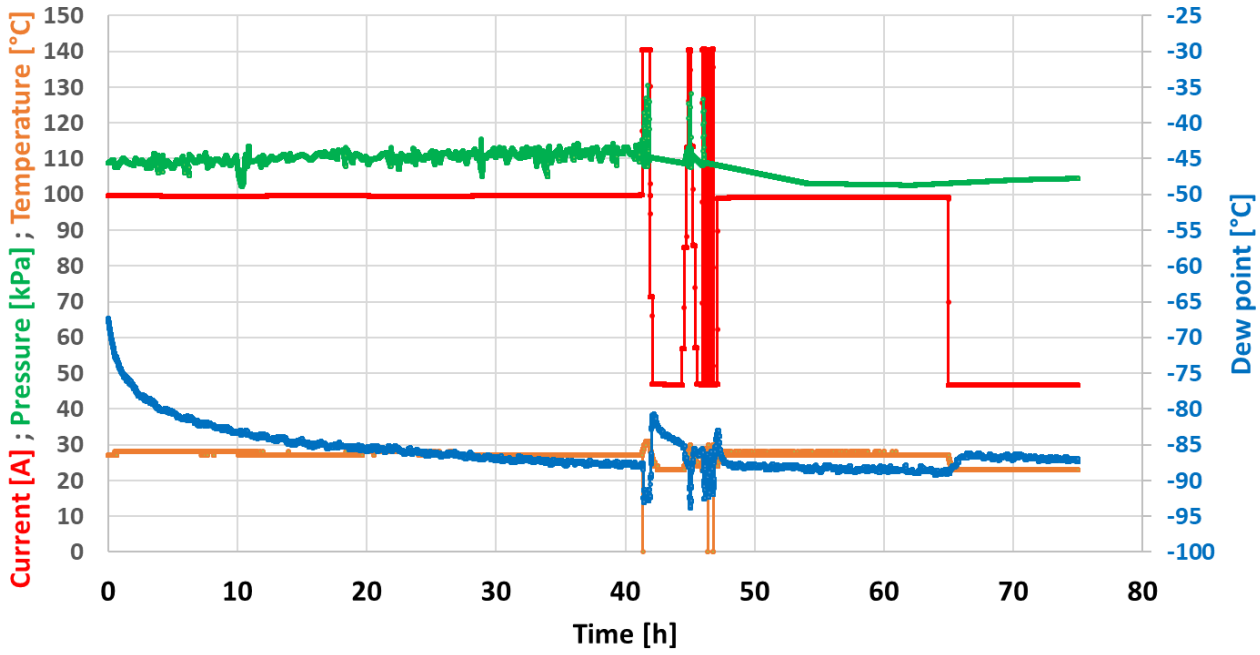

Figure 10 : Overall view of the humidity measurement test on SENEPY platform. Main operating parameters are detailed: Stack current, Pressure and Temperature (close to humidity sensor) (left axis) and dew point (right axis)

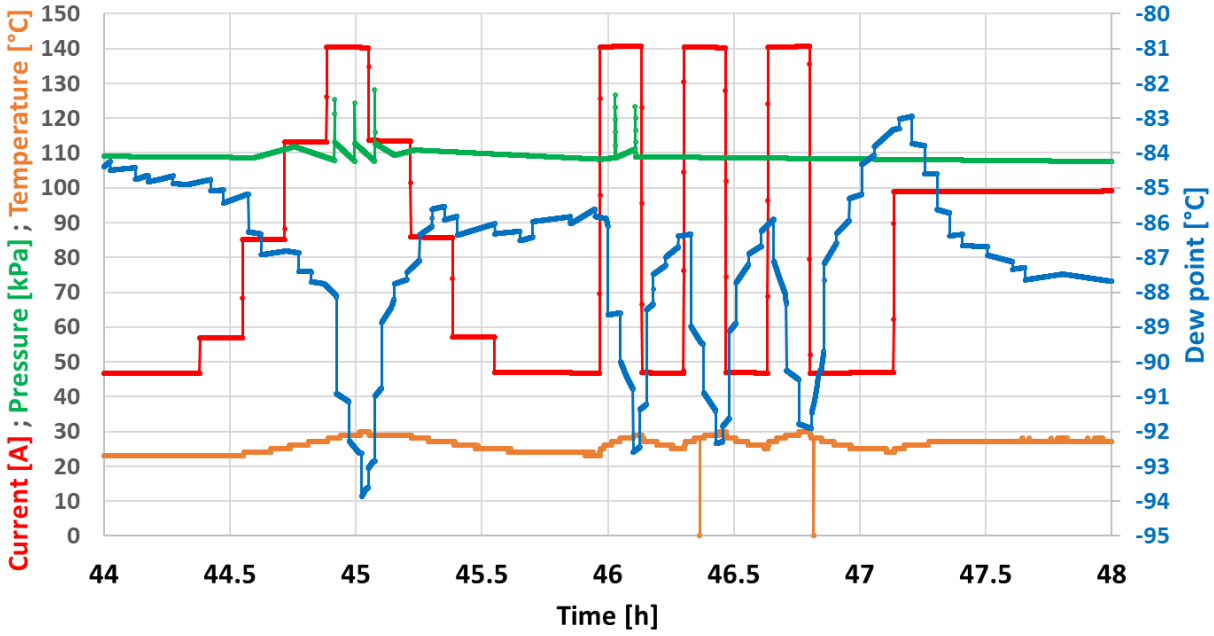

Figure 11 : Zoom on the humidity measurement test on SENEPY platform during variable current cycles. Main operating parameters are detailed: Stack current, Pressure and Temperature (close to humidity sensor) (left axis) and dew point (right axis)

Overall, the water content measurements performed on the SENEPY platform at CEA confirmed that the hydrogen quality from the HOGEN electrolyser meets its specified water content level of < 5 µmol mol^{-1}.

1.3.3 Additional hydrogen vehicle refuelling station water content measurements made by NPL

Additional electrolyser measurements using the online water content analysers calibrated in MefHySto (as reported in D1) were made by NPL at a hydrogen vehicle refuelling station (HRS) as part of the Metrology for Hydrogen Vehicles 2 (MetroHyVe2) EMPIR project which was running in parallel to MefHySto.

Figure 12 shows water content measurements using metal oxide and a fibre optic principle hygrometers measuring water content at the HRS buffer storage system pressure (approx. 2 MPa) alongside values measured by an NPL owned Tiger Optics CRDS water vapour spectrometer (Instrument A). Corrections to the measured values were applied from calibrations of instruments F, G and H against the NPL Multi-gas, multi-pressure primary standard humidity generator prior to their measurements of the HRS hydrogen quality.

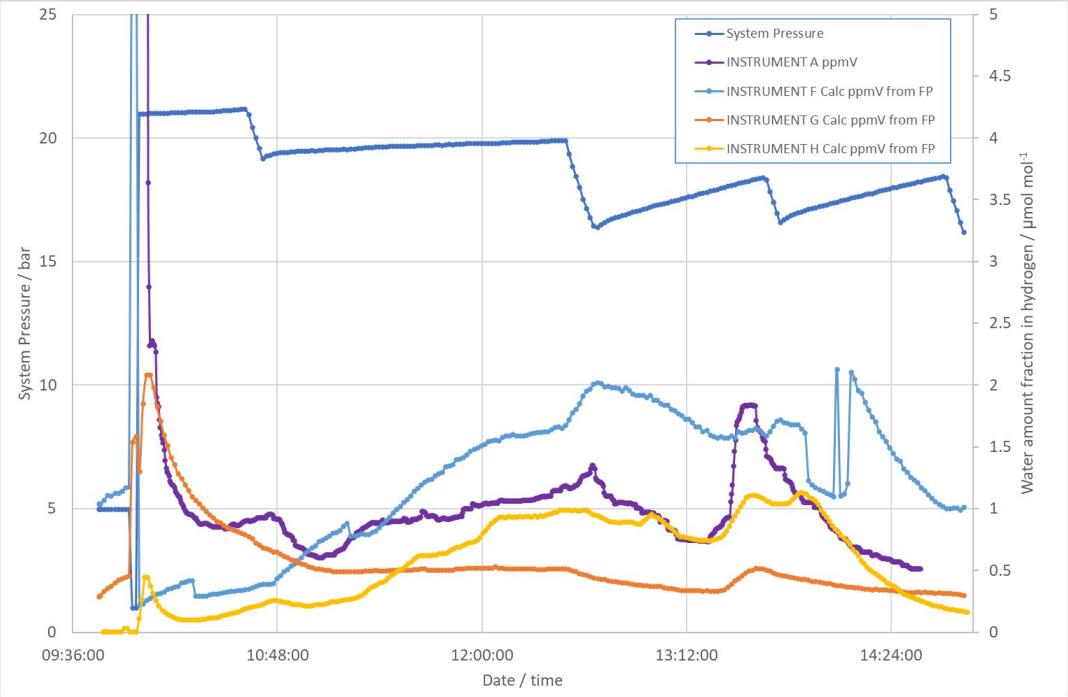

Figure 12 Water content measurements from metal oxide and fibre optic principles hygrometers measuring water content at HRS buffer storage system pressure alongside Tiger Optics CRDS instrument (Instrument A).

The response time to step changes of humidity of instruments F, G and H was previously tested and reported in D1 of this project and it was found that instrument F had the slowest response time of the instruments tested. The event at the HRS that occurred at a time around 13:30 causing a rise in the water content value was detected fastest by the CRDS spectrometer (Instrument A) and did not cause a rise in the measured value of instrument F until around 30 minutes after it had first been detected by the fastest recording instrument. This fact shows the importance of choosing an online instrument with a fast enough response time to allow appropriate reactive measures to be taken if the measurements are to be used for process control to ensure hydrogen fuel quality standards are met.

1.4 Application to industrial system: PEM electrolyser hydrogen quality measurements using fast response analysers: micro-GC and CRDS (NPL)

1.4.1 Introduction

Proton exchange membrane (PEM) electrolysis of water is a mature technology to produce hydrogen at an industrial scale. The direct use of electrolysers with solar panels is foreseen as a key aspect to the storage and stabilisation of renewable energy in the future.

Within the operation of a PEM electrolyser, there is a possibility that a small amount of oxygen and nitrogen will cross over the membrane from the air side into the hydrogen side of the electrolyser. The cross over is a function of the electrolyser operation condition and while affecting hydrogen quality may also affect the performance. Water amount fraction can be quite high at the outlet of the electrolyser and needs to be removed to be compliant with the end-users' requirements. Different types of purifier can be implemented, however the water amount fraction may be related to the performance and operation of the system. Therefore online monitoring may provide critical insights in terms of water amount fraction evolution, size of purifier and potential fluctuation with process control, and it is critical to monitor these contaminants to improve the performance of electrolysers.

Therefore, additional work was proposed to perform online monitoring of hydrogen quality from the cathode side of an electrolyser at an external partner site (Fusion Fuel) in Portugal. The objective was to apply the novel measurement techniques developed in the project on an industrial system to provide some real-life feedback on the new partner's new development.

The amount fraction of oxygen, nitrogen and water cross over were measured on the hydrogen line under different operating conditions.

Figure 13 : CUBE electrolyser at Fusion Fuel

1.4.2 Description of the system

Based on these measurement needs, the NPL Gas Metrology group used the facility developed in the project MefHySto to perform online analysis of hydrogen quality. As shown in Figure 14, the facility for online monitoring consists of several instruments including a cavity ringdown spectrometer CRDS, Tiger Optics), a micro-GC (Agilent) and an oxygen sensor (loaned from a collaborator). The micro-GC is used to measure oxygen and nitrogen in hydrogen with a measurement interval of 1 minute. The oxygen content in hydrogen is also being continuously monitored by the oxygen sensor. The comparison of the results of the microGC and the oxygen sensor would validate the application of such sensors in an industrial environment. The CRDS is dedicated to measurement of water in hydrogen with a measurement interval of a few seconds.

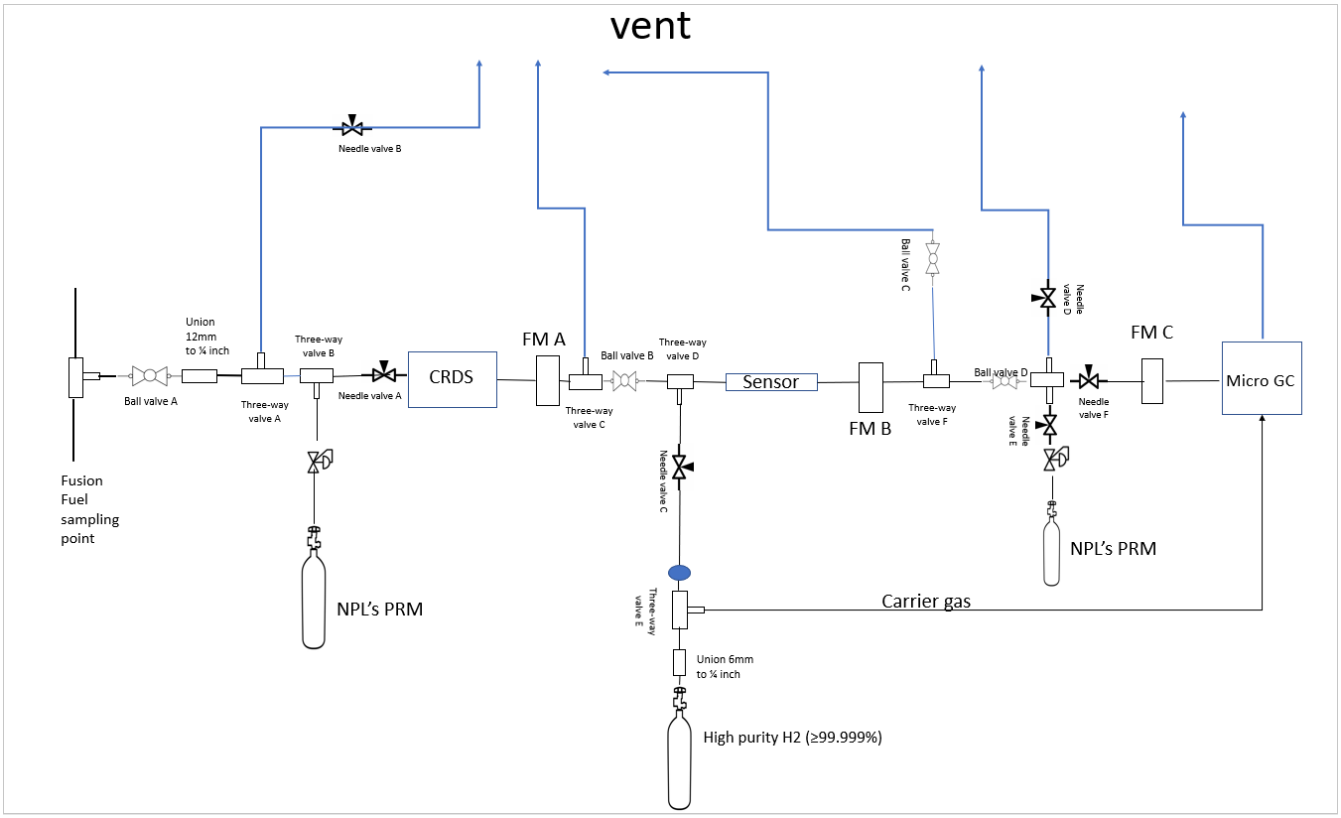

Figure 14 : Facility for online monitoring of hydrogen quality from a commercial electrolyser

1.4.3 Procedure

1.4.3.1 Calibration of instruments

Prior to performing any analysis, the instruments are calibrated. The calibration is realised using NPL PRMs developed as part of 19ENG01 MefHySto. Three gas mixtures are used for calibration of the CRDS and micro-GC. The CRDS is calibrated with 5 µmol mol^{-1} and 100 µmol mol^{-1} water in hydrogen mixtures. The micro-GC is calibrated with 5 µmol mol^{-1} and 50 µmol mol^{-1} oxygen in hydrogen mixtures. The details of the gas mixtures are shown in Table 2.

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Table 2 : Gas mixtures used for instruments calibration (n.a., not available as not present in the mixtures)

Cylinder number	D306725	1727R4	D089838R
	Amount fraction and uncertainty associated (µmol mol^{-1})		
O_2	50.90 ± 0.08	n.a.	5.330 ± 0.022
H_2O	n.a.	100.61 ± 0.13	4.544 ± 0.011
He	12687 ± 17	n.a.	n.a.
N_2	n.a.	n.a.	318.2 ± 0.8
H_2	Balance	Balance	Balance

Regarding the oxygen sensor, it was calibrated at NPL before being sent to the partner site for performing analysis and the calibration results could be found in D1 Section 2.5.3. From the lessons learnt of oxygen sensor testing reported in D1, it is critical to purge the oxygen sensor with pure hydrogen beforehand to achieve a better baseline and minimise the measurement drift. A high purity hydrogen cylinder is used for delivering pure hydrogen for the sensor purge.

1.4.3.2 System purge

After the calibration of instruments is completed, the line used for calibration is closed. The gas from the electrolyser system is then flowed through the analysis sample line. The system is purged with the hydrogen sample for one hour to completely remove air in the line hence avoid false measurement values of target contaminants. The amount fraction of water, oxygen and nitrogen is monitored to ensure a stable reading. Once stabilisation is achieved, the variation of operating parameters is realised to evaluate how this affects oxygen, nitrogen and water amount fraction in real time.

1.4.3.3 Online monitoring of hydrogen quality

Once the above steps are finished, the instruments started to measure oxygen, nitrogen and water in hydrogen samples. As advised from the manufacturer at Fusion Fuel, the flowrate of hydrogen samples ranged from 18 to 90 l min^{-1} and only hundreds of ml min^{-1} are required for the instruments, therefore a parallel line is implemented to divert most of flow to vent.

The flow into the instruments is regulated to 500 ml min^{-1} for CRDS and the oxygen sensor and 100 ml min^{-1} for the micro-GC, respectively. As the pressure from the electrolyser outlet is atmospheric pressure which meet the operation requirement of the instruments, there is no pressure regulation required in the system.

All analysis data was recorded in real time in the instruments and processed by scientists from NPL.

1.4.3.4 Online monitoring results

An archetype of PEM electrolyser was tested under various current loads (2, 4, 6, 8, 10, 12 and 15 A). Impurities fluctuation such as oxygen and nitrogen were monitored in the hydrogen gas produced. The sampling point was located at a hydrogen product line after gas-liquid separator and dryer (silica desiccant containers) to remove most of the liquid water from the hydrogen gas analysed.

The results of oxygen and nitrogen amount fraction in hydrogen produced from PEM water electrolysis (PEMWE) were presented in Figure 15 and Figure 16. It can be observed that the oxygen fraction in hydrogen is higher at lower current load, then decreases with increasing current load and is almost constant at the higher current loads (i.e., 12 A and 15 A). Similarly, the nitrogen fraction in hydrogen reduced with increasing current load. Therefore, at low current load, the nitrogen amount fraction crossing over the membrane is increasing more than the oxygen amount fraction while at high current load, oxygen crossing over the membrane seems to stabilise at around 100 µmol mol^{-1}. In contrast, the nitrogen crossover is reducing close to the instrument limit of detection (~40 µmol mol^{-1}) at high current load.

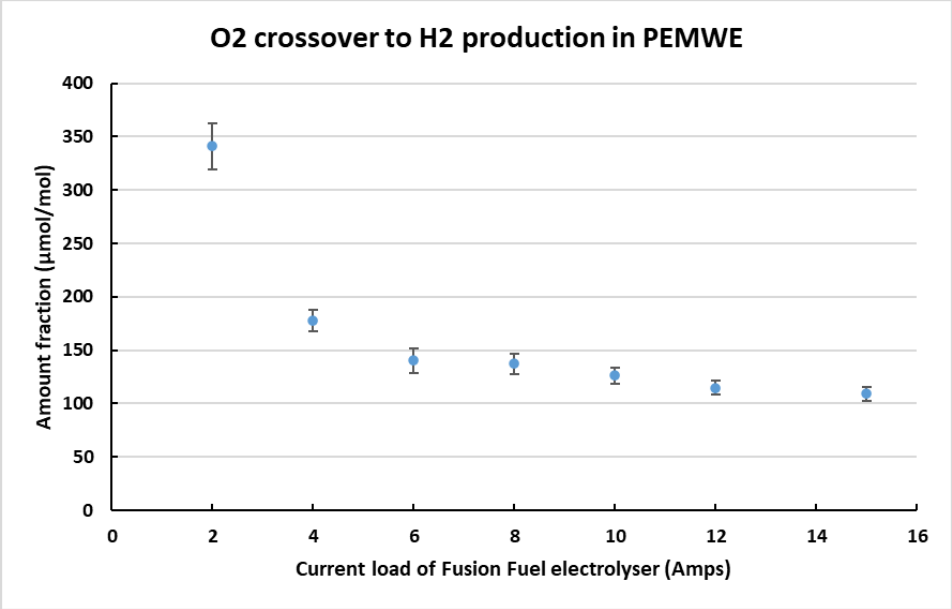

Figure 15 : Oxygen cross over into hydrogen product in PEMWE under different current

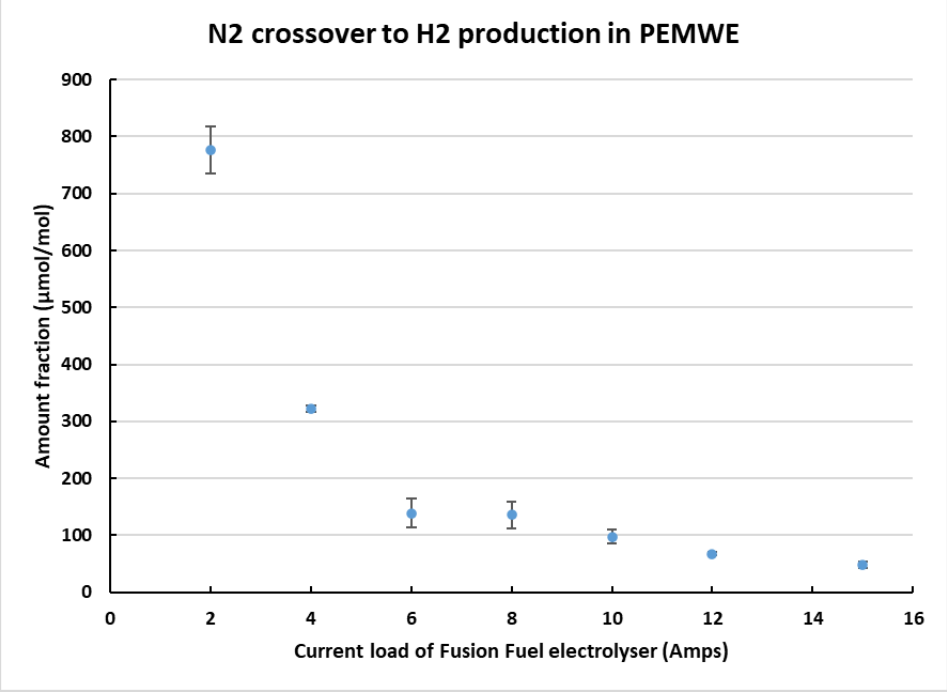

Figure 16 : Nitrogen cross over into hydrogen product in PEMWE under different current

The water amount fraction was saturating the CRDS detector (maximum amount fraction detection limit approximately 2000 µmol mol^{-1}). Despite selecting the driest sampling point of the system after the gas-liquid separator and dryer, the water amount fraction was still extremely high and would require an analyser with a higher measurement range to investigate fluctuations. This indicated at the industrial scale application, occurrence of high amount fraction of water is very likely due to potentially insufficient purification of hydrogen. For future study, it is recommended to use a higher measurement range water analyser initially and refine with CRDS once the hydrogen gas reaches suitable drying level.

It should be noted that the trial in real life conditions of an archetype electrolyser coupled to renewable energy sources remained challenging for the instrumentation due to the high level of water encountered. Because of this, new measurement challenges that could affect the quality measurements include:

- interference of water on the gas chromatography measurement (column saturation, baseline increases),
- saturation of analyser due to challenging operating conditions (i.e., high content of water due to insufficient drying)
- reliability of the calibration using dry gas (NPL PRM did not contain high water content). The impact of humidity on oxygen or nitrogen analysis is not well studied and critical for the reliability of the measurement for electrolyser in real operation conditions.

For this specific trial, the measurements highlighted the importance of appropriate purification techniques to improve hydrogen quality. Additionally, it is important to choose the instruments with suitable measurement range to perform analysis (i.e., CRDS was too sensitive for the hydrogen produced). Finally, the calibration gas (dry gas) impact may be future investigation topic to improve the reliability of the analysis for electrolyser developments (prior to high efficiency drying) especially for non-hydrogen for transport applications (i.e., storage, heat, power to X).

2 Conclusions

The laboratory electrolyser hydrogen quality measurements using traceably calibrated instruments proved that the impurity levels met those stated by manufacturer in the electrolyser technical specification.

Field measurements of the hydrogen refuelling station quality by multiple hygrometers in parallel showed the importance of choosing instruments with an appropriate response time for online measurement. Using an instrument with too slow a response time will delay feeding back impurity rise information to process control systems, delaying any action to bring the hydrogen quality back to levels that meet required specifications.

Field measurements at an industrial electrolyser manufacturer by several instruments highlighted the different behaviour of hydrogen contaminants (oxygen, nitrogen, and water) as a function of the operating parameters. It demonstrated the importance of impurity cross over in water electrolysis under different operating conditions. Accurate measurements of the contaminant levels in hydrogen are required to purify and optimise the system performance to achieve end-users' requirements (i.e., in storage, Power to X and power to electricity applications). The measurement of an archetype electrolyser highlighted new measurement challenges related to the high level of humidity (i.e. relevance of dry gas calibrant, measurement interference). These new challenges require further research and development to support electrolyser deployment with a robust and reliable measurement strategy.

3 References

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Appendix A

Table 3 : Load cycles, as percentage of maximum current, applied to the fuel cell during system testing at NPL.

Steps	
Elapsed Time / s	Load / %
0	20
600	40
1200	60
1800	80
2400	100
3000	80
3600	60
4200	40
4800	20
5400	
Max-Min	
Elapsed Time / s	Load / %
0	20
300	100
900	20
1200	
Constant	
Elapsed Time / s	Load / %
0	60
1200	