Grant agreement no.: 700127
Start date: *01.05.2016 –* ***Duration***: *36 months*
Project Coordinator: *Johnson Matthey plc*

DELIVERABLE REPORT 6.4 – STACK HIGH LEVEL TEST REPORT ISSUED FOR GEN 1 AND GEN 1.5

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Work Package	*WP 6*
Work Package Leader	*BMW*
Lead Beneficiary	*JM*
Date released by WP Leader	*12TH JUNE 2018*
Date released by Coordinator	*25TH JUNE 2018*

DISSEMINATION LEVEL		
PU	*Public*	***X***
PP	*Restricted to other programme participants (including the Commission Services)*	
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NATURE OF THE DELIVERABLE		
R	*Report*	***X***
P	*Prototype*	
D	*Demonstrator*	
O	*Other*	

SUMMARY	
Keywords	
Full Abstract (Confidential)	Performance and operational stability testing as well as initial durability testing for stack generations GEN 1 and GEN 1.5 are reported. Short stack performance and stability were measured for short stacks (GEN 1 and GEN 1.5), and a full-size stack (GEN 1.5). In addition, single cell measurements, using both screener cell and full-size cell, were performed. The tests with the full-size stack included parameter variation evaluating the sensitivity to operating temperature, pressure, humidification, and stoichiometry. The focus was to measure the stack performance and define stable operating conditions for the stacks with five INSPIRE test points. Failure analysis of MEAs has been performed in order to better understand the degradation mechanisms. Together with cell voltage and current distribution data, this forms the basis to mitigate degradation issues. Performance is, however, not the main issue. The full-size stack performance data show that project targets are achievable and the INSPIRE interim power density target of 1.2 W/cm² was accomplished. The performance after full activation is stable. The main problem is poor stability due to the anode side flooding. Several reasons for this were identified and lessons learned will be taken into account when designing the next stack generations GEN 2 and GEN 3 and planning experimental research for them.
Publishable Abstract (If different from above)	

REVISIONS			
Version	**Date**	**Changed by**	**Comments**
1.0	25/06/2018	S Buche, C Wayne	Final version

D6.4 – Stack High Level Test Report Issued for GEN 1 and GEN 1.5

Contents

1. Summary

In this report, performance and operational stability testing, as well as initial durability testing, for stack generations GEN 1 and GEN 1.5 are summarised. The overall test program for GEN 1 and GEN 1.5 was devised to help understand the essential aspects for validating the stack hardware effects.

Concerning performance and operational stability measurements, the purpose of the work has been stack and component validation. Short stack performance and stability were measured for short stacks (GEN 1 and GEN 1.5), and a full-size stack (GEN 1.5). In addition, single cell measurements using both a screener cell and a full-size cell were performed. In single cell measurements, current density measurements as well as electrochemical impedance spectroscopy (EIS) have been applied. The performance tests were carried out according to the test protocols defined in WP2 (Deliverables 2.1 and 2.3) at both short stack and full stack level.

The tests with the full-size stack (GEN 1.5) included parameter variation evaluating the sensitivity to operating temperature, pressure, humidification, and stoichiometry. These are reported in the Deliverable 6.3 Appendices. The focus so far has been to measure the stack performance and define stable operating conditions for the stacks with the five INSPIRE test points. Therefore, only steady state measurements have been performed, in addition to polarisation curves.

Dynamic performance (FC-DLC or similar load cycle) has not been studied yet; it will be studied for GEN 2 and GEN 3. In these measurements, operation under typical automotive load conditions for partial load, full load and over-load will be studied, as well as transition between the identified stable operation points.

Performance with extreme temperature operation (e.g. cold start, freeze start, high temperature operation) will also be studied for GEN 2 and GEN 3. Some of these (e.g. high temperature operation) will be performed only at the short stack level, since the cells can be easily replaced. Low temperature operation (especially cold start, freeze start) will be characterised only with the final large-scale stacks, as they are resource-intensive tests, to identify potential issues, such as media distribution, pressure drop, water condensation and liquid water transport.

The durability testing work with stack generations GEN 1 and GEN 1.5 has been limited, as the stack behaviour at some of the operating points has been unstable leading to very high degradation rates, due to channel flooding and hydrogen starvation. A test protocol for durability testing was developed and tested with the GEN 1.5 single cell including current distribution and EIS measurements.

Post mortem failure analysis of MEAs has been performed in order to better understand the degradation mechanisms. Together with cell voltage data and current distribution data this forms the basis to mitigate degradation issues.

2. The Test Programs for GEN 1 and GEN 1.5

2.1 Objective and scope of the test and test procedure

The test modules and test programs are based on the STACK-TEST project work reported in INSPIRE Deliverable 2.1. The test modules have been modified according to the needs of the INSPIRE project, taking into account the possibilities and limitations of test stations for single cell and stack testing. Test programs for each stack generation and a list of test programs are shown in Table 1 and in Table 2. The details of the test modules are reported in INSPIRE Deliverable 2.1.

Table 1: Test programs for each stack generation

Test program	Performance and stability P-							Durability D-			
Stack	01	02	03A	03B	03C	04	05	01A	01B	01C	01C
GEN 1 – short	x	x	x			x				x	x
GEN 1.5 – short	x	x	x			x		x	x	x	x
GEN 1.5– full size	x	x	x			x					
GEN 2 – short	x	x	x			x	x	x	x	x	x
GEN 2 – full size	x	x	x			x					
GEN 3 – short	x	x	x		x	x	x	x	x	x	x
GEN 3– full size	x	x	x	x	x	x		x	x		

Table 2: List of test programs

Number	Name
P-01	Stack Performance Assessment
P-02	Stack Performance Mapping
P-03A	Deviant Stack Performance - Fuel/Oxidant Composition
P-03B	Deviant Stack Performance - Low Temperature Test
P-03C	Deviant Stack Performance - Impact of Stack Tilt on PEMFC Stack Performances
P-04	Dead End Performance
P-05	Stack Performance Optimisation
D-01A	The influence of operation under a constant load profile
D-01B	The influence of operation under a dynamic load profile
D-01C	The influence of start-up phase
D-01D	The influence of shut-down phase

According to the INSPIRE Description of Action (DoA), GEN 1 only required testing at short stack level, while all the other stack generations should be validated at full stack level (up to around 400 cells). The overall test program for GEN 1 was also limited to the essential aspects for validating the stack hardware effects.

According to the DoA (Task 6.4), durability testing at full stack level will be carried out with at least one stack generation (GEN 3). Testing of start-up (SU) and shut down (SD) durability is not meaningful at full-size stack level, if representative gas change time during SU and SD cannot be achieved.

From the STACK-TEST project, the modules P-01 to P-03A were adapted in accordance with the stack specification from D2.1 and combined into one INSPIRE test protocol. This test protocol was transferred to test rigs at BMW, DANA and JM.

Test input parameters (TIP) for the five INSPIRE test points are reported in Deliverable 2.1; test input parameters for polarisation curve measurements are shown in Table 3.

Table 3: Test input parameters (TIP) for polarisation curve measurements

Anode				Cathode					Coolant	
Stoichio metry hydrogen	Inlet gas temperature	Temperature dew point	Pressure outlet	Volume flow air	Stoichio metry air	Inlet gas temperature	Temperature dew point	Pressure outlet	Temperature coolant inlet/test item	Temperature difference coolant
λ_{H2}	$T_{gas,A}$	$T_{dp,A}$	$p_{out,A}$	V'_{air}	λ_{air}	$T_{gas,C}$	$T_{dp,C}$	$p_{out,C}$	$T_{coolant,in}/T_{test\_item}$	$\Delta T_{coolant}$
[ ]	[°C]	[°C]	[bar_a]	[Nl/min]	[ ]	[°C]	[°C]	[bar_a]	[°C]	[°C]
1,50	85	46	2		2,00	85	46	2	60	

During the measurements, there were some variations in the coolant temperature difference (outlet-inlet). In single cell measurements, this was lower than 5°C, while in full stack measurements it was approximately 15°C. This may have important consequences for water management.

The test programs used are illustrated in Figure 1A and Figure 1B. In large single cell testing, current distribution was also measured at all measurement points. Current distribution was measured during the last minute of the measurement point. The break-in was only used in measurements with GEN 1.0 MEAs and the small single cell (43.56 cm²).

With this testing protocol, the MEAs developed during the INSPIRE project were tested, evaluated and compared to each other.

Figure 1: Test programs applied for GEN 1.0 and GEN 1.5 MEAs. a) Small single cell and stack testing b) Large single cell testing. (Impedance measured using one single frequency (1 kHz)).

Between the measurements, cells and stacks were kept in "nominal conditions", corresponding to about 0.75 V cell voltage and at 65° C, at high humidity conditions. These conditions were also used as a preconditioning step. During this preconditioning step, the minimum flow rates for the anode and cathode were 2.5 dm^3/min per cell for anode and cathode with TP288 hardware (INSPIRE GEN 1.0/1.5).

The five INSPIRE test points used in the measurements are shown in Figure 2. The measurement points at specific current densities are chosen based on these points. The details for the points are presented in INSPIRE Deliverable 2.1.

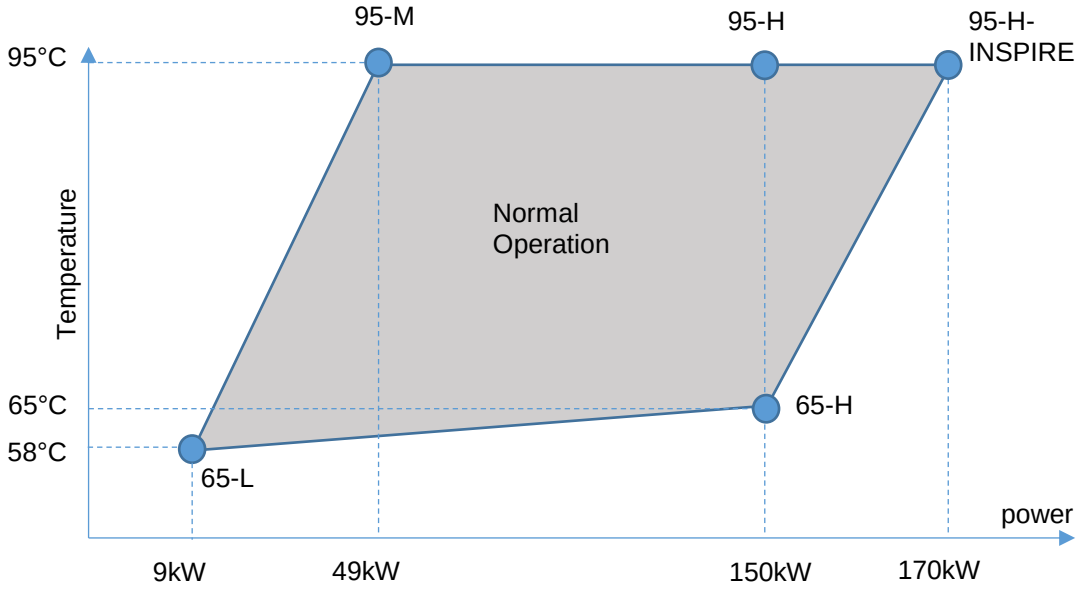

Figure 2: Operating conditions, power output versus stack outlet temperature

2.2 Description of test objects (stacks and cells)

The 43.56 cm² (50 cm²) screener single cell is described in INSPIRE Deliverable 4.1. It has a six-channel serpentine flowfield and is run counter current flow. Channel dimensions are larger than in large cells and stacks.

The test hardware TP288 (area 287.5 cm²) is described in INSPIRE Deliverable 4.2. This hardware has been used for both single cell and short stack measurements.

The screener cells were used at JM for the down-selection of the most promising materials and components. Both flowfield channel geometry and cell area are different in the screener cell compared to TP288 and, therefore, a different performance was expected, especially with high current densities and in wet conditions.

3. GEN 1.0 MEA AND STACK TESTING

The test program for GEN 1.0 MEA stack level testing (from Deliverable 2.1) is shown in Table 4. In addition to stack level testing, small and large single cell test results are reported here.

Table 4: Testing program of GEN 1.0

Test program	Performance and stability P-							Durability D-			
Stack	01	02	03A	03B	03C	04	05	01A	01B	01C	01C
GEN 1 – short	x	x	x			x				x	x

3.1 Single cell testing with GEN 1.0 MEA – small cell (43.56 cm²)

The test history of GEN 1.0 MEA samples in a small cell is presented in Figure 3.

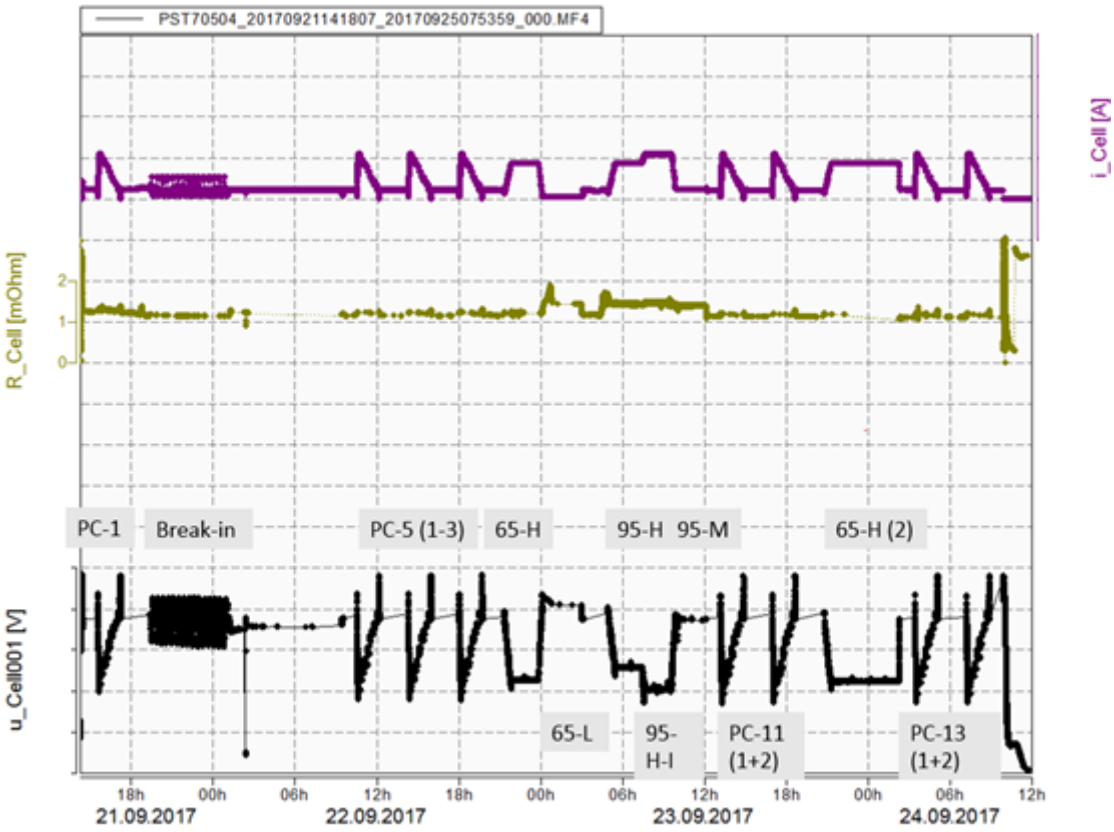

Figure 3: Test history of GEN 1.0 MEA tested in small cell (43.56 cm²).

In Figure 4, the polarisation curves at the different positions within the test protocol for GEN 1.0 MEAs in 43.56 cm² hardware are shown. A rapid decrease in performance of the polarisation curves is observed during the test protocol. Local hydrogen starvation is suspected to be the main cause for the degradation

in full-size cells and it is also considered as the probable cause for the degradation in small cells. However, contamination due to test station or cell components cannot be excluded.

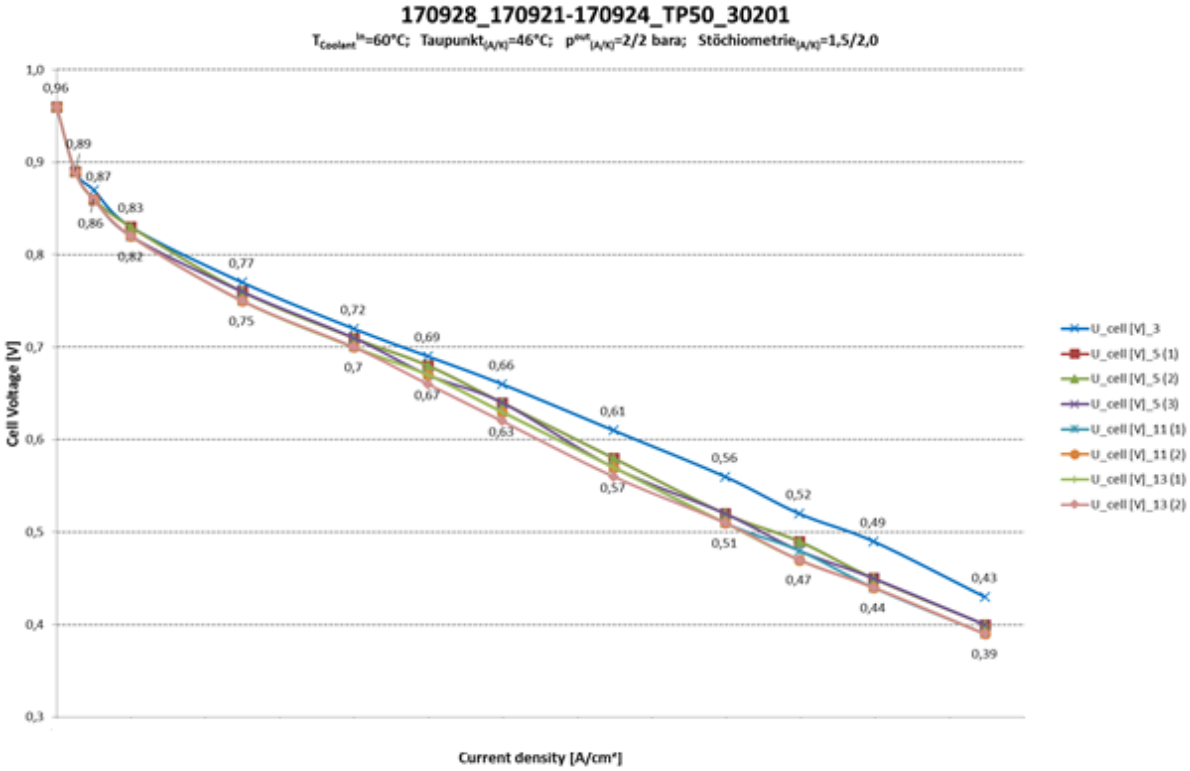

Figure 4: Polarisation curves of GEN 1.0 MEA in 43.56 cm² single cell at BMW fuel cell testing facility

The polarisation curves of the GEN 1.0 MEA are shown in Figure 24. The polarisation curve measured at the beginning of the testing (Ucell [V]_3) shows the best performance. This polarisation curve was obtained before the break-in procedure. All other polarisation curves after the initial one show lower performance. Due to this fact, the break-in procedure for future tests was discarded.

The reason for this performance loss could be related to the high humidity and anode water condensation near the outlet regions. These cause reverse current decay conditions and rapid cathode catalyst corrosion. Moreover, the start-up procedure shows very low current densities near anode outlet regions, which is seen in current distribution measurements. This indicates serious flooding conditions already during the start-up (preconditioning) step.

In Table 5 the cell voltage, the cell current and the 1 kHz cell resistance from a GEN 1.0 MEA under performance testing are shown.

Table 5: Table representation of performance testing from Mode 1 to Mode 5 operating conditions

		65- H (Mode 1)		65 - L (Mode 2)		95 H (Mode 3)		95- H-I (Mode 4)		95-M (Mode 5)		65- H (Mode 1)	
	Unit	measured	setting	measured	setting	measured	setting	measured	setting	measured	setting	measured	setting
Current	A	87,12	87,12	4,354	4,354	87,12	87,12	108,9	108,9	23,96	23,954	87,12	87,115
Coolant inlet temperature	°C	62	62	56	56	90	90	91	90	90	90	62	62
Anode													
Stochiometry		1,41	1,38	3,27	1,33	1,28	1,25	1,28	1,25	1,25	1,25	1,41	1,38
Dewpoint	°C	45	45	45	45	65	65	65	65	65	65	45	45
outlet pressure	bar_a	1,9	1,9	1,48	1,48	2,1	2,1	2,1	2,1	2,3	2,3	1,9	1,9
Cathode													
Stochiometry		1,6	1,6	4,2	1,6	1,4	1,4	1,4	1,4	1,4	1,4	1,6	1,6
Dewpoint	°C	45	45	45	45	65	65	65	65	65	65	45	45
outlet pressure	bar_a	1,55	1,55	1	1	1,75	1,75	1,75	1,75	1,85	1,85	1,55	1,55
1-kHZ-Resistance	mΩ	1,216	-	1,447	-	1,401	-	1,476	-	1,386	-	1,179	-
Cell Voltage	V		-		-		-		-		-		-

In Table 5 the results of the test protocol are presented. The five operating modes together with the operating parameter sets derived from D2.1 are shown. From Table 5, the diagram in Figure 5 is extracted.

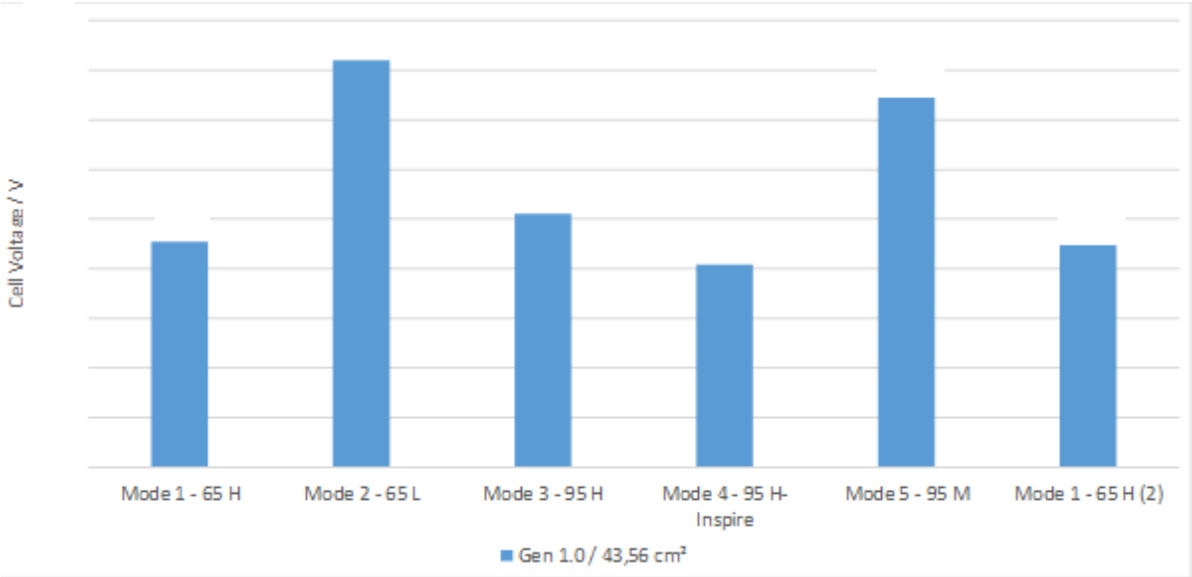

Figure 5: Data representation of cell performance in Mode 1 to Mode 5 (see Figure 2) in GEN 1.0 43.56 cm² single cell.

3.2 Single cell testing with GEN 1.0 MEA – large cell (288 cm²)

INSPIRE project partners JM and DANA delivered MEAs (GEN 1.0) and 288 cm² bipolar plates to BMW. According to the assembly manual of the TP288 cell holder, a GEN 1.0 MEA was assembled.

The test result is shown in Figure 6. Due to the fact, that the break-in of the 43.56 cm² single cell led to a lower performance (compare to Figure 4), the break-in was skipped for the TP-288 testing.

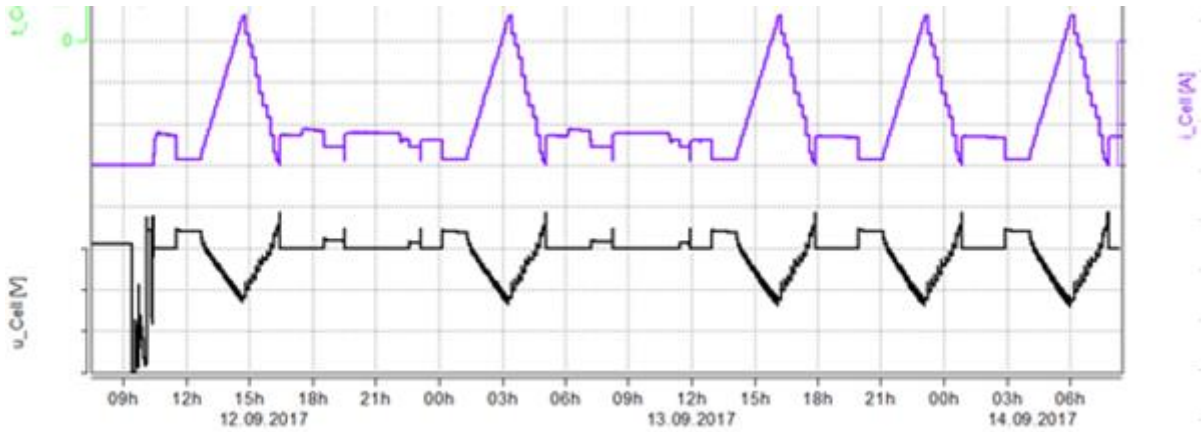

Figure 6: Test history of the beginning of TP288 GEN 1.0 single cell testing.

The results obtained from the test protocol from the 43.56 cm² single cell and the TP288 single cell are in good agreement with each other. The results from the polarisation curves are shown in Figure 7.

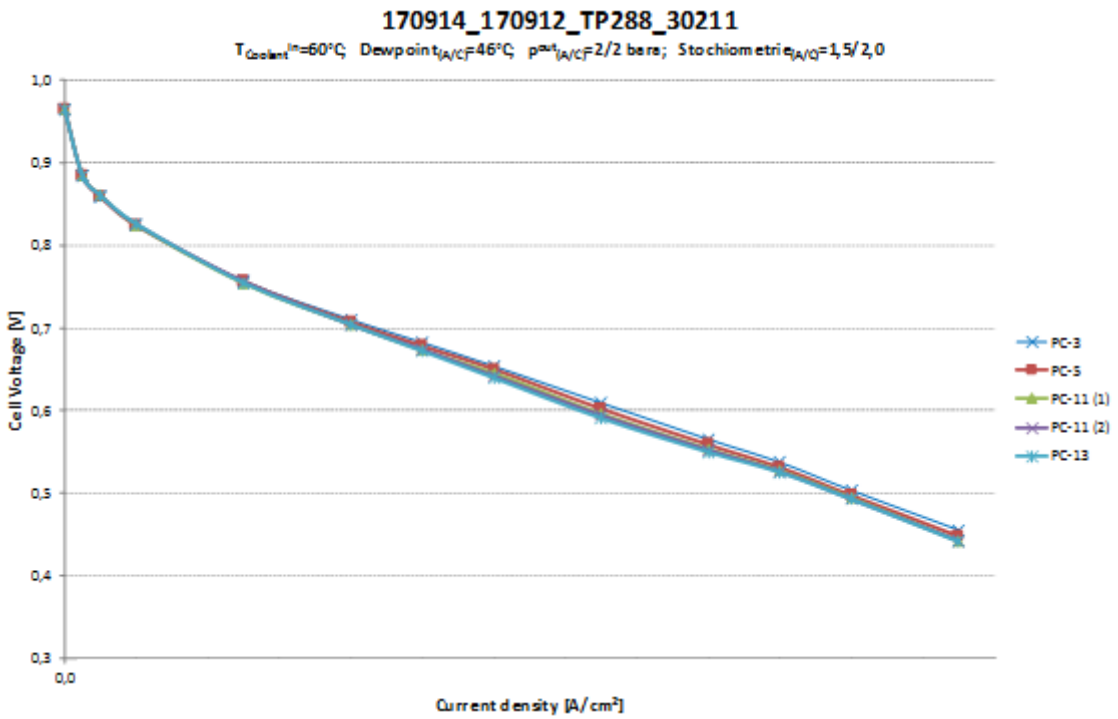

Figure 7: Polarisation curves obtained at the different parts of the testing protocol with GEN 1.0 MEA and TP288 cell hardware.

The polarisation curves in Figure 7 show no degradation within the measurement and test rig error. This is in sharp contrast to all the other results.

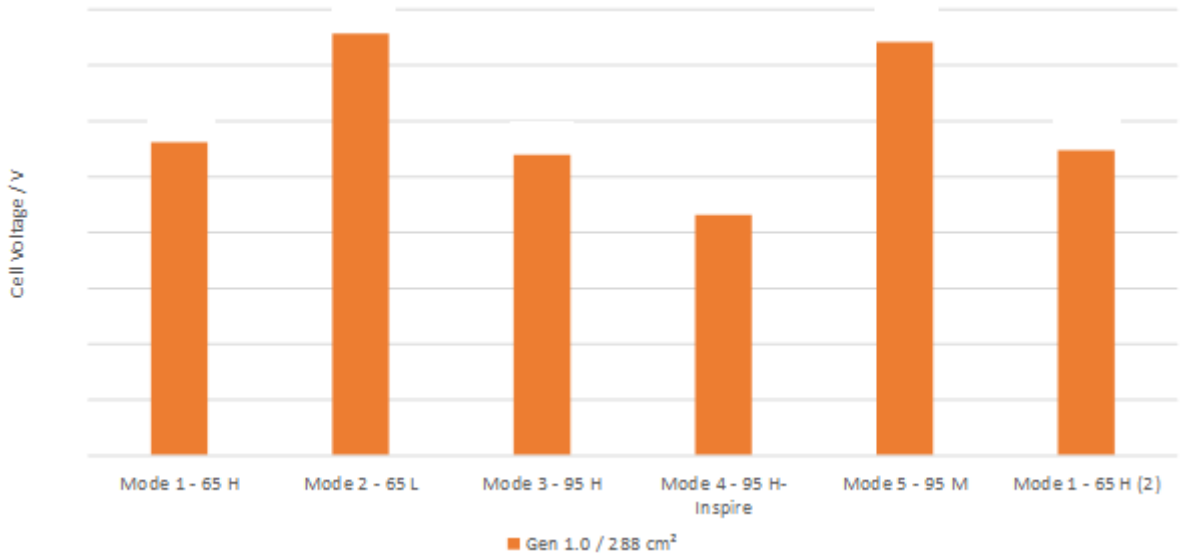

Figure 8: Cell voltage of TP288 single cell with GEN 1.0 MEA at defined operating points.

In Figure 8 the cell voltage at the Mode 1 to Mode 5 INSPIRE operating conditions is shown. Compared to the 43.56 cm² single cell, the cell voltage at higher power densities > 0.1 A/cm² increased significantly. A maximum power density of 1.12 W/cm² was therefore achieved at operating point 65-H.

Figure 9 shows the cell voltage of the GEN 1.0 MEA in the different cell hardware compared to the INSPIRE target values. Beginning of life data is used for the small cell, due to rapid degradation.

At operating conditions where high current densities are set, the TP288 full-size cell hardware shows significantly better performance than the small-size cell.

It was not possible to run the GEN 1.0 short stacks (10 cells) at the desired operating points (M1-M5) at BMW. A very unstable cell voltage behaviour was observed up to current densities of 1.2 A/cm² (at lower current densities than 1.2 A/cm²).

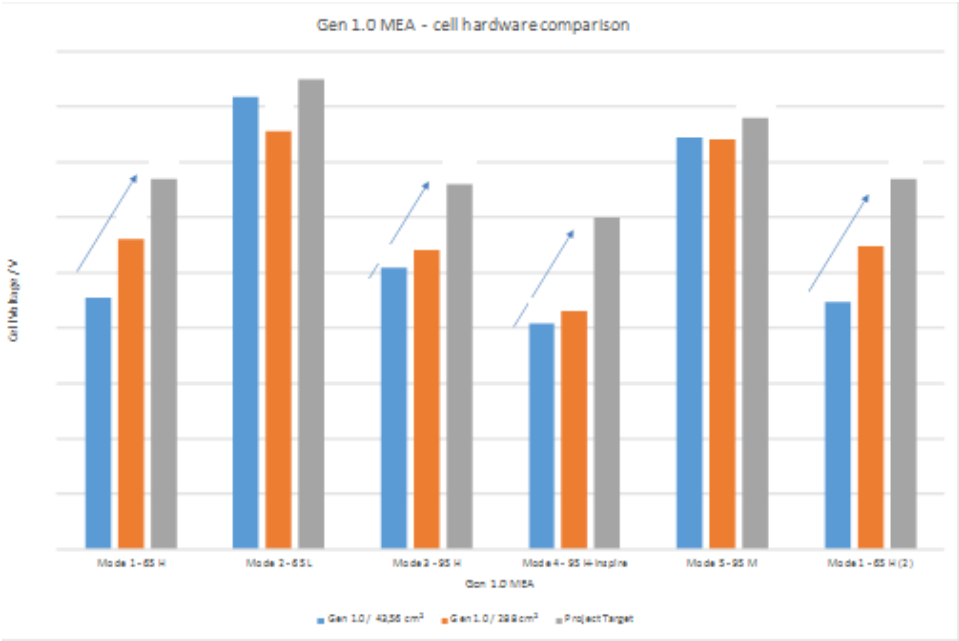

Figure 9: Cell voltage of GEN 1.0 MEA in 43.56 cm² and 288 cm² cell configuration.

3.3 Short stack testing with GEN 1.0 MEA - 4-cell stack

In Figure 10 the polarisation curves of the best, the worst and the mean cell voltage of the TP288 4-cell stack are shown for the first polarisation curve. A very unstable behaviour of the individual cells at current densities lower than 1.2 A/cm^2 was observed. The operating points M1 – M5 were not able to run at the stack level due to instability problems.

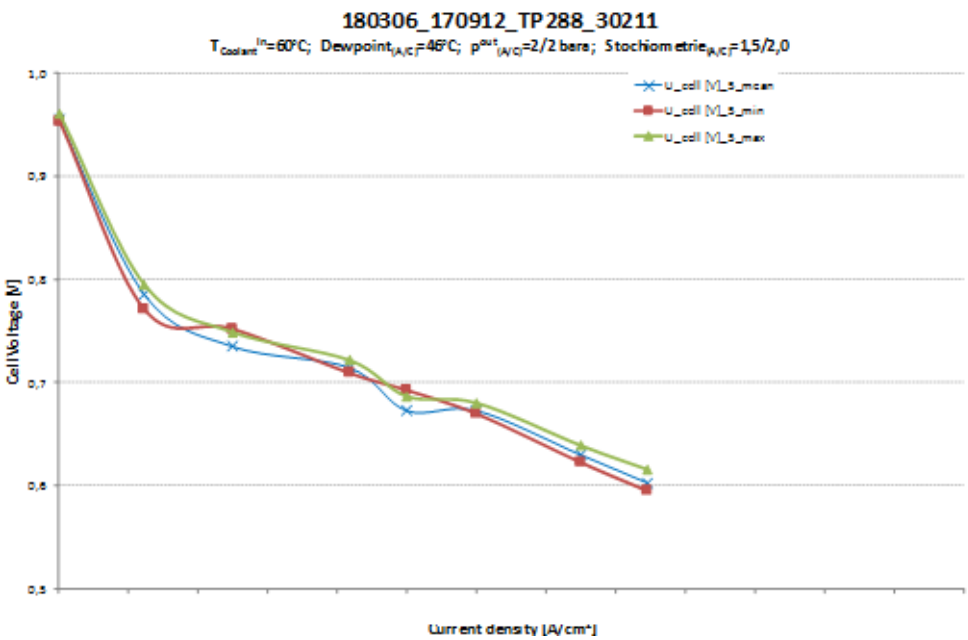

Figure 10: Polarisation curves of GEN 1.0 short stack tested at DANA

The bar charts in Figure 11 show the cell voltage at 1.7 A/cm^2 for the polarisation curves of all four cells. A rapid decrease in cell voltage over testing time can also be seen.

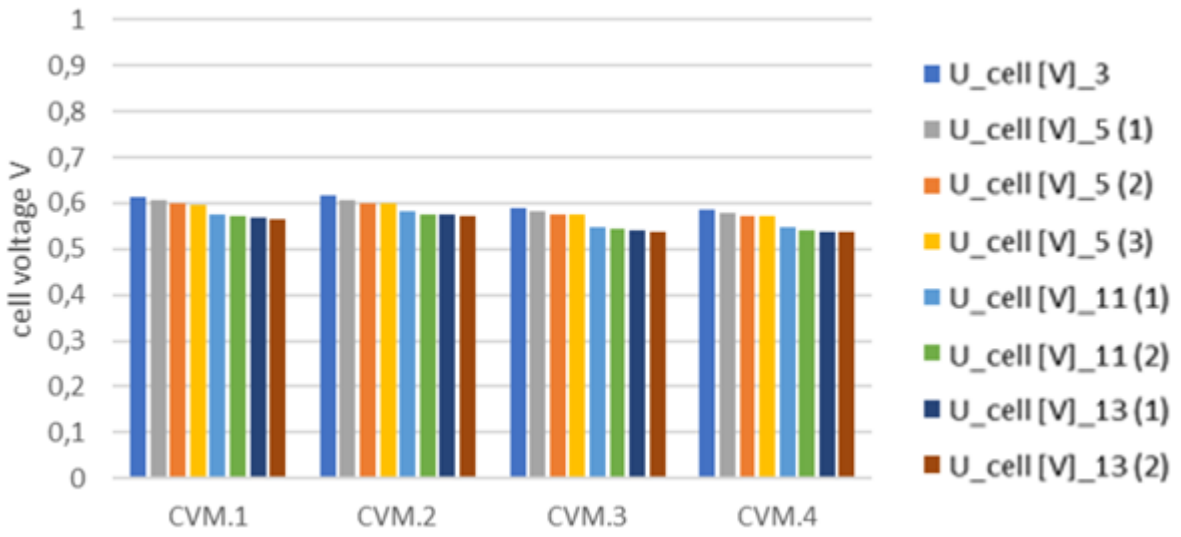

Figure 11: Cell voltages at extracted from the polarisation curves at different positions in the test protocol

After disassembling the stack, a degradation mechanism was observed. In Figure 12 the damage of the cathode electrode layer near the anode outlet region is visible. The SEM picture on the right side shows the crack formation in the electrode layer and in the membrane in this region.

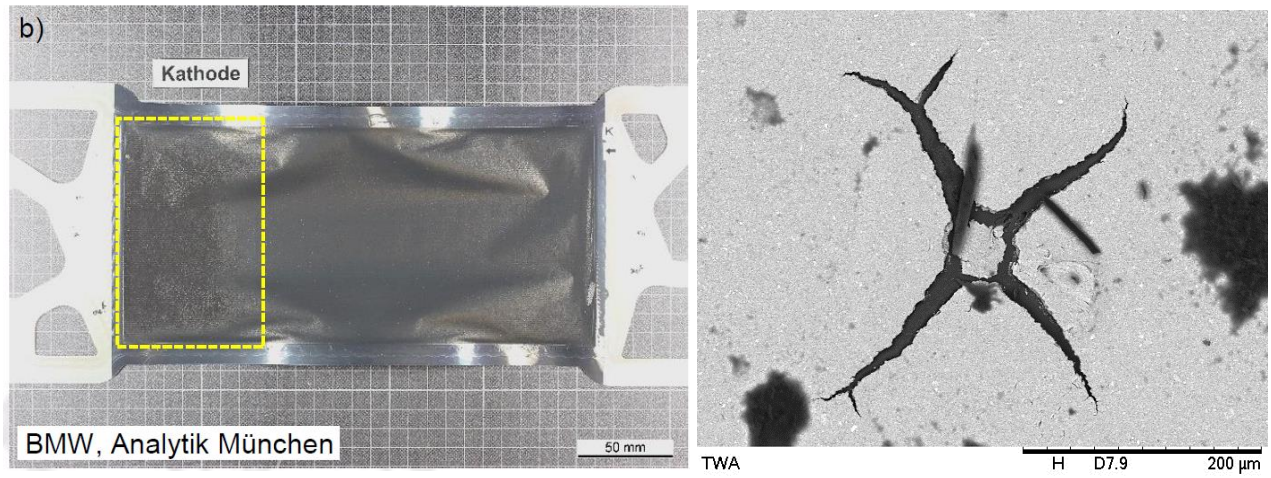

Figure 12: Post-mortem analysis of CCM of GEN 1.0 4-cell short-stack. Damage of cathode catalyst layer near anode outlet region is visible. SEM picture (right) shows cracks in electrode layer and membrane.

3.4 Conclusions from GEN 1.0 MEA testing

In GEN 1.0 MEA testing, numerous experimental difficulties were faced. These challenges have limited the amount of useable testing and have restricted our ability to analyse the data thoroughly and draw clear-cut conclusions.

In GEN 1.0 setups, a rapid voltage degradation over testing time occurred for both small single cell and 4-cell stacks. In the 4-cell stacks this can be explained by a local hydrogen starvation due to flooding in the anode outlet region.

Other causes, such as catalyst poisoning due to contaminants (from test station or cell materials) cannot be excluded. However, in single cell measurements using TP288 hardware, practically no degradation could be observed.

When stable operation was achieved with single cell (TP288 full-size cell) hardware, the results were promising compared to the power density objective of the INSPIRE project.

4. GEN 1.5 MEA TESTING

The test program for GEN 1.5 MEA stack level testing (from Deliverable 2.1) is shown in Table 6. In addition to stack level testing, small and large single cell test results are reported here. In addition to tests applied for GEN 1.0, full-size stack testing is included for GEN 1.5.

Table 6: Testing protocols for GEN 1.5

Test program	Performance and stability P-							Durability D-			
Stack	01	02	03A	03B	03C	04	05	01A	01B	01C	01C
GEN 1.5 – short	x	x	x			x		x	x	x	x
GEN 1.5– full size	x	x	x			x					

4.1 Single cell testing with GEN 1.5 MEA – small cell (43.56 cm²)

JM provided the GEN 1.5 G MEA in 43.56 cm² and 288 cm² format to BMW. The testing was carried out at the BMW Fuel Cell testing facilities in Munich according to the agreed INSPIRE test protocol (compare Figure 1). In these measurements a break-in procedure was not applied.

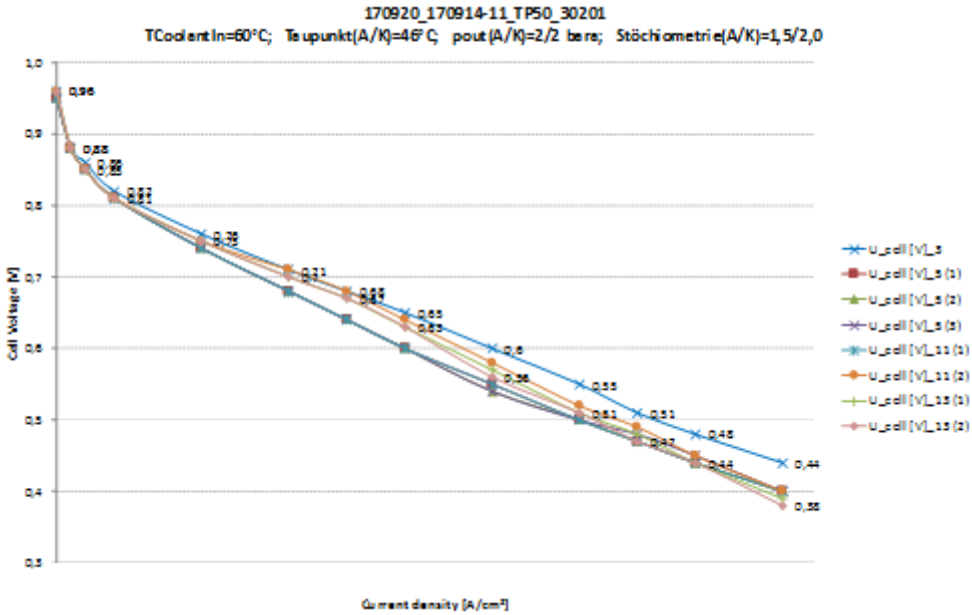

Figure 13: Polarisation curves of GEN 1.5 G MEA in 43.56 cm² test hardware according to INSPIRE test protocol

In Figure 13 the polarisation curves of the GEN 1.5 G MEA in 43.56 cm² test hardware are shown. The trend again shows lower cell voltages with increasing testing time. The polarisation curve U_Cell [V]_3 shows the highest performance of all recorded polarisation curves during the test protocol. Taking into account the limited amount of test time, the degradation rate is very high.

In Figure 14 the cell voltages extracted from the testing protocol of GEN 1.0 and GEN 1.5 G MEAs are shown as bar charts. At the operating points 65-H and 95-M, an increase in cell voltage was observed. The cell voltages at the other operating points showed a lower cell voltage compared to the GEN 1.0 MEA.

The performance decrease over runtime is more pronounced compared to the GEN 1.0 MEA. The cell voltage at the 65-H operating point decreased from 0.466 V at the start of the test to 0.439 V at the end of the test.

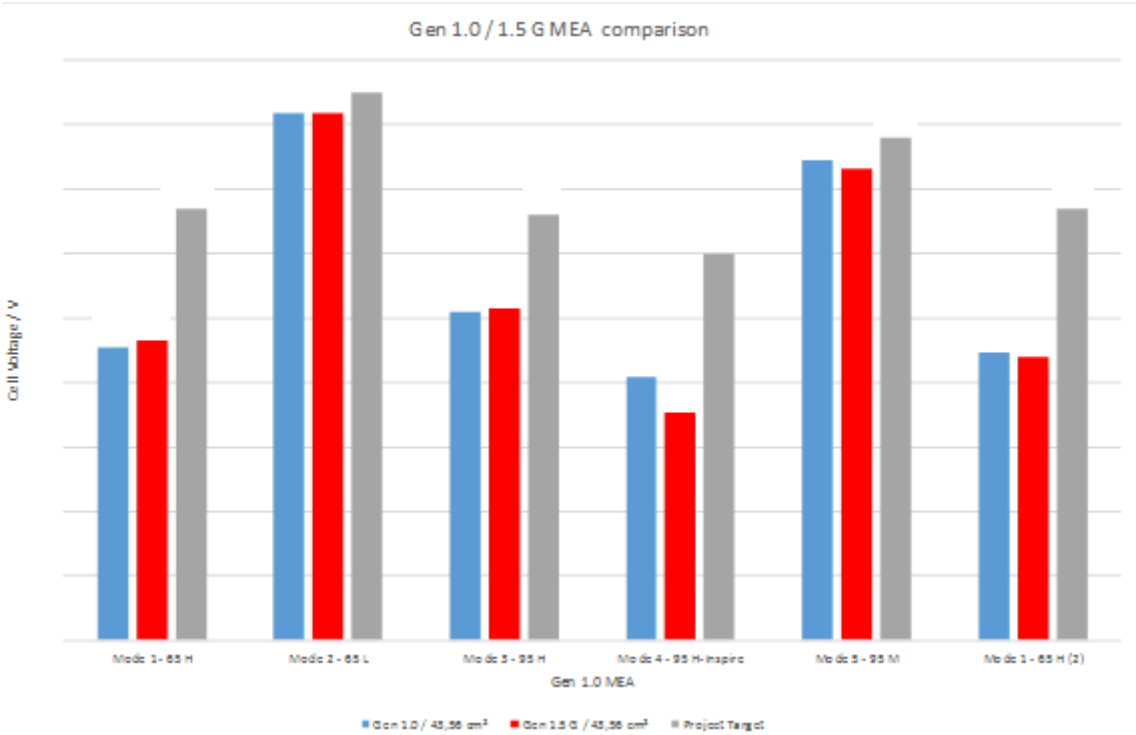

Figure 14: Comparison of GEN 1.0 and GEN 1.5 G MEA in 43.56 cm² cell hardware.

In addition to the cell voltage information, Figure 15 shows the high frequency resistances of the GEN 1.0 and the GEN 1.5 G MEAs.

The GEN 1.5 G MEA showed significantly lower resistances compared to the GEN 1.0 MEAs. The resistance difference, which is also illustrated in Figure 15, confirms the trend, which was observed in the cell voltage representation. Operating Points 65-H, 65-L and 95-M show the highest benefit compared to the other operating points. In particular, operating points at higher temperatures show the lowest benefit. This indicates a first sub-optimal water management of the GEN 1.5 G MEA.

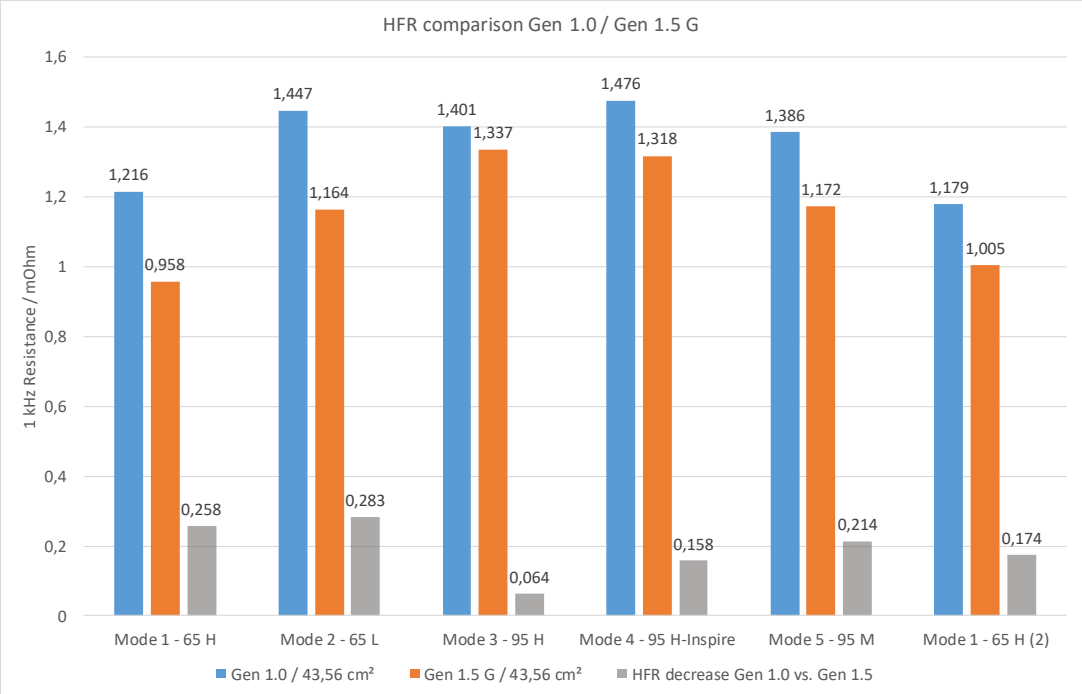

Figure 15: 1 kHz Resistance of GEN 1.5 G and GEN 1.0 MEA

4.2 Single cell testing with GEN 1.5 MEA – large cell (288 cm²)

4.2.1 Overview of results

The test history of the GEN 1.5 G MEA in the TP288 single cell is shown in Figure 16. This can be compared to the test history of the GEN 1.0 G MEA in the TP288 single cell (Figure 6).

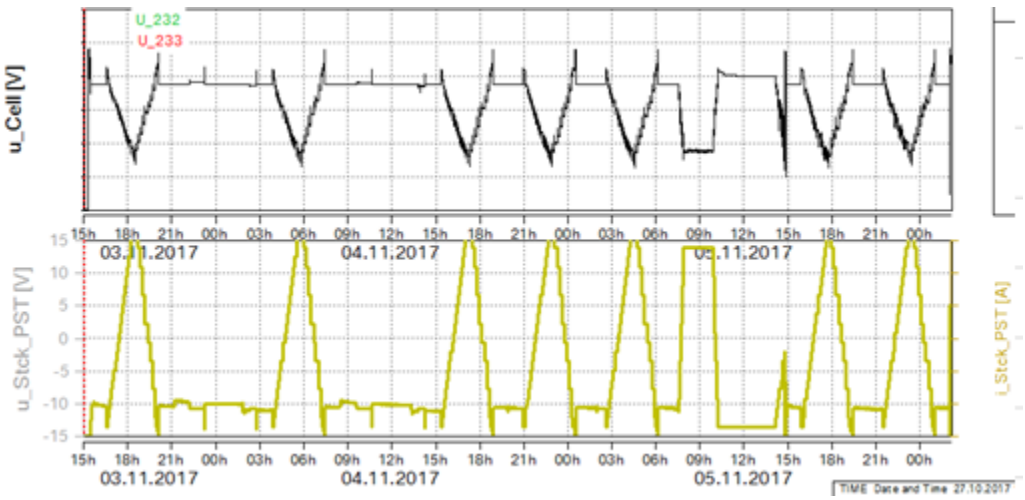

Figure 16: Test history of GEN 1.5 G MEA in TP288 single cell according to INSPIRE test protocol.

During this test, the current density distribution was recorded at the end of each measurement point. The extracted results are shown in the following sections.

4.2.2 Current and temperature distribution measurements

In Figure 17 the cell voltage as well as current density and temperature distributions in the TP288 single cell with the GEN 1.5 G MEA at operating point 65-H are shown. The cell voltage fluctuates between 341 and 362 mV. The cell voltage distribution shows very low current densities near the anode outlet region. This indicates serious channel flooding.

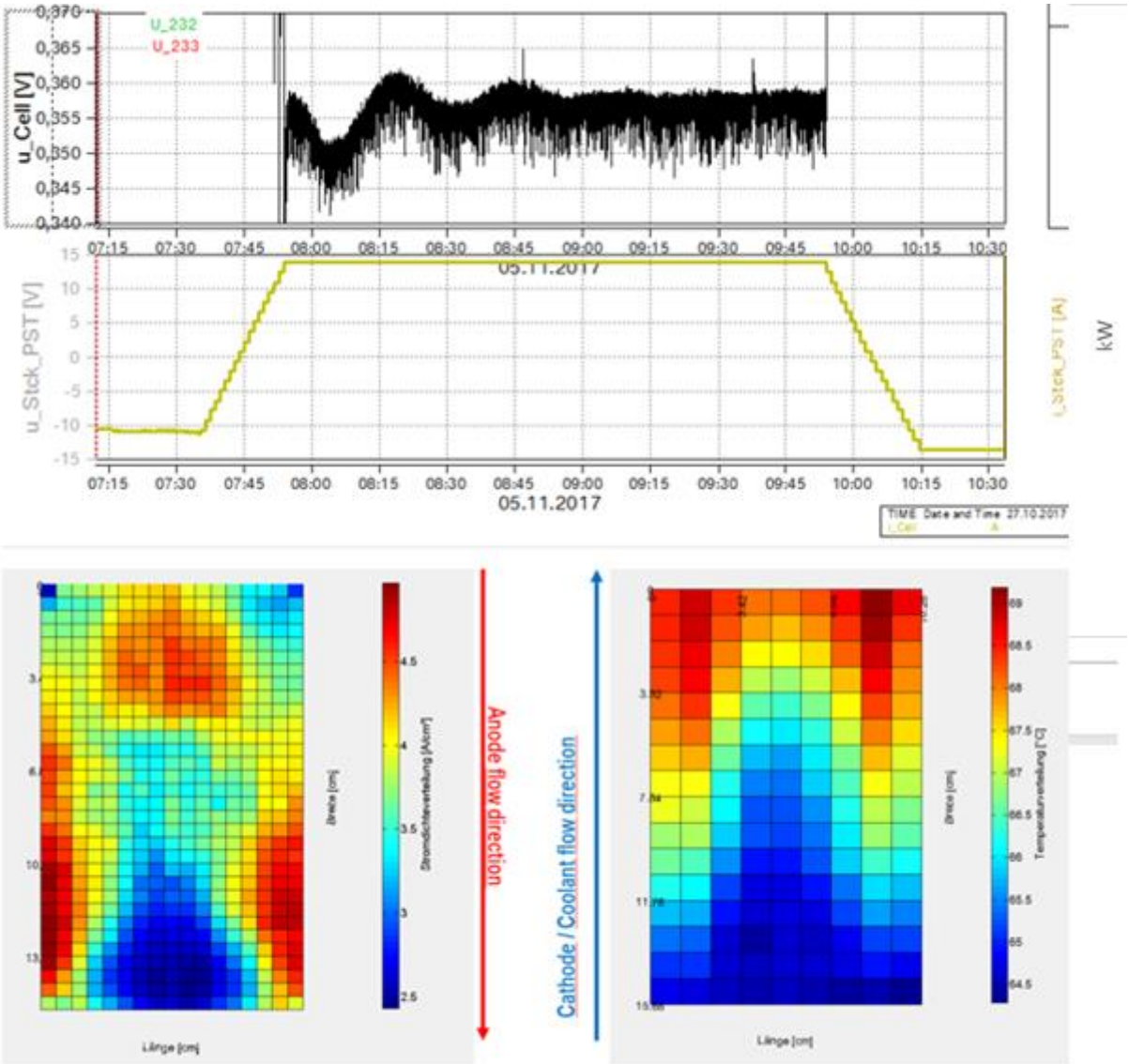

Figure 17: Cell voltage measured at Operating Mode 65-H with corresponding current density and temperature distribution (average current density is 2 A/cm²)

In Figure 18 the influence of a hydrogen stoichiometry increase on the current density distribution at operating point 65-H is shown. An increase of hydrogen stoichiometry from 1.33 to 1.8 led to a cell voltage increase > 100 mV and a much more uniform current density distribution. However, even with highest hydrogen stoichiometry, the highest current density was at the cathode outlet, where oxygen partial pressure should be lowest.

This means that for a higher and more stable cell voltage, the H_2 stoichiometry has to be increased to 1.5 for stable or 1.8 for optimal operation. This also indicates that the water condensation or water flooding issue near the anode outlet region is the dominant cause of the instability.

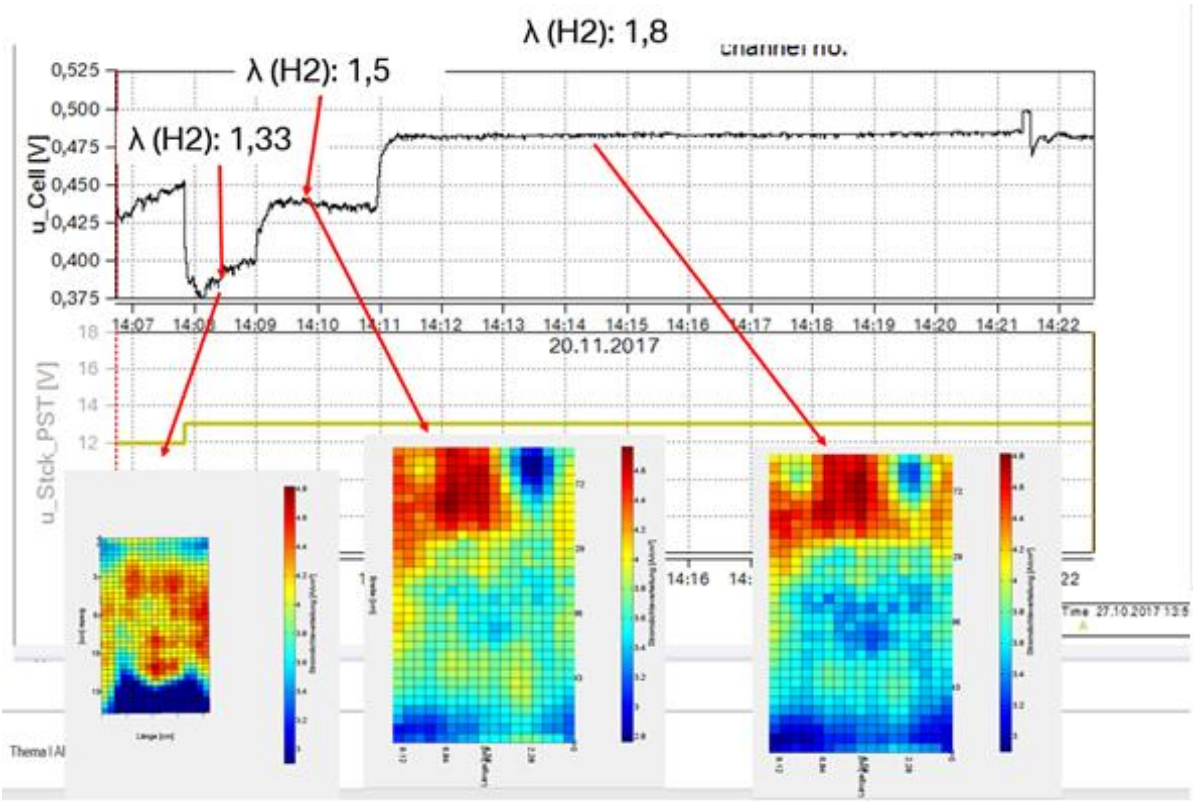

Figure 18: Influence of increase of hydrogen stoichiometry on cell voltage and current density distribution.

In Figure 19 the cell voltage, current density and temperature distribution at operating point 65-L (current density ca. 0.1 A/cm^2) are shown. Here the highest current density is again recorded at the anode inlet regions and the relative current density is much more uneven (ratio 3.8 vs. ratio 2) compared to operating point 65-H. The cell voltage shows lowering of cell voltage during 4 hours of operation. All these results indicate serious flooding of anode channels.

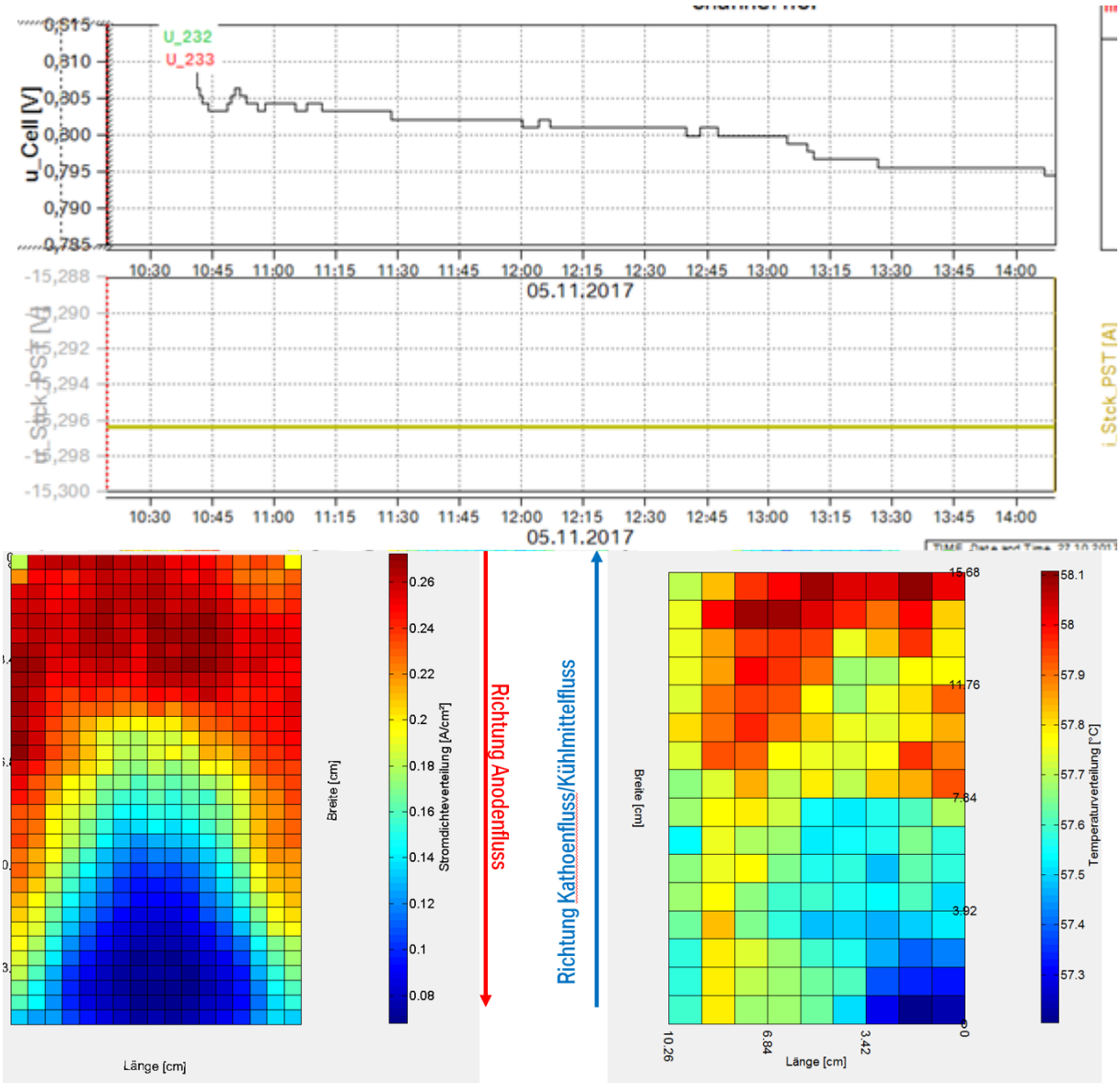

Figure 19: Cell voltage, current density and temperature distribution at operating point 65-L.

4.3 Short stack testing with GEN 1.5 MEA – 10-cell stack

For testing short stacks, the test protocol developed in D2.1 was used. A 10-cell short-stack in TP288 cell hardware with GEN 1.5 MEAs was built and first tests were carried out at the BMW fuel cell testing facilities. As mentioned in Section 3.2, measurements with the 10-cell GEN 1.0 stack were not successful at all and a current density of less than 1.2 A/cm^2 was achieved. For the 10-cell short-stack (GEN 1.5), polarisation curves up to 2 A/cm^2 could be recorded.

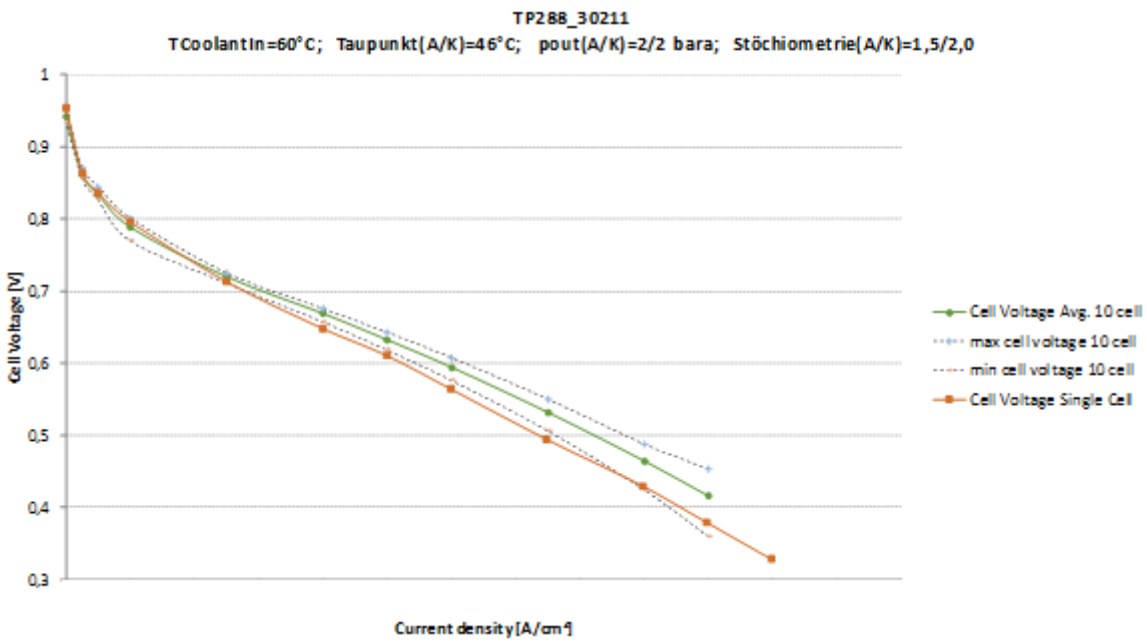

Figure 20: Comparison of 10-cell short-stack polarisation curves with single cell

In Figure 20 the first polarisation curve of the 10-cell short stack is shown. The comparison of the polarisation curve with the large single cell shows good agreement with each other. The single cell data is just outside of the cell-to-cell deviation of the short stack.

4.4 Stack testing with GEN 1.5 MEA – full size stack

Since short stack (4-10 cells) measurements can result in additional difficulties due to the low number of cells, the real performance of the stack can only be verified by full scale testing.

The GEN 1.5 G full-size stack, consisting of 394 cells, was tested according to the STACK-TEST net protocols.

The best performance that was measured with the full stack is shown in Figure 21. A peak power of 150 kW was achieved at 63 °C outlet temperature but at slightly higher stoichiometry than was originally defined. The cell-to-cell voltage variation was too high under these conditions. At reasonable stoichiometry of anode/cathode equal to 1.5/1.7 and an outlet temperature of 80 °C, the INSPIRE interim power density target of 1.2 W/cm² was accomplished. This is indicated as the two green operating points within the graph. In this case, as well, the low performing cells limited the overall output. A reference curve at 65 °C is also included in this graph as an overview.

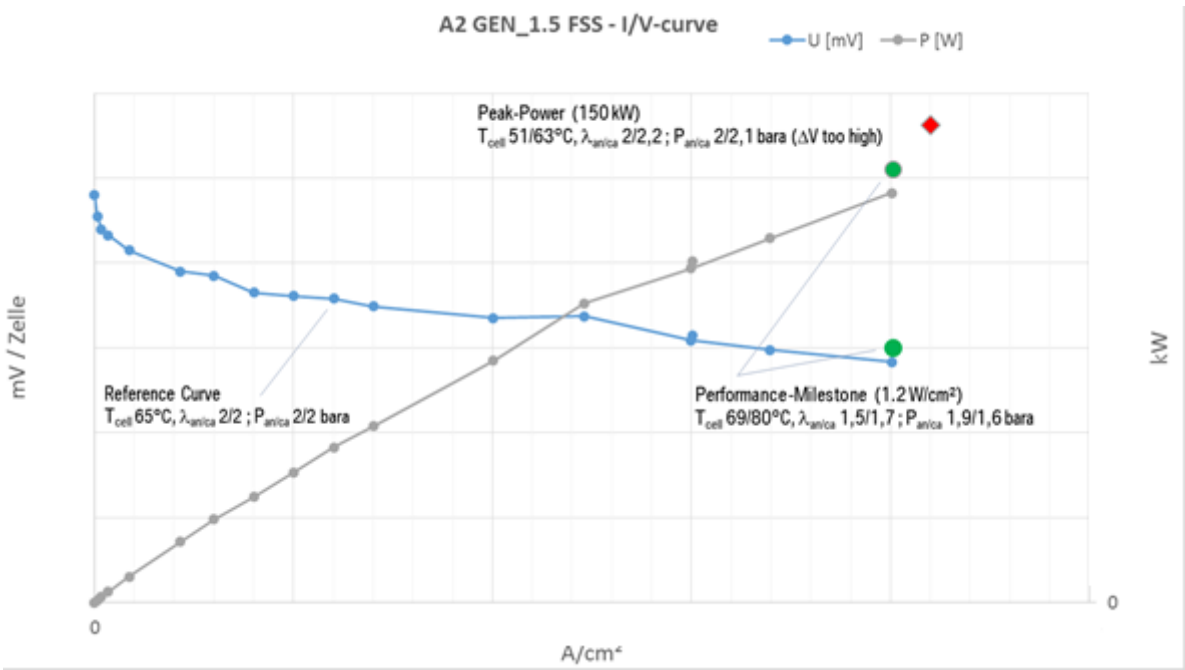

Figure 21: Polarisation curve of the GEN 1.5 - 394-cell full stack at different operating conditions

After disassembling the stack, the low performing cells were analysed in order to find the root cause for the high voltage spread. During this analysis, several defects were found within the MEAs, which explained the unexpected behaviour. The stack was then stripped down to 383 cells and rebuilt for further testing, in anticipation of a much more homogeneous voltage distribution. The tests have not started at the time of submission of this report.

The sensitivity tests defined in D2.2 were performed and completed, wherever the lowest cell voltage was not limiting the operation. The results are summarised in the appendix of Deliverable 6.3.

4.5 Conclusions from GEN 1.5 MEA testing

The results from GEN 1.5 MEA testing are not sufficient to draw firm conclusions. Problems leading to uneven flow distribution and unstable conditions made it impossible to evaluate the performance accurately. On the other hand, the performance at full stack level was very promising, as the best cells exceeded the INSPIRE Milestone 2 targets.

5. Comparison Between GEN 1.0 and GEN 1.5 MEA Results

The most relevant data for comparison between GEN 1.0 and GEN 1.5 MEA results would be at the stack level with large cell size. However, as stack level measurements were largely unsuccessful, the comparison at the large cell level could be carried out only at single cell level.

In Figure 22 the performance extracted from the test protocol of the GEN 1.0 and GEN 1.5G MEA is shown. Only operating points 65-H and 65-L were possible to run with cell voltages > 300 mV.

The limited amount of data does not allow firm conclusions. However, this type of comparison with different cell hardware will be more useful for GEN 2 and GEN 3 single cells and stacks.

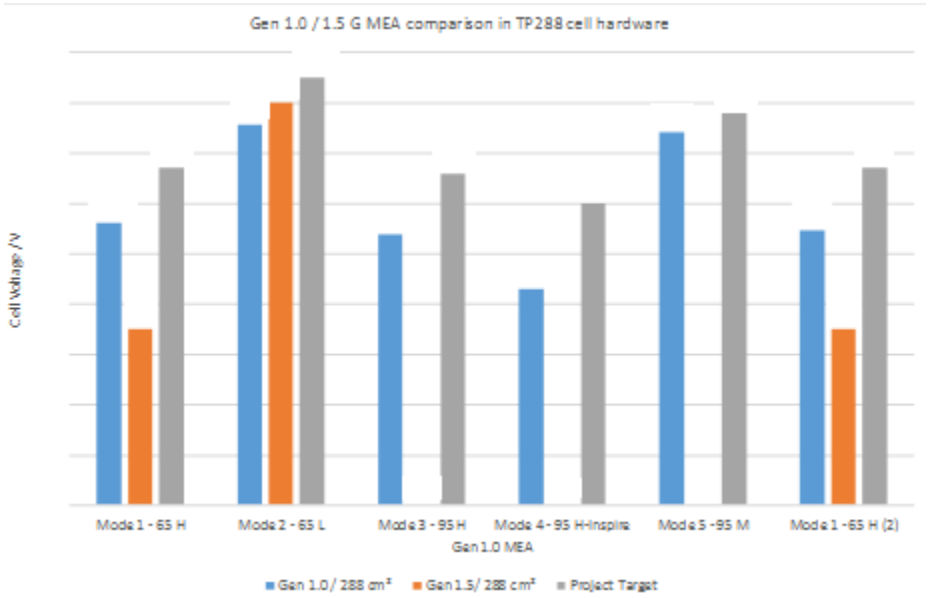

Figure 22: Comparison of GEN 1.5 G MEA performance with GEN 1.0 MEA in TP288 single cell

6. DURABILITY TESTING

As discussed in the Summary, the durability testing work has been limited, as the stack behaviour at some of the operating points was unstable leading to very high degradation rates, which was due to anode channel flooding and following hydrogen starvation. A test protocol for durability testing was developed and tested with the GEN 1.5 single cell. This protocol and the corresponding current densities and temperatures are presented in Figure 23.

During this testing, current distribution measurements and EIS measurements were performed. The development of current distribution is shown in Figure 24 and EIS Measurement in a Nyquist plot representation is shown in Figure 25.

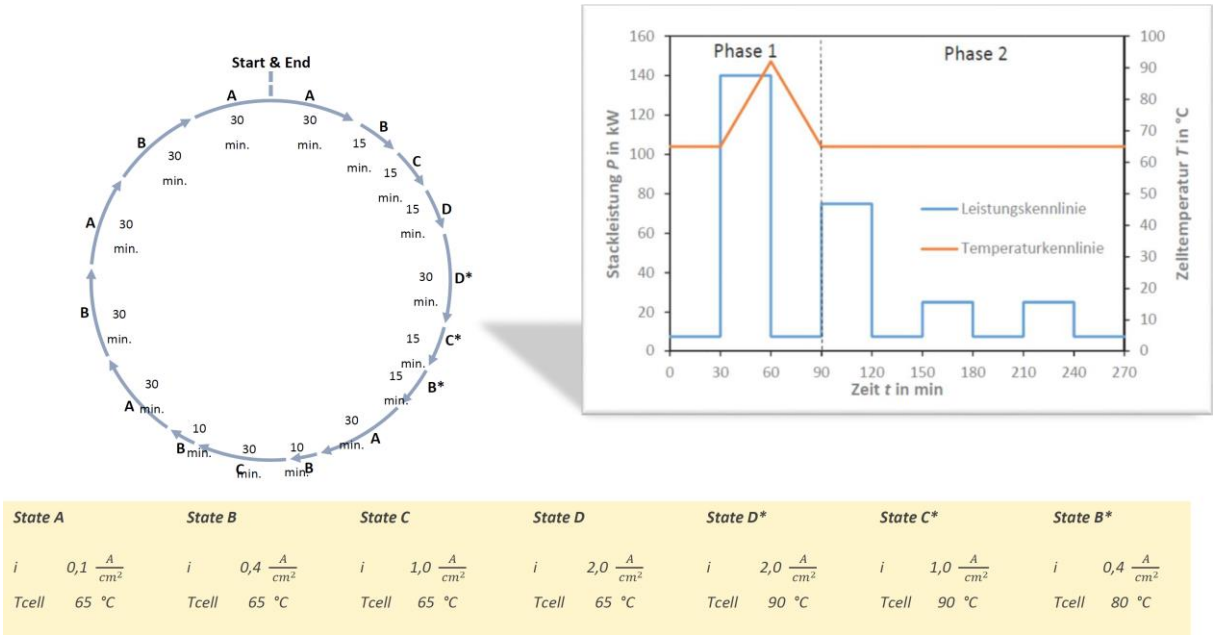

Figure 23: Durability test protocol.

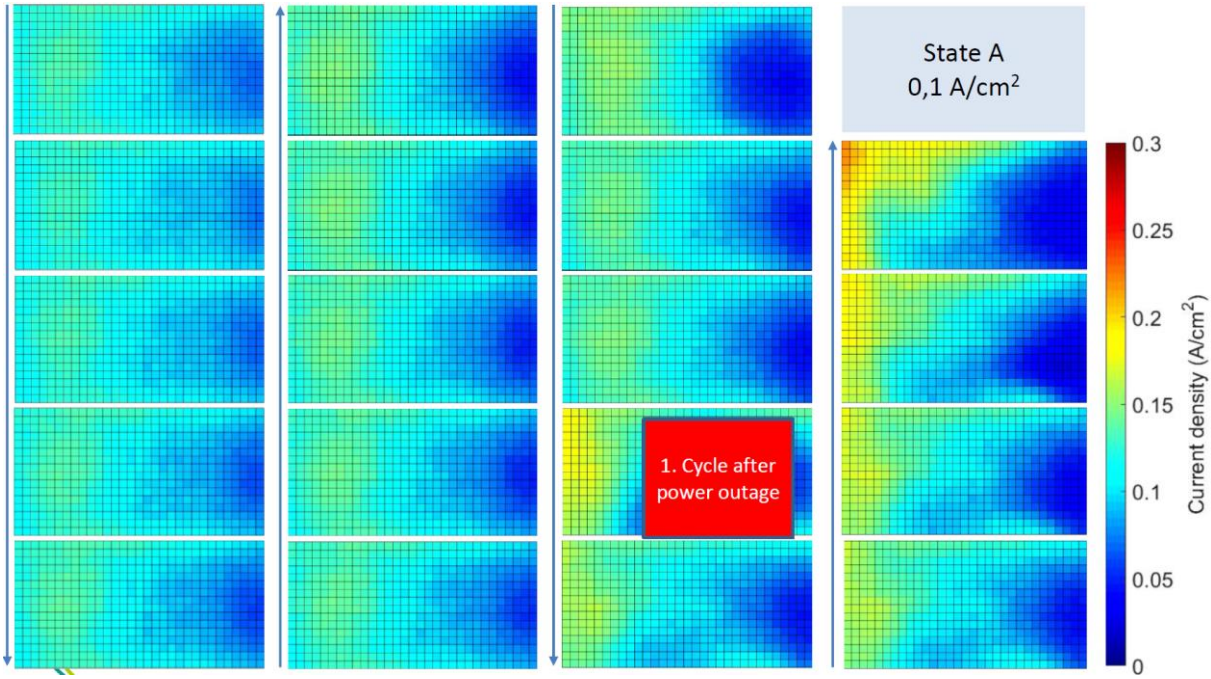

Figure 24: Current distribution measurements for the durability testing protocol development.

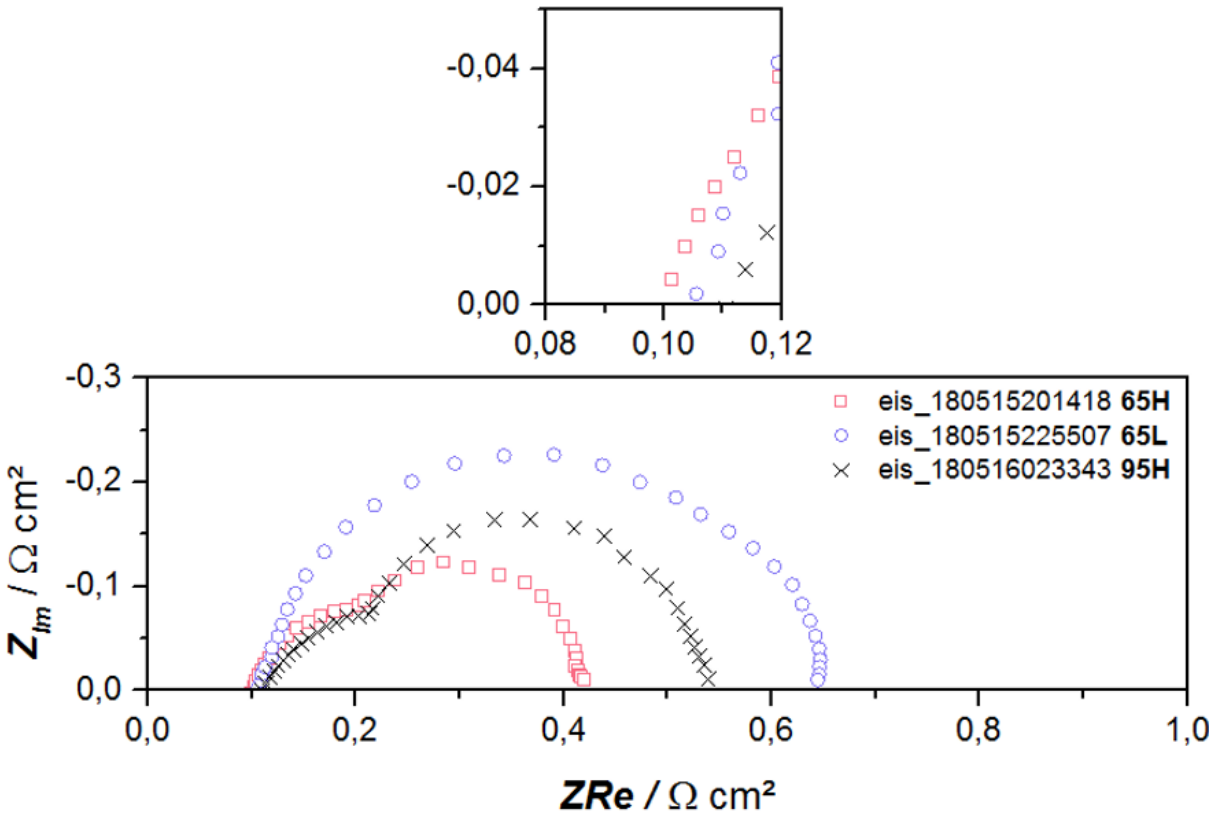

Figure 25: EIS Measurement in Nyquist plot representation at operating points 65H, 65L and 95H recorded before degradation testing was started for GEN 1.5 MEA with improved subgasket. Insert shows high-frequency intercept of imaginary part with x-axis.

7. Conclusions and Recommendations for Further Testing

The conclusions from the stack generations GEN 1 and GEN 1.5 measurements can be summarised as follows:

Performance is not the main issue. The full-size stack performance data show that project targets are achievable and the INSPIRE interim power density target of 1.2 W/cm² was accomplished. The real performance after full activation is stable.

The main problem is poor stability due to anode side flooding. Several reasons for this were identified and lessons learned will be taken into account when designing the next stack generations GEN 2 and GEN 3 and planning experimental research for them.