PROJECT FINAL PUBLIC REPORT

Grant agreement number: 303466

Project acronym: **IMMEDIATE**

Project title: Innovative autoMotive MEa Development – implementation of Iphe-genie Achievements Targeted at Excellence

Funding Scheme: European Commission – 7th Framework Programme – Fuel Cell and Hydrogen Joint Undertaking – Collaborative Project – FCH-JU-2011-1 – SP1-JTI-FCH.2011.1.5 Next generation European MEAs for transportation applications

Date of latest version of Annex I against which the assessment will be made:
3 August 2015

Project period: **from** 01.01.2013 **to** 31.03.2016

Name of the organisation coordinating the project: IRD Fuel Cells A/S, Denmark

Tel.: +45 63633000

Public project website: www.immediate.ird.dk

Contents

Final publishable summary report

I. EXECUTIVE SUMMARY

IMMEDIATE aimed at developed a medium temperature proton exchange membrane fuel cell membrane electrode assembly for operation at up to 95 °C, with a Pt loading of 0.15 g Pt/kW, and using new materials developed during the project. In WP2, the specification and evaluation activities were focused on two areas: defining performance and durability for the MEAs in the case of city-bus use, and estimation of the cost of an alternative powertrain based on the cost of the MEA. The IMMEDIATE MEA shows excellent durability characteristics, since it degrades <10 % during 500 h of testing in aggressive bus-cycle tests. The cost estimate shows good improvement, with the cost share of the MEA decreasing significantly. Considerable reductions in the estimated total powertrain costs are expected, since the system parts contribute very heavily to the total costs. In WP3, new carbon support materials with intermediate surface area and optimised pore structure were designed and thoroughly characterised. Two catalyst preparation procedures were developed and optimised for the preparation of high-loading platinum catalysts, which were characterised for their Pt loading, Pt size and morphology. The catalysts were further evaluated for their electrochemical surface area, activity and stability. The most promising catalysts were up-scaled and transferred to WP6 for the preparation of MEAs. In WP4, a low equivalent weight short side chain ionomer was developed and short and long side chain cross-linkable ionomers were prepared. Preparation conditions suitable for a modulated degree of ionomer cross-linking were developed. An increased molecular weight short side chain ionomer was prepared and thin reinforced membranes prepared from it and provided to WP6. An effective means for stabilisation of membrane chemical properties was developed by laminating an electrospun ionomer nanofibre web comprising nanometric radical scavenger particles to give a composite membrane with an anode/cathode oriented protective layer. WP5 aimed at the understanding and improvement of gas-diffusion layers (GDLs) for MEAs with low precious metal content for operation under rather dry conditions with high electric efficiency. The activities focused on the improvement of electronic conductivity as well as on a suitable balancing of the gas diffusivity and water retention capabilities of the GDL. Substantial improvements with respect to dry performance and corrosion stability of the GDL were demonstrated with GDLs containing novel microporous layers consisting of graphite–carbon-nanotube blends. In WP6, initial MEA development was focused on the collection and assembling of state of the art component membrane, catalyst and gas diffusion layer materials to ink preparation processes and MEA preparation procedures. These materials were also used for initial ink and electrode optimisation. In the second period a significant amount of materials developed in WP3, WP4 and WP5 were all used for MEA integration and MEA development as they became available during the project period. Design of the electrode structure was done in an iterative way aiming at the manufacturing of the advanced electrodes with (ultra)thin catalytic layers. The optimisation work was guided by characterization of MEAs performed in WP7, where the testing comprised determination of IV performance, accelerated stress testing and diagnostic measurements. The durability of two embodiments of the low PGM loading 2G MEAs, identical apart from the nature of the cathode catalyst, was investigated in duty cycle test and EU harmonised test protocols for endurance testing. IMMEDIATE has achieved a significant reduction in Pt and, more generally, PGM loading with new set of materials and MEA processing developed during the course of the project, culminating in Pt loading of 0.27 g Pt/kW at 0.68 V (0.2 g/kW at maximum power density), for a MEAs of total loading 0.2 mg Pt/cm^2. One indicator of IMMEDIATE success is that the performance at rated power is identical to the DoE 2015 status reported in the DoE MultiYear Research, Development and Demonstration Plan 2016 and, even more encouragingly, the performance 0.8 V exceeds the DoE 2015 status, and in fact achieves the DoE 2020 target for this metric, under EU harmonised protocol conditions.

II. PROJECT CONTEXT AND OBJECTIVES

Overall project objective

The overall objective of the IMMEDIATE project is to develop a medium temperature PEM MEA °C that will fulfil the OEM requirements with respect to cost, performance and durability and and at the same time is a significant step towards the ultimate goal which is to have a PEM FC able to operate at >100 °C at minimal RH, Pt-loadings <0.15 g/kW at >55% efficiency and >5,000 h lifetime at dynamic operation. IMMEDIATE will do this by developing catalysts for PEM fuel cells to further reduce the use of platinum in the MEAs and increase catalyst performance and electrochemical stability, developing novel materials for gas diffusion layers (GDLs), optimising composition and morphology of both the micro-porous layer (MPL) and the electrodes, and developing new ionomers with high proton conductivity and high thermal and dimensional stability, all in combination with high-quality manufacturing methods and adequate testing of the MEAs.

The prime focus of the IMMEDIATE project was to the develop high-performing membrane–electrodes (MEAs) through materials R&D and process optimisation.

The technical targets for IMMEDIATE are as follows:

- Development of a durable membrane with
  - Proton conductivity of at least 0.1 S/cm at 120°C and <25% RH
  - Proton conductivity >10 mS/cm at -0°C
  - Thermal stability up to 160°C
  - Low dimensional changes (<10%, <25% RH/>99% RH, 10 000 cycles)
- Development of a GDL with
  - Through plane conductivity >2 S/cm at nominal operating conditions
  - In plane conductivity >100 S/cm at nominal operating conditions
- Development of MEAs with the following targets
  - Platinum loading of <0.15 g Pt/kW
  - BOL performance of >1.0 W/cm^2 @ U_{Cell}=0.68 V, nominal operating conditions
  - EOL performance of >0.9 W/cm^2 @ U_{Cell}=0.68 V, nominal operating conditions
  - The produced MEAs will be subject to automotive accelerated stress test (AST) protocols to ensure that the EOL performance is probable after 5,000 hours of operation
  - Operation temperature range -25°C to 130°C, nominal 120°C
  - Production method that can be scaled to produce MEA's with >300 cm^2 active surface area

The achievement of the overall targets for the MEA requires comprehensive component integration and MEA testing. The reduction of the MEA cost is largely related to the catalyst loading, whereas the performance, stability, and durability of the MEA is dependent on all the involved components and the interplay between them, which again depends on the applied MEA processing technology.

The approach on the IMMEDIATE project was based on improvement and incorporation of commercially available pre-cursers and during the project incoporate the new innovative materials for which the proof of concept has already been given. The aim is to significantly increase existing automotive performance and durability by developing:

- Novel catalyst support materials with tailored surfaces and pore structure will be developed, tuned to optimise both the Pt utilisation and the mass transport of the reactants and products

- Innovative low equivalent weight cross-linking PFSA ionomers and catalysts that survive the high temperature and low RH by improvement of the oxidation durability and the proton conductivity
- Innovative (cross-linked) low-equivalent weight ionomer will be used for the fabrication of the membrane ensuring an enhanced proton transport and improved oxidation stability
- In order to further improve proton conduction in the catalytic layer under the conditions of quasi-dry operation at elevated temperature routes to modify the ionomer with inorganic particles such as zirconium phosphate or silica will be explored
- GDL materials and MPL will be further optimised for improved water and gas management

The mutual compatibility of materials and their durability shall be verified by assembling high performance MEAs for benchmarking purposes and for testing, in which use will be made of commonly accepted automotive test cycles (including start-stop and freeze/thaw cycles) to prove their potential.

Specific WP objectives

WP1: Coordination and Management

The main objective in coordination and management for the project is:

- Financial management
- Communication and interface between the FCH-JU officers, the project and its partners
- Coordinate the scientific and technical activities of the project
- Establish communication tools and interactions between the partners
- Coordinate and finalise deliverable and milestone reports, technical progress reports and financial reports

WP2: Specification and evaluation

The specific objective of WP2 on the 0M-18M period was to specify MEA test protocols with the operational window to be applied in WP7 and the delivery test protocol defining the real-life load on/off cycles of the final fuel cell system.

WP3: Catalyst

The overall objectives of WP3 (as described in the DOW) are as follows:

- Develop durable carbon supports with tailored mesopores in the range of 10-50 nm
- Develop non-carbon oxide, carbide and nitride supports for Pt catalysts
- Precipitate high load platinum catalyst on the developed supports

WP4: Membrane and ionomer

The overall WP objective is to develop a new, durable ionomer and membrane, including a composite membrane system comprising radical scavengers, based on low equivalent weight cross-linkable PFSA-polymers that possess high proton conductivity (>100 mS/cm @ 120°C & 25% RH), high thermal stability (up to 160°C), and high dimensional stability (<10% change upon wetting/drying) enabling automobile fuel cell operation in a wide temperature range (–25°C to 95°C) and in a low humidity (<25% RH) environment.

WP5: GDL

WP5 aims at identifying the specific material properties, which are required for the gas diffusion layers (GDL) under the rather unusual operating conditions given within IMMEDIATE. In particular, this work package is dedicated to the development of a novel gas diffusion layer grade, which effectively prevents dehydration of the proton exchange membrane at elevated temperatures. In order to attain the desired power density at the desired electric efficiency (55%), additional improvement of the thermal and electrical conductivity will become necessary.

WP6: MEA

The overall objective of WP6 is to fabricate durable high yielding MEAs with low catalyst loading ($\leq$0.15mg Pt/cm^2). The final key-target for the IMMEDIATE project is a MEA capable of dynamic operation starting at temperatures down to -25°C yielding 1.0 W/cm^2 @ @ η_{el} $\geq$55% at the nominal operational conditions (T=95°C, RH $\leq$25% & P $\leq$1.5 bar(abs).

The goal defined for the 1XG MEA is a performance >0.5 W/cm^2 @ η_{el} >55%, Temperature ≥80°C, RH ≤ 50%/30% & P≤ 2.3/2.5 Bar and < 0.3 mg Pt/cm2

The goal defined for the 2G MEA is a performance > 1.0 W/cm^2 @ η_{el} >55%, Temperature ≥95°C, RH ≤25% and P ≤1.5 Bar$_{abs}$ and <0.15 mg Pt/cm^2 but with special focus at the EU harmonized protocol as a standard for the FC community agreed upon (**T ≥ 80 °C, RH ≤ 50%/30% & P≤ 2.3/2.5 Bar and < 0.15 mg Pt/cm2**

.

WP7: Test

The objective is to assess the performance and durability of the MEAs developed in IMMEDIATE, on the basis of MEA single cell tests and in the second period of the project in short stack tests.

WP8: Dissemination

To ensure that the results and developments of the project are disseminated. The dissemination will be done by presenting the project results through a dedicated website, in workshops, conferences and publications in scientific journals and the general press. The specific objective for RP1 was to release the project web site, and to initiate the presentation of non-confidential results at international conferences.

III. SCIENTIFIC RESULTS/FOREGROUNDS

WP1: Coordination and management

Partners: IRD, ICPF, CNRS, FUMA, SJTU, Volvo, SGL, JRC, TC. **Duration:** M1–M39

The activity of WP1-Project management was essentially aimed at providing efficient project coordination and management to support the partners in their achievement of the project objectives, to interface with the FCH JU Programme Office, and to provide tools for communication between partners inside the consortium. The coordination activity has been specifically addressed to ensure that each of the technical work packages started effectively and in a timely manner, so as to avoid any delays with respect to the project schedule.

Significant efforts were addressed to allow completion and submission of all deliverables due by the end of the project as well as to the achievements of the general objectives of the project and the specific milestones.

Steering committee and technical progress meetings have been attended by the partners, with active participation and discussion especially in relation to protocols, methods, activities, results, achievements, work planning and dissemination of project results.

Following the advice of the project reviewers given to the project partners at the mid-term review meeting and the corresponding report, the overall target with respect to fuel cell operating temperature was reduced from 120 °C to 95 °C, so as to improve alignment with near and mid-term targets of the automotive industry for fuel cell transport applications. Indeed, an operation temperature of 120 °C, still desired for reasons of system thermal management, is currently a long term target of the industry. Some experimental activities in particular those seeking to achieve very high membrane conductivity at 120 °C and low relative humidity were therefore re-directed to realizing that objective at 95 °C.

Furthermore, additional effort that had not originally been planned was engagement of the project coordinator in the working group on "**EU HARMONISED TEST PROTOCOLS FOR PEMFC-MEA TESTING IN SINGLE CELL CONFIGURATION FOR AUTOMOTIVE APPLICATIONS".** The EU harmonised testing protocols were implemented in the IMMEDIATE project as a the result of a collaborative effort between industry partners and research organisations participating in several Fuel Cell and Hydrogen Joint Undertaking funded projects in automotive applications. These harmonized protocols were used in IMMEDIATE to validate the MEAs resulting from the project efforts in WP3-WP6, in addition to those targeting the IMMEDIATE operating temperature of 95 °C.

CONCLUSION

The collaboration within the IMMEDIATE consortium has worked very fine, resulting in very good project progress and a frequent exchange of knowledge, materials and samples between partners. A strong dedication to the work performed in the IMMEDIATE project is felt, which has resulted in many fruitful scientific discussions in particular at the technical meetings and in the in-between frequent communication between the partners by phone and E-mail.

WP2: Specification and evaluation

Partners: IRD, ICPF, CNRS, FUMA, SJTU, Volvo, SGL, JRC, TC. **Duration:** M1–M39

SUMMARY

The specification and evaluation activities were focused on two areas: Defining performance and durability required for the MEAs in the case of city-bus use, and estimation of the cost of an alternative powertrain based on the change of the cost of the MEA. The IMMEDIATE MEA shows good durability characteristics, meaning that it degrades less than 10 % during 500 hours of testing in aggressive bus-cycle tests. The cost estimate shows good improvement, with the cost share of the MEA decreasing significantly. Considerable reductions in the estimated total powertrain costs are expected, since the system parts other than the fuel cell have not been analysed in detail and are presently contributing very heavily to the total costs.

WP2 consisted of two tasks, where in Task 2.1 the operational window for the fuel cell was defined via a set of test protocols, whereas economic evaluation of the developed MEA in the fuel-cell powertrain was done in Task 2.2.

The objective of Task 2.1 was to specify test protocols mimicking the real-life, load-on/off cycles of the final fuel-cell system. This goal was achieved thanks to the joint effort between Volvo's knowledge on vehicular applications and the expertise of all partners, and a public deliverable report with test protocols, D2.1 *Report on OEM designed MEA test protocols*, was produced.

From an OEM perspective, delivering a test protocol is similar to delivering a list of requirements for the concerned components. To this end, in order to get a good visualisation of how the system could or should be used in the vehicle, it was necessary to build a vehicle model. As agreed among the partners, the focus was put on a fuel-cell-propelled city bus, which is an application where Volvo, as an OEM, sees the most potential. Based on a full-electric city-bus model, the fuel-cell-propelled city-bus model integrates in addition a fuel-cell-system model able to feed the traction electrical network with power according to the specified control law. Then several possibilities can be considered. The powertrain can use either a large battery and a small fuel cell which delivers nearly full power most of the time (range-extender concept), or a very small battery acting as a buffer and a high-power fuel cell as a prime mover to propel the vehicle. For this reason the lifecycle evaluations in this project were implemented on different cycles in order to be representative of both concepts.

Test protocols for high-temperature automotive MEAs and stacks were selected and designed drawing on, as far as possible, existing test protocols previously described in literature and/or regularly and widely used within the research community. The tests include basic performance tests as well as tests for durability aimed particularly at MEA technologies developed for operation at elevated temperatures. Performance tests include parametric studies of the influence of temperature, pressure, air and fuel stoichiometries, humidity and fuel composition. Durability tests include protocols targeting specific known degradation mechanisms of MEAs such as, e.g., membrane (mechanical, chemical) degradation, catalyst degradation, and carbon corrosion mechanisms. In addition, new duty cycles representative of a fuel-cell city-bus application were derived from vehicle simulations. The mission profiles simulated were adapted in order to cope with the test equipment capabilities and integrated into the relevant test procedures in D2.1 with all the details enabling the practical implementation of the tests. Several meetings were organised between all the WP participants in order to share the simulation results and to agree on the tests to include in the protocols, in accordance with each partner's expertise. Representatives of the project also took part in the initiative on harmonisation of test procedures lead by the JRC, and D2.1 was produced in close cooperation and in accordance with this initiative.

The various test protocols define tests to be performed on a single-cell MEA as well as tests that can be performed on a 10-cell short stack. Some tests are defined for both the single-cell MEA and the short stack, these being the standard polarisation curve test and the parametric tests. The tests targeted at durability were aimed at the single-cell MEA, and the fuel-cell city-bus cycles described above were also applied for the testing of MEAs.

The designed city-bus test cycles are shown schematically in figures 2.1 and 2.2 (left graphs in both figures). They proved to be very aggressive compared to the industry standard test cycles. However, the IMMEDIATE MEA endured 500 hours of testing using both cycles as shown in figures 2.1 and 2.2 (right graphs). The voltage loss was lower than 10 % at all the load levels. No other MEAs have been tested with these cycles, making a comparison impossible.

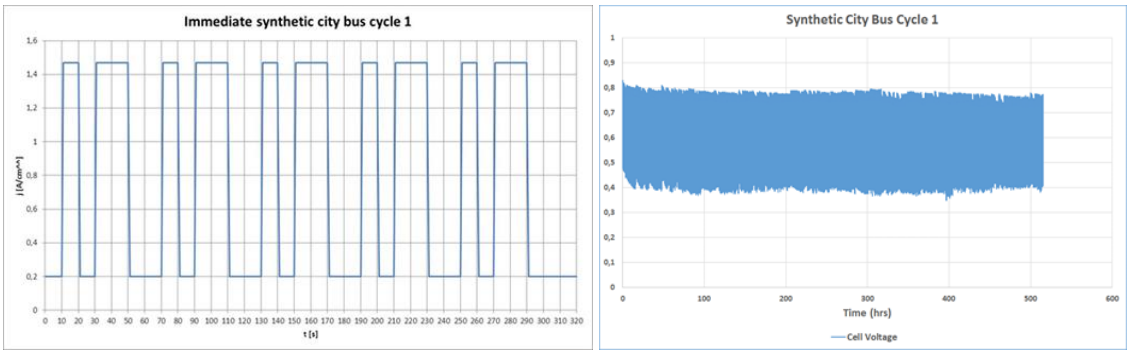


Figure 2.1: Synthetic city bus cycle 1 (left) and testing of an IMMEDIATE MEA during 500 hours (right).

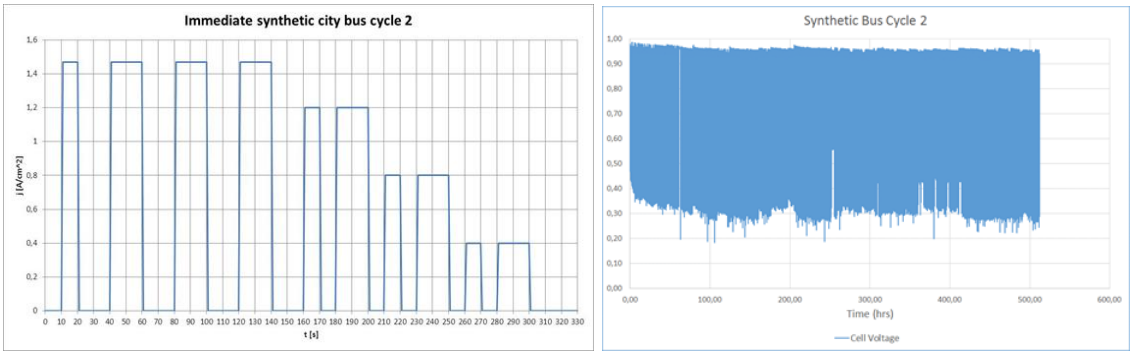


Figure 2.2: Synthetic city bus cycle 2 (left) and testing of an IMMEDIATE MEA during 500 hours (right).

The cost modelling of the system in Task 2.2 was performed using results from WP8 of the cost calculation of the MEA developed in this project as well as complete stack costs from the Auto-Stack CORE project (FCH JU GA n° 325335). In addition to this we used the total cost of ownership model for buses used at Volvo. The MEA has a significant impact on the cost of the fuel-cell system as well as on its performance, and the improvements achieved in this project could benefit the potential fuel-cell customer. The calculation of system costs involves many assumptions, since, e.g., the size of the fuel-cell stack is a choice to be made as mentioned above. This choice will have a significant impact on the cost of the vehicle; however, this choice depends on the electric infrastructure where the vehicle operates. The cost calculation of the whole infrastructure is not included in this project since it would be a study of significant size in itself. Furthermore, there is most likely room for improvement of the cost model with respect to the powertrain system parts other than the fuel cell. These other constituents have not been analysed in detail and are presently contributing very heavily to the total cost.

CONCLUSION

The fuel-cell test cycles designed and used in the IMMEDIATE project, which should be representative of a city-bus driving pattern, proved to be manageable. The degradation during these cycles is moderate for the MEA developed in IMMEDIATE. This is a good indication, but it is difficult to make a comparative assessment since no reference test exists.

The cost and performance improvements obtained for the IMMEDIATE MEA benefit the potential fuel-cell customer. There is, however, a significant level of uncertainty in the estimation of the absolute powertrain costs since there are many decisions still to be made on the complete vehicle system and use before a reasonable cost level can be forecast.

WP3: Catalyst

Partners: IRD, ICPF, CNRS, TC. **Duration:** M1–M30

SUMMARY

In WP3 new carbon support materials with intermediate surface area and optimised pore structure were designed and thoroughly characterised. Two different catalyst preparation procedures were developed and optimised for the preparation of high-loading platinum catalysts (60 wt%). The fabricated catalysts were characterised in order to determine loading, Pt size and morphology. The catalysts were further evaluated electrochemically with focus on electrochemical surface area, activity and stability. The most promising catalysts were up-scaled and transferred to WP6 for the preparation of MEAs for testing in WP7.

The work in WP3 was divided into four tasks and the responsibilities were shared between the WP3 partners.

The work in Task 3.1 consisted of designing improved carbon supports by changes to production processes or by post treatments, and in developing carbon-free platinum (Pt) catalyst supports. In the initial phase of the project three carbon supports with a low, medium and high specific surface area, respectively, were sampled by TC (Imerys) to the partners preparing catalysts (ICPF and CNRS). It was decided that in order to evaluate the influence of the carbon pore structure, surface graphicity and surface functionality on Pt dispersion or corrosion resistance, the specific surface area should be fixed. Initial characterisations and electrochemical characterisation on catalysts prepared with the three carbons led to the decision to focus on carbon supports with intermediate specific surface area. Therefore six (6) carbon supports with the same (intermediate) specific surface area but varying in structure, morphology and surface chemistry were prepared and thoroughly characterised by TC. As the carbon supports were prepared, they were sampled to ICPF and CNRS for Pt deposition.

The work on optimisation of the preparation procedure for catalyst powders with a Pt loading of up to 60 wt% was considered in Task 3.2. Initially a screening of various Pt catalyst preparation routes was performed by ICPF. The targeted high loading (60 wt%) of Pt and Pt particle diameter in the nanometer range could be achieved with all preparation routes. However, aqueous impregnation with H_2PtCl_6 followed by reduction in hydrogen at 190 °C gave the best reproducibility and dispersion and this preparation procedure was therefore selected for the continuing catalyst preparations. Calcination of these catalysts before reduction led to slight decrease of Pt surface area, but also greatly increased the stability towards electrochemical ageing. ICPF further evaluated different dechlorination procedures to decrease the content of potentially problematic hydrolysable chloride in the catalysts to below 100 ppm and the procedure using extraction with NaOH was selected since it gave the catalyst with the best electrochemical performance.

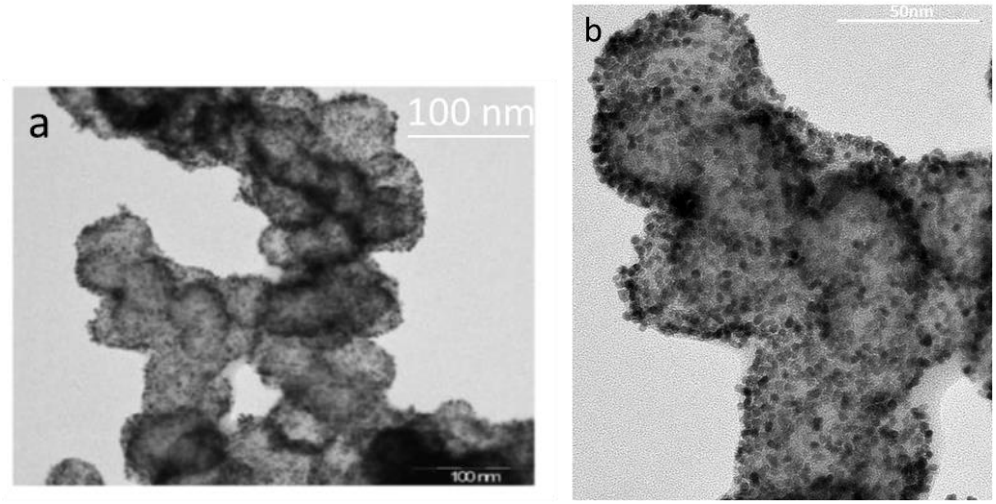


Figure 3.1: TEM micrographs of a Pt/C catalyst at low (a) and high magnification (b).

The work at CNRS in Task 3.2 focused on the preparation of Pt nanoparticles and their deposition onto the different carbon black samples with a targeted Pt loading of 60 wt%. The Pt nanoparticle synthesis was carried out by a microwave-assisted polyol method which was tuned so as to allow preparation of monodisperse Pt particles of target size of 3.5 nm. The nanoparticles were then deposited onto the carbon blacks. Platinum catalysts with good dispersion and the targeted high loading of 60 wt% Pt could be achieved. The good dispersion can be visualised from TEM images shown in Figure 3.1 for a selected catalyst.

CNRS also development of carbon-free Nb doped titania nanofibre supports by electrospinning and accelerated corrosion tests proved that they are significantly more stable to electrochemical corrosion at 1.4 V than carbon supports, however their conductivity is lower.

In Task 3.3 the partners performed catalyst characterisation and stability screening of the prepared catalyst powders. A lot of efforts were put in characterising the catalyst powders (CNRS, ICPF) in order to gain important knowledge of the Pt content and size of the Pt particles, and the presence of any residual impurities from the preparation procedure. The electrochemical evaluation (IRD, CNRS) of the catalysts involved characterisation of electrocatalytic properties and voltage cycling for the determination of the stability of the catalyst particles and of the support material. The screening was based on rotating disc electrode cyclic voltammetric measurements. The electrochemical evaluation was concentrated on the carbon based supports.

The electrochemical surface area was relatively similar among all the samples; around 30 m^2/g Pt. This was somewhat lower than that of the high-surface-area reference catalyst (HiSPEC® 9100) which is assumed to be partly due to the slightly larger Pt particles of the new developed catalysts compared with the reference. The specific activities for the new catalysts were larger than for the reference, again ascribed to the particle-size effect (i.e. the surface gets more active as the particle increases) but the mass-specific activity remains slightly higher for the reference. The results are summarised in Figure 3.2.

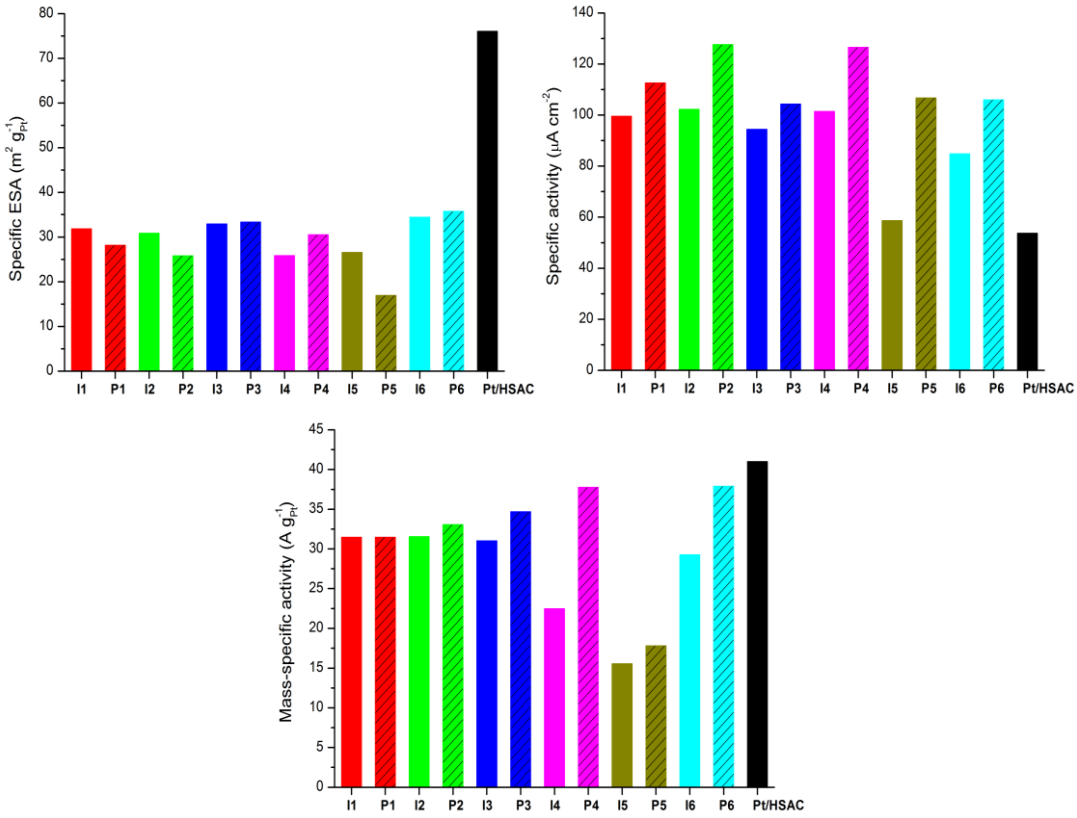


Figure 3.2: Specific ESA, specific activity and mass-specific activity at 0.90 V vs. RHE for six (6) catalyst prepared with impregnation method (I1-I6), microwave-assisted polyol method (P1-P6) and for the reference.

Differences in the electrochemical test results between the different catalysts using different carbon supports were believed to be linked to the differences in hydrophilicity, microporosity, aromaticity and crystallinity of the carbons. These properties were characterised at CNRS using flow calorimetry. Carbon supports with hydrophobic character and low crystallinity seemed to perform best.

The changes in electrochemical surface area due to degradation (of support and catalyst) were monitored and the new supports showed significantly lower degradation than the reference catalyst, which shows the benefit of using a support with moderate surface area instead of a high-surface-area carbon support as in the reference catalyst HiSPEC® 9100.

Comparing the two catalyst preparation procedures showed that the mass-specific (Figure 3.2) as well as specific activities were slightly higher for the CNRS samples (microwave-assisted polyol method, P1–P6) than for the corresponding ICPF samples (impregnation method, I1–I6). Furthermore, the CNRS prepared catalysts performed slightly better than those from ICPF with respect to specific activity in accelerated stress. On the other hand, the durability of the Pt particles (as expressed by electrochemical surface area change) was slightly better for the catalysts prepared by impregnation.

After summarising the results from the electrochemical screening a down-selection of the most promising catalysts was made.

Task 3.4 consisted of a laboratory level scaling-up of the down-selected catalysts in batch sizes up to 10 grams, which was a sufficient amount for MEA preparation in WP6. ICPF proved the possibility of preparing up to 10 g of selected catalysts with the impregnation procedure. CNRS up-scaled their catalyst production by developing a continuous flow microwave-assisted polyol method and further optimised the synthesis conditions. 10 g could be produced of the selected catalysts. The properties (crystallite size and Pt content)

and the electrochemical performance of the synthesised material were in agreement with the previously prepared catalyst on small scale, demonstrating the reproducibility of the up-scaled methods. The best of the optimised catalysts showed specific and mass-specific activities that exceed those of the HiSPEC® 9100 catalyst by 73 % and 14 %, respectively.

CONCLUSION

Thanks to a close collaboration between the partners of WP3, active and stable, highly loaded Pt/C catalysts could be prepared in sufficient quantities for MEA preparation (WP6) and testing (WP7). Important knowledge about the optimum carbon support properties was obtained; intermediate surface area, hydrophobic character and low crystallinity were found to give the best performance. Two different Pt catalyst preparation procedures were developed and optimised. The first was based on aqueous impregnation followed by calcination. Reduction and dechlorination steps were added, which improved the catalyst. The second was based on the preparation of Pt nanoparticles by a microwave-assisted polyol method and a following deposition on carbons. Both methods proved apt for the preparation of highly loaded Pt/C catalysts (60 wt%) with good Pt dispersion and purity, and both could also be up-scaled to at least 10 g. Electrochemical screening showed that the specific activities for the novel catalysts were larger than for the reference (HiSPEC® 9100), which is probably linked to the slightly larger Pt particles of the developed catalysts compared with the reference (as the surface gets more active as the nanoparticle increases). The changes in electrochemical surface area due to degradation (of support and catalyst) was significantly lower than for the reference catalyst, which showed the benefit of using the new developed carbons with intermediate surface area. The results from the electrochemical screening allowed a down-selection of the most promising catalysts for integration into MEAs.

WP4: Membrane and ionomer

Partners: CNRS, FUMA, SJTU, Volvo. **Duration:** M1–M36

SUMMARY

In WP4 the low equivalent weight short side chain ionomer was developed at SJTU and short and long side chain ionomers were modified to make them suitable for crosslinking. The ionomers were characterised and transferred for membrane preparation to FUMA. Considerable efforts were made on finding preparation conditions suitable for ionomer crosslinking to an extent that improves the membrane mechanical properties but without impacting too significantly the membrane electrical resistance. The crosslinked ionomer membranes are at a developmental stage and were not sufficiently advanced for integration into screener cell size MEAs. For this purpose the short side chain ionomer, the molecular weight of which was improved during the course of IMMEDIATE, was used in a reinforced membrane prepared at FUMA, and the thickness reduced to 15 µm. CNRS developed a means for stabilisation of membrane chemical properties by design and development of an electrospun ionomer nanofibre web comprising nanometric radical scavenger particles, that is laminated to give a composite membrane, and the protective layer oriented selectively to the anode or cathode side of the MEA.

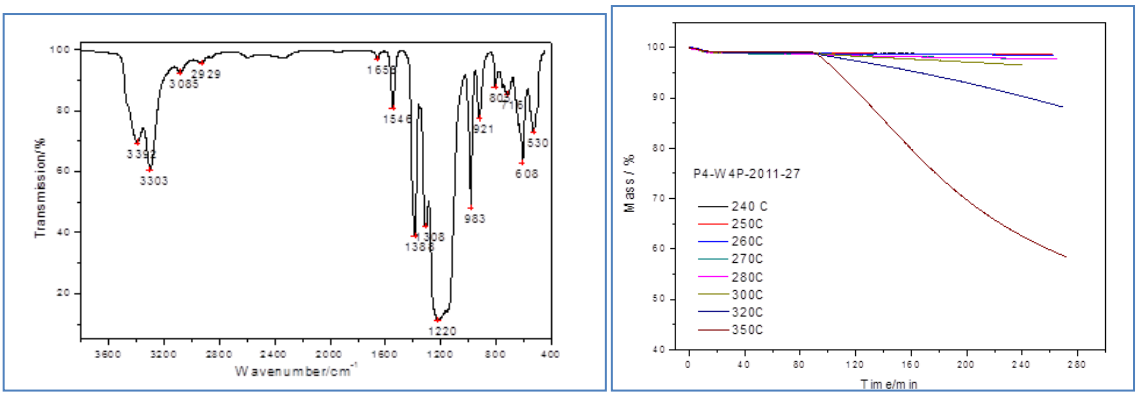
Three tasks are included in WP 4. Task 4.1 is ionomer development, SJTU is responsible for synthesis of the ionomer and polymer (Task 4.1). The Task 4.2 is membrane casting and cross-linking, the ionomers fabricated from Task 4.1 were delivered to FUMA to investigate the cross-linking progress and membrane

fabrication/characterisation (Task 4.2). The Task 4.3 is membrane modification and characterisation, which was led by CNRS.

Low equivalent weight cross-linkable PFSA ionomers based on perfluoroalkyl halide side chain cross-linkable groups like CF_2Br and SO_2F, SO_2NH_2 were developed. The synthesis conditions were investigated in detail and the synthesis process was also optimised. Polymers with different EWs and compounds of cross-linkable groups were synthesised and characterised with standard polymer physics and chemistry analytic methods as well as for gel particle size distribution. Polymers were supplied for further membrane cross-linking /preparation.

The polymer membrane preparation was based on dispersions delivered from Task 4.1. Membrane casting and cross-linking by thermal and radical procedures were performed on the laboratory scale. Optimisation has been done for the membrane casting process and refinement of cross-linking processing parameters also for the optimal degree of cross-linking. Scale-up is investigated for the membrane fabrication and membrane supplying to project partners.

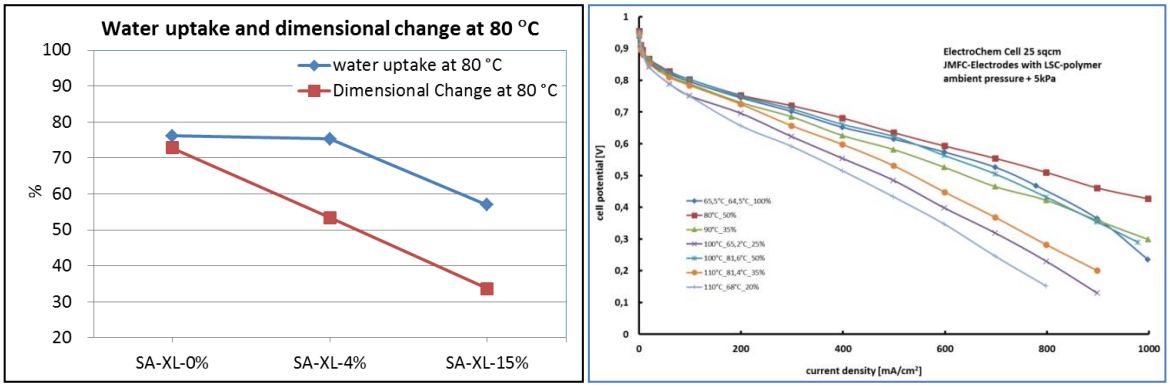
An improved molecular weight SSC PFSA membrane has been used, which resulted in improved processing properties. The cross-linked membranes were prepared also and tested for the 2G MEA. The mechanical strength is comparable to the 1G membrane and has good chemical stability. Thinner SSC PFSA membranes can suffer higher temperature and low humidity in fuel cell and show very promising performance for the application. For the 2G MEAs test a SSC PFSA membrane Fumapem® FS-720rfs was supplied in sufficient amount for the MEA/stack test.



a) b)

Figure 4.1: a) FT-IR spectrum of sulfonamide ionomer. b) Thermal stability of sulfonamide evaluated by TGA at SJTU.

Two different cross-linking (CL) strategies were developed. The sulfonamide PFSA reacted with SO_2F PFSA to format a bis-sulfonimide cross-linking bond was studied and the membranes with different CL degrees were fabricated and characterised. The sulfonamide blending with sulfonic acid PFSA to form a strong ionic cross-linking bond was investigated. LSC and SSC PFSA blending with sulfonamide membranes were compared and SSC membranes show better conductivity but also weaker mechanical stability. Cross-linking processes and membrane preparation were investigated based on the cross-linkable sulfonamide PFSA polymers with sulfonyl fluoride/sulfonic acid groups. The trial version of cross-linked membrane based on sulfonamide/sulfonate acid blending was provided for a single cell test.



a) b)

Figure 4.2: a) Effect of cross-linking degree on the water uptake of bis-sulfonimide cross-linked membranes. b) Performance of 2G SSC-PFSA membrane at different RH and temperature determined at FUMA.

Two objectives were included in the Task 4.3. One is the development of chemically stabilised PFSA membranes based on electrospinning process for incorporation of radical scavengers within PFSA nanofibres, and the second was the development of characterisation methods for the cross-linked membranes. Activities at CNRS in Task 4.3 focused on the development of methodologies for electrospinning of a nanofibre web of short and long side chain low EW PFSA and a cerium oxide radical scavenger, and bonding the web to one side of the membrane by hot-pressing. The membrane was then assembled into an MEA, and investigation made of the effectiveness of the presence of this interlayer when incorporated preferentially at the anode or cathode side of the MEA.

The goal of the task is to fabricate a stabilised composite membrane PFSA with radical scavenger layer. A nanofibre web of PFSA and a cerium oxide radical scavenger oxide had been integrated into the MEA for the possibility of chemical modification and cross-linking/interaction with the PFSA matrix.

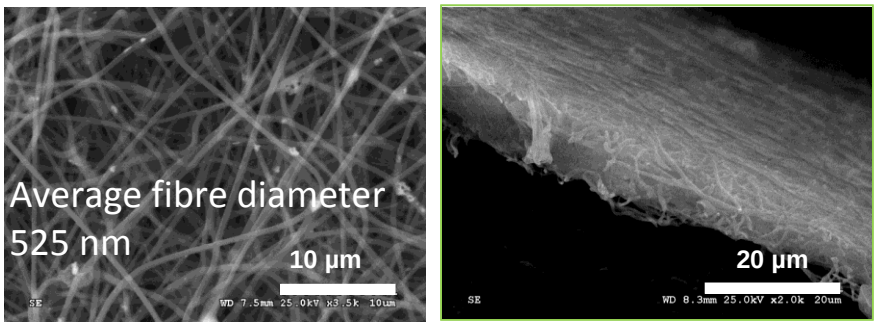


Figure 4.3: Electrospun mat comprising nanofibres of long-side-chain PFSA and CeOx nanoparticles prepared at CNRS.

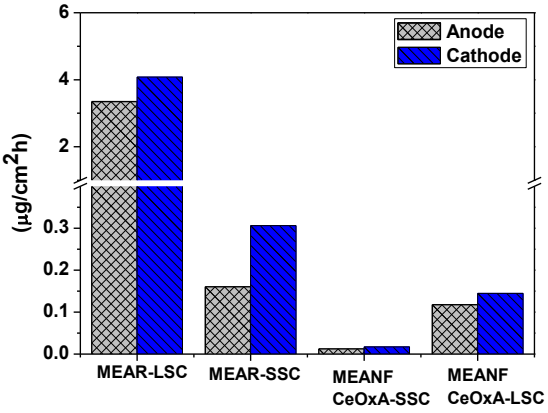


Figure 4.4: Comparison of the fluoride emission rate from MEAs held at OCV at 90 °C and 50% RH: MEANF CeOxA-SSC and MEANF CeOxA-LSC are MEAs protected by a CeOx-nanofibre layer at the anode side of SSC and LSC membranes respectively. The other MEAs are references, with no CeOx protective layer.

The electrospinning approach was also applied at CNRS to prepare a phase-separated cross-linked membranes i.e. where the cross-linkable PFSA component is electrospun into a nanofibre web into which the ionomer is impregnated with appropriate processing so as to cross-link the electrospun fibres to the impregnated polymer.

CONCLUSION

Cross-linkable ionomers were developed including bromine containing side chain and sulfonamide cross-linkable PFSAs that were used to prepare crosslinked membranes. The bromine containing PFSA was cross-linked through thermal and peroxide radical cross-linking. The cross-linking conditions as well as the influence of factors like initiators, temperature, solvents and coagents were investigated. A novel route to bis-sulfonimide cross-linking was investigated using a successful solution-based process. Cross-linked membranes were prepared characterised, and those based on a blend sulfonamide/sulfonic acid were provided for a single cell test. The molecular weight of SSC PFSA membrane has been increased, leading to improved processing properties. The advanced SSC PFSA membranes show high conductivity, including at low humidity and have been supplied to IRD for MEA development in WP6.

With the development of electrospinning method and optimisation of the electrospinning conditions, the objectives of preparation of nanofibre materials from both sulfonylamide precursorand L-Br functionalised PFSA were achieved in Task 4.3. A methodology was developed for electrospinning a nanofibre web of PFSA and a cerium oxide radical scavenger oxide, and laminated the web to one side of the membrane. The investigation has been made of the effectiveness of the presence of this interlayer when incorporated preferentially at the anode or cathode side of the MEA. Nanofibre interlayers of electrospun PFSA/CeOx are effective in mitigating chemical degradation. Under the AST conditions used, greater effect was observed when the protective layer is located at the anode side.

WP5: GDL

Partners: IRD, CNRS, FUMA, SGL, TC. **Duration:** M1–M36

SUMMARY

WP5 aimed at the understanding and improvement of gas-diffusion layers (GDLs) for MEAs with low precious metal content which should be able to operate under rather dry conditions with high electric efficiency. The development activities with respect to the GDL focused on the improvement of electronic conductivity as well as on a suitable balancing of the gas diffusivity and water retention capabilities of the GDL. Substantial improvements with respect to dry performance and corrosion stability of GDL were demonstrated with GDLs containing novel microporous layers consisting of graphite–carbon-nanotube blends.

The work package on gas-diffusion layer (GDL) contained four tasks; specification, GDL optimisation, microporous layer (MPL) optimisation, accelerated stress testing. All these tasks were seen a crucial aspects for the development of a novel GDL type which is able to provide the best possible contribution to the MEA performance targets of IMMEDIATE (dry operation, elevated temperature, low catalyst loading while maintaining high electric efficiency). In the first period of the project, several carbon fibre paper backings (differing in fibre length and fibre volume content) were tested with respect to their suitability for dry operation of PEMFCs. New GDL binders based on different (carbonisable) thermoset resins were studied in order to enhance the GDL conductivity. As a second approach for this goal, trials with elevated carbonisation/graphitisation temperatures were undertaken. These gave substantial conductivity gains. Unfortunately, these high temperatures gave rise to a "softening" of the binder carbons which, in turn, lead to poor mechanical properties of the GDL. All further GDL were therefore manufactured on the GDL 28 carbon fibre paper.

The most substantial performance increase was achieved by tuning the MPL of the GDL. A series of different carbons (acetylene black, furnace black, mesoporous carbons and various graphite types) from different commercial sources (including several grades from the project partner TC) were screened with respect to their conductivity and the MPL performance under dry conditions. The best MPL formulation for the IMMEDIATE MEA operating conditions identified was based on graphite (type KS6 from TC) blended with (20–30 %) multi-walled carbon nanotubes (MWCNTs) and a PTFE content of 20–25 %. The benefits of this combination might be due to the following properties:

- High water-retention capability of the graphite matrix
- Favourable effects of the MWCNTs on conductivity and pore size distribution ("pore former")

For a fast screening of different GDL materials, single-cell (25 cm^2) tests with commercial CCMs (total Pt loading of 0.5 mg/cm^2) using pneumatic compression were carried out. Based on the obtained performance, three types of GDL (GDL 28 BC plus IMMEDIATE batches #23 and #24) were down-selected for integration into the IMMEDIATE MEA (along with the reference material 24 BC from the beginning of the project).

Accelerated stress testing (AST) of the GDLs was performed with these three types. Corrosion of the GDL mainly proceeds at the surfaces of the MPL carbons and to a much lesser extent at the carbon fibre surface. As expected, the lowest electrochemical corrosion rate was observed at graphite-based MPLs.

For the best GDL candidate identified, an upscale trial (pilot production of rolled goods) has been run (#30), and very reproducible GDL performance has been obtained.

Table 5.1 summarises the key results within the IMMEDIATE project pertaining to the GDL. The contribution of the improved GDLs (against the reference material 24 BC at the beginning of the project) to the MEA performance targeted within IMMEDIATE could be estimated from the voltage gain at a current density of 1.47 A/cm^2 obtained in the measurement using commercial CCMs (#1 and #2).

Table 5.1: Performance and AST results for GDLs.

	28 BC	IMMEDIATE #23	IMMEDIATE #24 (#30)
Calculated GDL voltage gain vs. reference GDL @ 1.47 A/cm^2 based on improvement of GDL/MPL conductivity	+3 mV	+13 mV	+15 mV
Measured voltage gain (in-situ) vs. reference GDL @ 1.47 A/cm^2 80°C, 25% RH 1.5 bara, 1.5/2.0, CCM#1, 18 µm	+ 30 mV	+ 35 mV	+ 46 mV
Measured voltage gain (in-situ) vs. reference GDL **@** 1.47 A/cm^2 80°C, 50% /30% RH 2.5./2.3 bara, 1.3/1.5, CCM#2, 15 µm	-	-	+ 38 mV
AST of GDL/MPL Corrosion rate (in mC/cm^2/h) at 1.4 V vs. SHE in 1 M H_2SO_4	3.8	3.3	2.8

CONCLUSION

Within WP5, novel GDL/MPL types which enable better MEA/PEMFC performance under dry conditions (RH < 30 %, T above 80 °C) have been developed and successfully produced on a pilot scale. Apart from better GDL and MPL conductivity, it has been verified that graphite-based MPLs effectively prevent membrane dehydration which is a major source of voltage losses at current densities of around 1.5 A/cm^2. Moreover, the corrosion resistance of the GDLs with graphite-based MPL has been improved substantially. Detailed performance testing of MEAs containing all IMMEDIATE subcomponents along with suitable diagnostics might help to identify further development potential for GDLs for MEAs/PEMFCs with favourable efficiency and cost.

WP6: MEA

Partners: IRD, ICPF, CNRS, FUMA, Volvo. **Duration:** M6–M36

SUMMARY

IRD initiated MEA manufacture of reference MEAs based on SoA components in order to establish and initiate testing to take place in WP7 and using the protocols from WP2 (cf. deliverable report 2.1). During the first period the initial MEA development was focused on the collection and assembling of SoA components ranging from component membrane, catalyst and gas diffusion layer materials to ink preparation processes and MEA preparation procedures. These materials were also used for initial ink and electrode optimisation. In the second period a significant amount of materials developed in WP3, WP4 and WP5 were all used for MEA integration and MEA development as they became available during the project period. Design of the electrode structure was done in an iterative way aiming at the manufacturing of the advanced electrodes with (ultra)thin catalytic layers. The optimisation work was guided by characterization of MEAs performed in WP7.

The methodology adopted in the IMMEDIATE project is in line with the outcome of the work as described in the document "**EU HARMONISED TEST PROTOCOLS FOR PEMFC-MEA TESTING IN SINGLE CELL CONFIGURATION FOR AUTOMOTIVE APPLICATIONS".**

The development of **materials** entails R&D of new materials such as membranes, gas diffusion layers and catalysts based on a variety of innovative methods, processes and manufacturing techniques. Once these new materials and components have been developed they are then "screened" *in-situ* or *ex-situ* for their potential use as candidate materials for the membrane electrode assemblies (MEA) which in turn are subjected to further systematic screening most often in **single cell** test configurations to identifying the most promising MEAs with enhanced performance and durability.

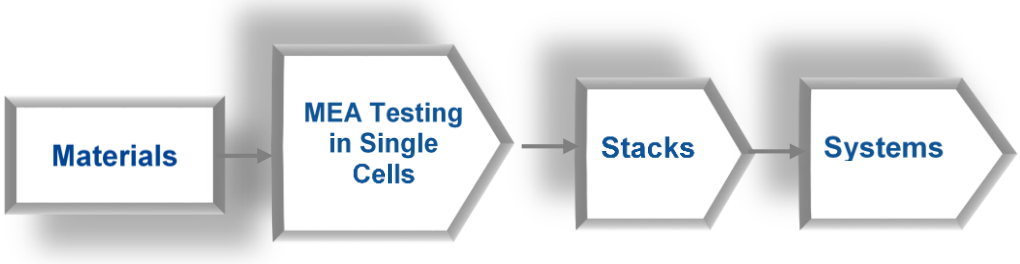


Figure 6.1: Schematic of the process chain for fuel cell development, Ref. [1]

All the MEA component materials and samples in the IMMEDIATE electrode development and characterization work reported were "screened" *in-situ* for their potential use as candidate materials for the membrane electrode assemblies as complete 25 cm^2 and/or 50 cm^2 MEAs in single-cell test hardware.

Design of the electrode structure was done in an iterative way aiming at the manufacturing of the advanced electrodes with (ultra)thin catalytic layers.

The optimisation work was guided by:

i) Fuel cell testing under realistic conditions as outlined in D2.1

ii) *Ex-situ* microstructure characterisation

iii) *In-situ* and *ex-situ* electrochemical characterisation

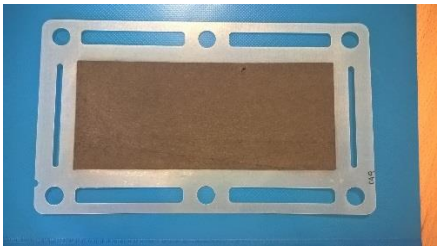
The overall work in WP6 with respect to catalyst and electrode design is rather comprehensive as the project aimed for development of all MEA precursor materials i) ionomer and membrane ii) catalyst support and catalyst and iv) gas diffusion layer and MPL combined with processing and coating parameters. The combinatorial experimental matrix changing only one materials precursor or electrode/MEA process parameter is rather extensive. Commercially available components were also used for benchmarking during the development phase.

The electrochemical reaction at the electrodes can only occur at "triple-phase boundaries" (TPB), where electrolyte, gas, and electrically connected catalyst regions contact. The TPB-boundary area in turn depends significantly on the fabrication procedure of the MEA in addition to other important parameters such as catalyst loading and ionomer. The electrode designs in IMMEDIATE are based on CCMs – directly coated to the membrane to match the overall aim to fabricate thin electrode layers with reduced precious group metal (PGM) level.

The electrode designs work included:

1. IMMEDIATE 1G optimized electrode design based on IRD's SoA materials: used as reference catalyst material for the electrode process optimization work with the aim to reduce the precious metals loads to the levels defined by the project targets.
2. Electrode development using the selected IMMEDIATE catalyst scaled to 1 g batches (WP3).
3. Study effect of lowering the overall PGM content compared to Beginning-of-Project.
4. Membrane-electrode interface: for optimal catalyst integrity in complete MEAs the electrode interface formed by IRD's coating technology on either sides of the membrane both baseline membrane refered to as SoA long side chain (LSC) PFSA and the short side chain (SSC) membrane developed in WP3
5. Incorporation of low EW ionomer in the Catalyst Layers (CL).
6. Electrode optimization and manufacture using scaled catalyst (10 g batches)
7. Electrode design manufacture with lower overall PGM content

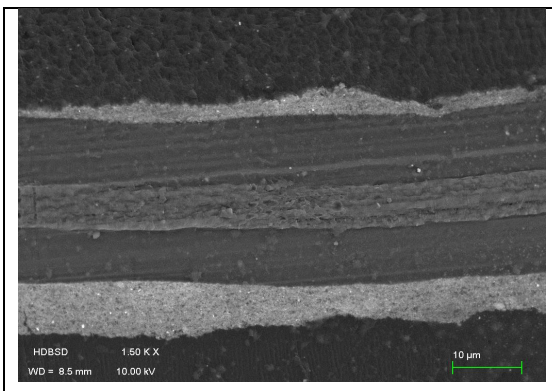
The electrode and MEA development aimed to focus on scalable processing routes aimed for cost efficient volume manufacture. IRD fabricated a broad range of 25, 50 & 100 cm^2 2G MEA candidates based on the various materials developed and up-scaled in WP3, WP4 and WP5. The MEAs were manufactured for initially screening test at CNRS and IRD in 25 & 50 cm^2 single-cell testing respectively with the overall aim to select the best 2G candidates for validation and conclusion of the IMMEDIATE project achievements in WP7.2 and WP7.3.

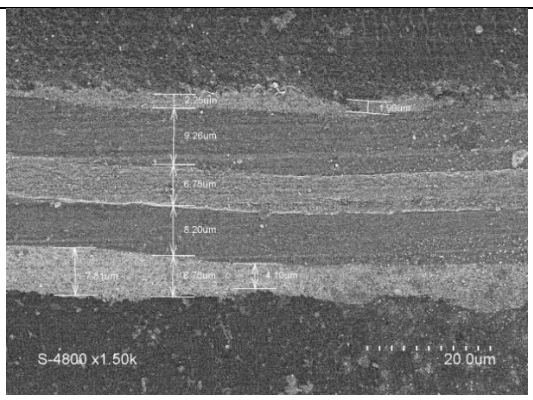


100 cm^2 MEA

Figure 4.3 MEA 100 cm^2 for performance test.

The work was guided using ex situ characterization of the MEA components with focus on catalyst layer and the electrode membrane interface for understanding the changes in the materials properties and their effect on the fuel cell performance. SEM analysis of CCM cross sections was performed using high and low resolution instruments.





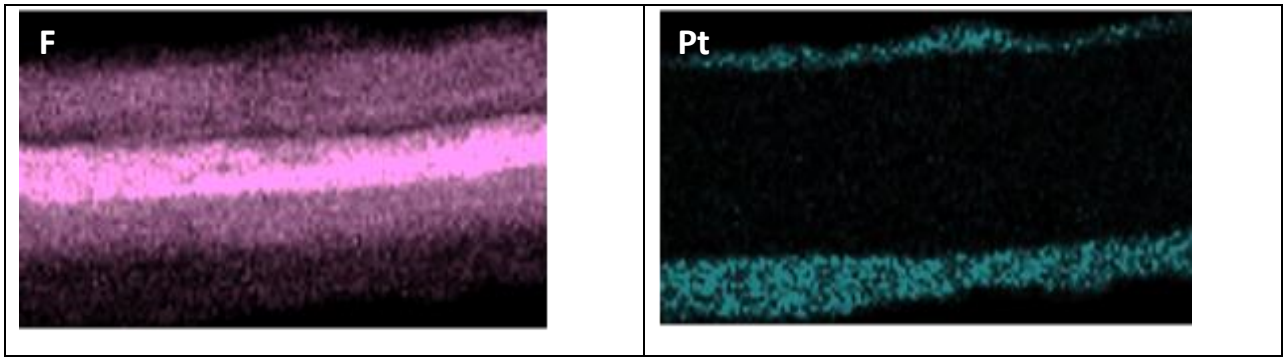


Figure 6.2 SEM analysis of MEA cross sections.

Points of interest for the microscopic observation of samples were:

- *Measurement of the thickness of anode and cathode catalyst layers;*
- *Study of catalyst morphology - mainly Pt dispersion;*
- *Observation of the membrane – electrode interface;*

Observation of the electrode morphology was performed by TEM. The Pt distribution, interface between electrode and membrane or influence of applied ionomer on the electrode integrity were examined in detail.

CONCLUSION

The technique for developing an optimized electrode assembly with a high degree of catalyst utilization - essential to achieve the project target of low catalyst content - while simultaneously increasing the performance aimed for operation at high current density, is not a trivial matter. In conclusion, ink and electrode optimisation using the SoA and project materials led to significant improvements. This work was accomplished using scalable processing routes and it provides a vital link between the development of fundamental science and its implementation towards industrial manufacture. Further improvements in the electrode design and MEA processing in associating the novel components in a future 3G MEA are also expected to increase their robustness.

WP7: Test

Partners: IRD, ICPF, CNRS, FUMA, SJTU, Volvo, SGL, JRC, TC. **Duration:** M14–M39

SUMMARY

In WP7 the the MEAs developed in IMMEDIATE were evaluated on the basis of electrochemical single-cell and short stack performance to assess the advantages of the project materials and MEAs with respect to performance and durability. A very large number of MEAs developed in WP6 were provided to WP7 and tested using the single cell testing protocols defined in D2.1. This testing mainly comprised IV performance, and diagnostic measurements including high frequency resistance and mass activity determination. The durability of two embodiments of the low PGM loading 2G MEAs, identical apart from the nature of the cathode catalyst, was investigated in different types of AST: i) Duty cycle test and ii) EU Harmonised test protocols for endurance testing, and the voltage loss determined, in addition to comparison of hydrogen crossover and changes in catalyst mass activity and electrochemical surface area induced by the testing conditions.

A very large number of MEAs developed by IRD in WP6 as well as experimental MEAs elaborated in WP4 by FUMA and CNRS were characterised in single cells. In Task 7.1 this testing used the single cell testing protocols defined in D2.1 and it mainly comprised IV performance, and diagnostic measurements including high frequency resistance and mass activity determination. In Task 7.2, where the durability of second generation MEAs was evaluated using accelerated stress testing and simulated bus duty cycles, these diagnostics were supplemented by electrochemical surface area and hydrogen crossover measurements made at the beginning and end of the test.

In WP7, characterisation of MEAs comprising, initially, a single novel project component in association with state of the art materials for the other components allowed a robust screening procedure to be implemented. This screening led to the down-selection and validation of most promising membrane, catalyst, ionomer and gas diffusion layer candidates for the second generation MEA (2G MEA): FS-720-rfs membrane, S15 catalyst on XE-N carbon, #24 type GDL. In parallel, characterisation of MEAs developed in WP6 with lower platinum group metal loadings at the anode and cathode enabled identification of the anode/cathode loadings providing highest platinum specific power density and then application of the optimised processing routes and catalyst loadings with WP3 catalysts.

The IMMEDIATE project target was to attain 0.04/0.11 mg Pt/cm^2 at anode/cathode, with a total loading of 0.15 mg Pt/cm^2. From the initial total loading of 0.60 mg Pt/cm^2 (1G MEA) the status at project mid-term was 0.45 mg Pt/cm^2 (1XG MEA). Although progress was made from the project start to the 1XG MEA, the mid-term Pt specific power density of 0.58 g Pt/kW remained far from the target. Since the mid-term point of IMMEDIATE, excellent progress has been made with 2G MEAs by reducing Pt loading to anode/cathode loadings of 0.05/0.15 mg Pt/cm^2 (total 0.2 mg Pt/cm^2). Initial ink composition and deposition processing optimisations were carried out with SoA catalysts. IRD prepared several series of MEAs with different loadings of commercial catalysts with 60, 50 and 40 wt% Pt on carbon. Polarisation curves, Tafel plots, HFR and impedance measurements were determined. MEAs were then prepared at IRD with three different anode catalyst loadings to evaluate the effect on power density of Pt loadings of 0.15, 0.10 and 0.05 mg/cm^2. Under EU reference automotive conditions, the power density of these three MEAs was lower by only 17% for the MEA with a three times lower anode catalyst loading. Building on this result, an anode loading of 0.05 gm/cm^2 was used in the development of low loading 2G MEAs with IMMEDIATE WP3 catalysts.

The various GDLs developed in WP5 were evaluated in WP7. In particular GDLs with backing type 28 with different composition MPLs were developed in WP5, supplied to WP6 for MEA development, and screened in WP7 by comparison to the reference GDL 28BC. Figure 7.1 shows one set of polarisation curves obtained under EU automotive reference conditions. On the basis of the high performance of IMMEDIATE type #24 relative to 28BC, and to the other experimental IMMEDIATE type #23, IMMEDIATE type #24 was carried forward for the 2G MEA.

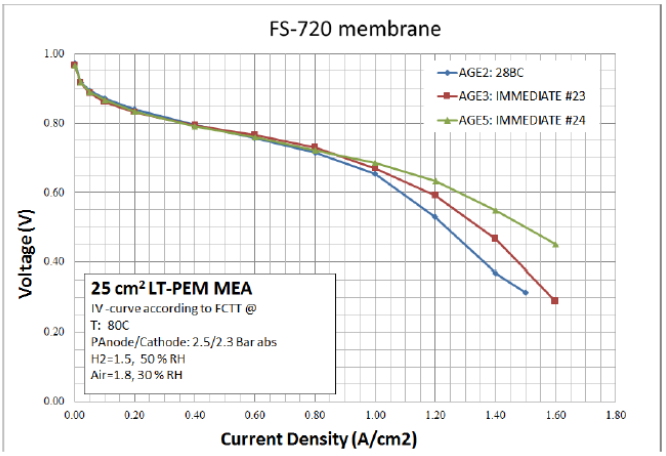


Figure 7.1. (Left) Performance of MEAs integrating IMMEDIATE FS720 membrane and IMMEDIATE GDL types #24 and #23, and comparison with 28BC under EU reference automotive conditions.

Series of CCMs were prepared at IRD using the FuMA-Tech FS720 membrane and the IMMEDIATE GDL type #24, and the WP3 catalysts prepared at CNRS and ICPF on IMERYS carbon support. The beginning of life performance of CCMs with total PGM loading 0.2 mg Pt/cm^2 prepared with CNRS cathode catalysts is shown in Figure 7.2.

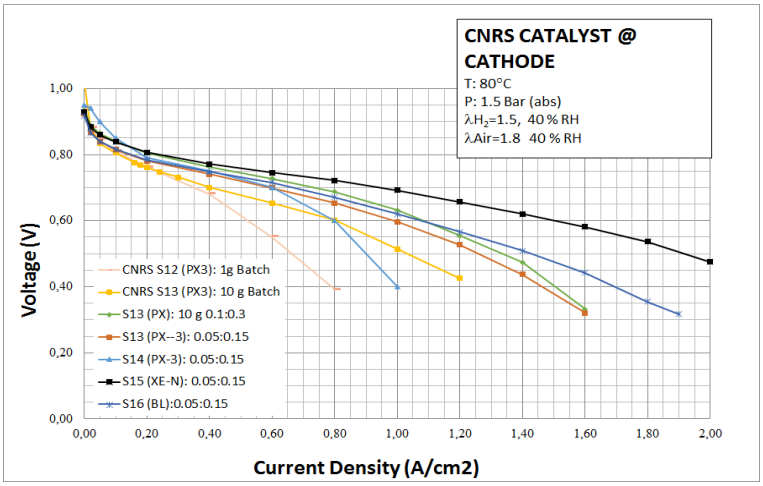


Figure 7.2. MEAs based on upscaled CNRS catalysts (10 g batch), anode/cathode loading 0.05/0.15 mg Pt/cm^2. IMMEDIATE reference test conditions at 80 °C and 40 % RH, 1.5 bara.

Of these, the catalyst S15 prepared with XE-N IMERYS carbon stands out for its higher performance. Under IMMEDIATE reference conditions of 80 °C, 40% RH, 1.5 bara, this CCM provides a maximum current density of 0.809 W/cm^2 at 0.68 V corresponding to 0.25 g Pt/kW. Under automotive reference conditions of 80 °C, 50%/30% RH and 2.5/2.3 bara, it gives 0.94 W/cm^2 at 0.68 V and 0.21 g Pt/kW. Finally, at 95 °C, 50% RH and 1.5 bara, the maximum power density is 0.811 W/cm^2 at 0.68 V, which corresponds to 0.24 g Pt/cm^2. The MEA with the S15 cathode has high mass activity (0.2 A/mg Pt at 0.9 $V_{IR\ free}$) and ECA (68 m^2/g), and gives 0.6 V at 1.5 A/cm^2.

The same optimised processing route was applied to upscaled ICPF catalysts at IRD. Figure 7.3 shows results with ICPF catalysts prepared using IMERYS XE-N carbon. Improved performance was observed by MEA process improvements allowed by the larger catalyst batch.

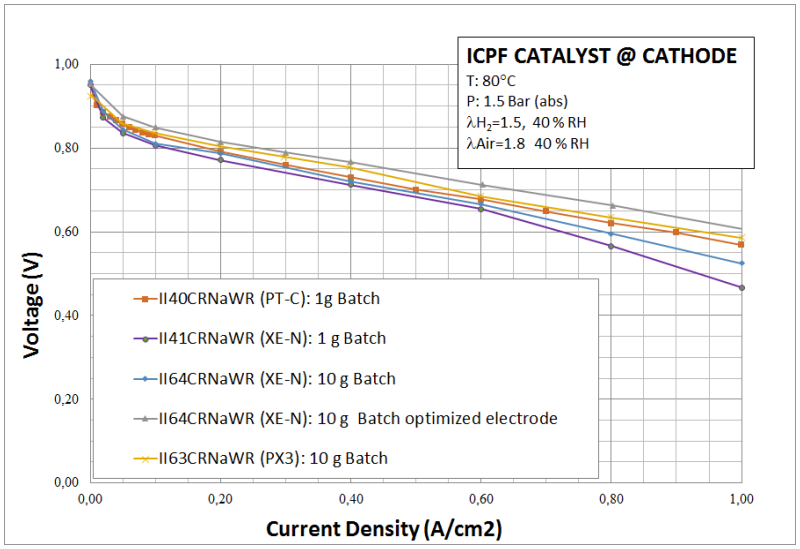


Figure 7.3. MEAs based on 1 g and 10 g batch ICPF catalysts, anode/cathode loading for 10 g batch optimised electrode 0.05/0.15 mg Pt/cm^2. IMMEDIATE reference test conditions 80 °C and 40 % RH, 1.5 bara.

The Pt specific power densities obtained with CNRS and ICPF catalysts in M39 MEAs are collected in Figure 7.4. The lowest loading/kW of 0.21 g/kW (S15) approaches the project target of 0.15 g Pt/kW, allowing confidence that this target can be reached in future work with one or more project catalysts with further ink composition and process optimisation.

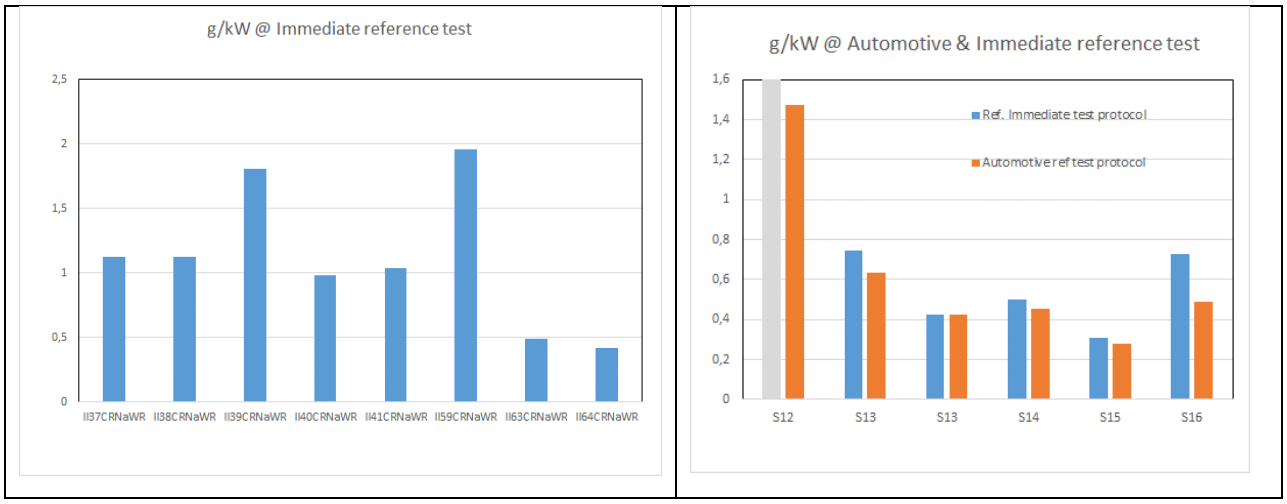


Figure 7.4 Pt specific power density of MEAs based on (left) ICPF and (right) CNRS catalysts, under automotive (CNRS) and IMMEDIATE (ICPF, CNRS) reference test conditions.

As one example of remaining parameter space for improvement, investigation was made of the effect of the ionomer type (long or short side chain) and the ionomer equivalent weight (EW) that is used in the catalyst layer. The results showed that the CL ionomer EW affects not only the HFR (as expected) of the MEA, but also the mass activity of the catalyst, with lower mass activity in the catalyst layers prepared with low EW ionomers. This is explained by the fact that the ionomer/catalyst ratio had been optimised for high EW (1100 g/mol) ionomers, and is clearly not fully appropriate for low EW ionomers, in particular for EW<800 g/mol. There is therefore clear parameter space for improvement of the present 2G MEA design with regard to the catalyst/ionomer ratio.

Under EU reference automotive conditions, the 2G MEA provides initial performance of 0.75 W/cm^2 at 0.68 V (0.27 g Pt/kW), and a maximum power density of 1.0 W/cm^2 (0.2 g Pt/kW).

Following validation in Task 7.1, the durability of two embodiments of the low PGM loading 2G MEA, identical apart from the nature of the cathode catalyst, was investigated in Task 7.2. This first entailed staged improvements to high temperature PEMFC stack hardware, in order to achieve closely similar average performance in the stack as in the 25 and 50 cm^2 screener single cell testing of Task 7.1. These improvements comprised flow field (active area and channel design) and gasket recess modification, and changes to the manifold inlet/outlet to match operation at <100 °C. The 2G MEAs were validated in different types of AST:

- Duty cycle test: These tests aim to reproduce the actual usage of the FC stack in a fuel cell system of the chosen application (city bus) using two load profiles referred to as Simulated City Bus Cycle 1 and Cycle 2
- EU Harmonised test protocols for endurance testing: These tests aim to assess the cell degradation rate using two load profiles referred to as Dynamic Load Cycling (DLC) and On-Off Cycling.

In addition to the above testing, the 2G IMMEDIATE MEAs comprising a complete new set of development materials such as membrane, electrode design, gas diffusion layers and new manufacturing processes with low PGM loading were tested using Accelerated Stress Test (AST) protocols, which included a 500 hours Open Circuit Voltage (OCV) hold test mainly designed for testing the membrane durability, and AST for stability of the electrocatalyst layers. The latter protocol is designed to mimic a driving pattern in which the fuel-cell load is continuously changed between full load when driving (corresponding to a cell voltage of 0.6 V vs. RHE) and idling (corresponding to open-cell voltage, i.e., about 1.0 V vs. RHE).

The duty cycle 1 was applied to the 2G IMMEDIATE MEAs with low PGM loading, and in all cases the voltage loss was lower than 10% at all the load levels.

The steady state OCV measurements on the 2G MEAs with low PGM loading, Figure 7.5, shows the reinforced FS720 membrane to be very durable, and the voltage loss after 500 hours at OCV is lower than the 2G MEA tested using the Bus cycle 1, Figure 7.5.

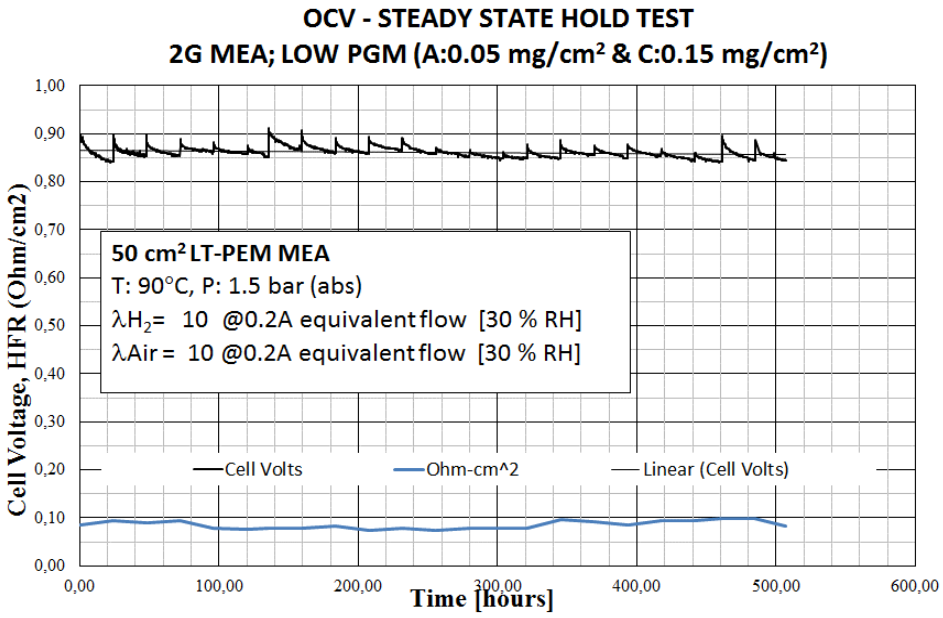


Figure 7.5: 500 hours AST OCV test conducted on 2G IMMEDIATE MEA AKDP

The durability assessment procedures included running the EU harmonized endurance test on the 2G IMMEDIATE MEAs. The dynamic load cycle, Figure 7.6 and the corresponding IV-data after 900 cycles shown Figure 7.6 indicate that this MEA, that incorporates a novel IMMEDIATE catalyst, is able to withstand the 900 cycles.

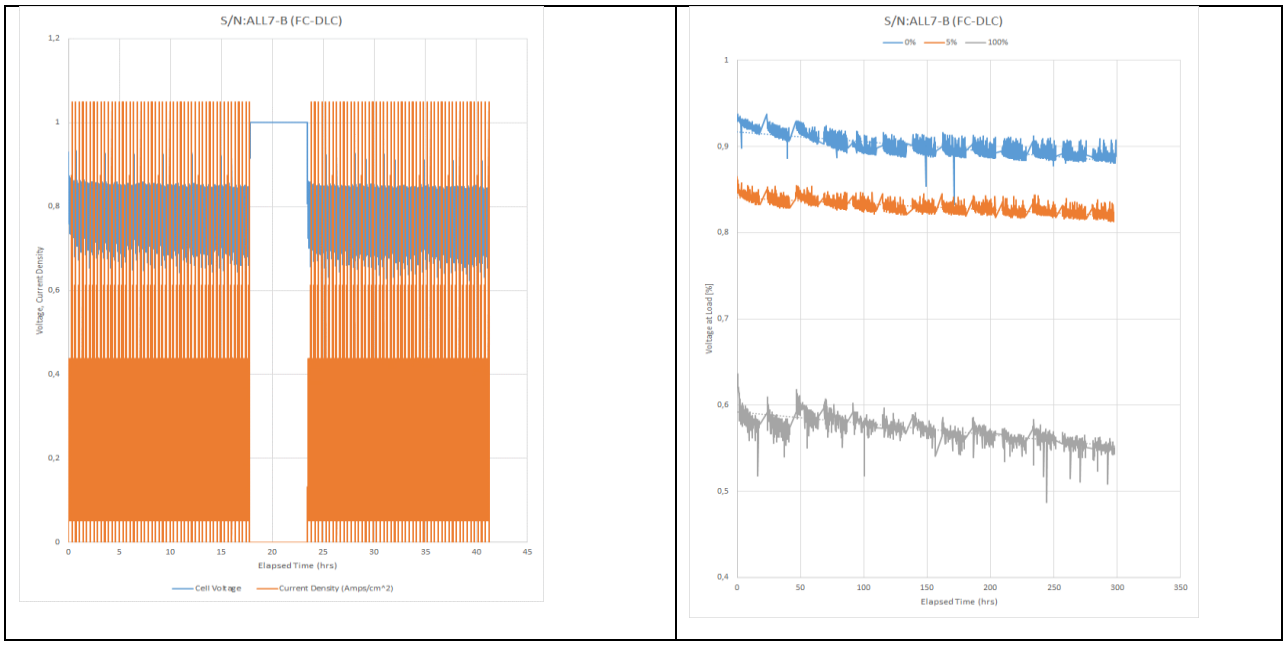


Figure 7.6 Dynamic load cycles conducted on IMMEDIATE 2G-2 MEA

However, the On/Off endurance test applied to the two 2G IMMEDIATE versions showed severe loss after 400 and 160 cycles respectively. Overall, hydrogen cross-over is significantly higher using the On/Off and

Dynamic Load Cycles, than when using either of the Simulated Bus Cycles, however, additional data is required to confirm this last observation.

A very clear indicator of IMMEDIATE project success is that the beginning of life performance at rated power (810 mW/cm^2) is identical to the DoE 2015 status reported in the DoE MultiYear Research, Development and Demonstration Plan 2016 and, even more encouragingly, the performance 0.8 V (300 mA/cm^2) exceeds the DoE 2015 status (240 mA/cm^2), and in fact achieves the DoE 2020 target (300 mA/cm^2) for this metric.

Finally, further improvements in the processing associating the novel components in a future 3G MEA are also expected to increase their robustness.

CONCLUSION

IMMEDIATE has achieved a significant reduction in Pt and, more generally, PGM loading with new set of materials and MEA processing developed during the course of the project. At M0, and using the state of the art 1 and 2 type MEAs, >0.9 g Pt were required per kW power under the EU harmonised test conditions. Steady progress in reducing this Pt loading was made as new materials and processing were implemented into the 1G, 1XG-1, 1XG-2, 2G, 2G-1 and 2G-2 MEAs, in the preparations made in the preceding WPs and shown by the testing in WP7. Although the final value of 0.27 g Pt/kW is still higher than the final project target, the large advances made, and with further optimisation areas already identified, confirm the overall success of the work carried out both in this WP and the preceding materials and MEA development WPs. A very clear indicator of IMMEDIATE success is that the performance at rated power is identical to the DoE 2015 status reported in the DoE MultiYear Research, Development and Demonstration Plan 2016 and, even more encouragingly, the performance 0.8 V exceeds the DoE 2015 status, and in fact achieves the DoE 2020 target for this indicator.

WP8: Dissemination

Partners: IRD, ICPF, CNRS, FUMA, SJTU, Volvo, SGL, JRC, TC. **Duration:** M1–M39

SUMMARY

The dissemination and outreach activities in the IMMEDIATE project comprised the participation in 3 FCH JU Programme Review Days workshops and 15 conferences, the presentation of 7 talks and 9 posters, the writing of 6 papers and filing of 1 utility-model application, and the administration of a public project website and a partner share point. All was done in line with the project targets and relevant procedures and guidelines

For the elucidation of exploitation and commercialisation aspects, cost calculations were done for the components and MEAs that have been developed within IMMEDIATE. Price projections for carbon support from TC, catalyst from ICPF, catalyst from CNRS, GDL from SGL, membrane and ionomer from FUMA, and MEAs from IRD were made for cases of annual productions of MEAs for up to 500,000 stacks, based on evaluations of the potentials for up-scaling to industrial production levels. The prices generated were used in WP2 for the economic assessments of the up-scaling of MEAs and stacks in a fuel-cell powertrain scenario.

An exploitation plan identifying exploitable results, market opportunities and commercialisation expectations was made according to the project plan, and the project milestone on the exploitation plan was achieved.

The project partners have obtained many results that will be utilised solely and/or in combined efforts. All partners identified the exploitable results (foreground knowledge), and an exploitation plan identifying exploitable results, market opportunities and commercialisation expectations was made.

The objectives of WP8 are to ensure that the results and developments of the project are disseminated and to assess the overall industrial scalability of the developed components and outline the steps required for product commercialisation. There are two tasks, where Task 8.1 has been dedicated to outreach and dissemination and Task 8.2 to exploitation.

In Task 8.1 a project website was constructed and published in the very first stage of the project. In addition to the public information about the project, the website also contains a non-public share point, which is accessible only for the project partners and the FCH JU project officer. Here confidential reports, meeting details, technical results from partners and project presentations are located. These sites were continuously updated by IRD throughout the entire project.

The addresses of the public website and the non-public partner share point are:

- Public website: http://www.immediate.ird.dk/
- Partner share point: http://immediate.ird.dk/ (password required)

Representatives of the project coordinator (IRD) participated in the FCH JU Programme Review Days in Brussels in 2013 (11–12 November), 2014 (10–11 November) and 2015 (17–18 November). At all three events an updated poster on the IMMEDIATE project was presented, and the stage was set for discussion and exchange of experience and ideas among the numerous participants/stakeholders.

Representatives of the project partners participated in 15 scientific conferences, where they gave presentations of the IMMEDIATE work and results in the form of talks (seven) and posters (nine). The conferences are listed in Section A in the *Use and dissemination of foreground* chapter, along with details on the oral and poster presentations given in them.

The partners prepared six article manuscripts on the IMMEDIATE work for submission to peer-reviewed scientific journals. By the end of the project three of these were published in journal issues while one was accepted and published online, another one submitted and under review, and the last one still in preparation. The project milestone on the submission of five papers to peer-reviewed journals was thus achieved. Details on the papers can be found in Section A in the *Use and dissemination of foreground* chapter.

All dissemination was performed in line with the targets and procedures set up in Annex I of the project and in agreement with the guidelines of the FCH JU. The following acknowledgement – or a very similar phrasing – was included in all publications: “The research leading to these results has received funding from the European Union’s Seventh Framework Programme (FP7/2007–2013) for the Fuel Cells and Hydrogen Joint Technology Initiative under grant agreement n° 303466 IMMEDIATE”.

In addition the publications mentioned above, an application for a utility model was filed in the Czech Republic, where it was granted (CZ 27949 U1). Details can be found in Section B in the *Use and dissemination of foreground* chapter.

In Task 8.2 the potential for commercial exploitation was assessed through evaluation of the developed components and MEAs with respect to pricing, industrial scalability, potential markets and exploitation possibilities.

Towards the end of the project each component-producing partner (TC, ICPF, CNRS, SGL and FUMA) and the MEA manufacturer (IRD) made cost assessments of their products. They first considered the production cost for their product when manufactured on the scale used in this project and then made an economic scale-up evaluation. The following assumptions were used for the fuel-cell stack and annual productions volumes, in line with a cost-assessment model from the Auto-Stack project (FCH JU GA n° 245142) that was found to suggest appropriate assumptions for the exercise of scaling up to industrial production levels:

- 95 kW gross stack power (at 0.68 V cell voltage)
- 1 W/cm^2 power density

- 300 cm^2 active area per cell
- 315 cells per stack
- Price assessments at production rates of 1,000, 10,000, 50,000, 100,000 and 500,000 stacks per year.

Hence cost calculations were done for the MEA components that have been developed in the IMMEDIATE project; i.e., carbon support from TC, catalyst from ICPF, catalyst from CNRS, GDL from SGL, and membrane and ionomer from FUMA. For these components, price projections were made for each of the five annual stack production volumes, based on evaluations of the possibilities and requirements for up-scaling to industrial production levels. From these projected component prices, MEA sales prices at the same stack production volumes were estimated by IRD. The resulting prices were used in WP2 for the economic assessments of the up-scaling of MEAs and stacks and their use in the powertrain.

The project partners have obtained many results that will be utilised solely and/or in combined efforts. All partners considered the results (foreground knowledge) and identified the exploitable ones, defined as being achieved and expected results coming from the project which have commercial significance and c be exploited as a stand-alone product, process, service, etc. (Such results might, however, need further R&D, prototyping, engineering, validation, etc. after the project before they become commercially exploitable.). The exploitable results were filled into an Excel template, which helped define and classify them. The list can be found in Section B in the *Use and dissemination of foreground* chapter.

For each exploitable result a questionnaire was filled in, which elucidated on its content, potential, market, etc., as well as the time frame, partners and requirements involved in its exploitation. These analyses are included in the deliverable report D8.4 *Draft exploitation plan*.

CONCLUSION

Project dissemination and outreach activities were done that comprised the participation in 3 FCH JU Programme Review Days workshops and 15 conferences, the presentation of 5 talks and 9 posters, the writing of 5 papers and filing of 1 utility-model application, and the launching and updating of the public project website and the partner share point. All was done in line with the project targets and relevant procedures and guidelines. The project milestone on the submission of five peer-reviewed papers was achieved.

To elucidate on exploitation and commercialisation aspects, cost calculations were done for the MEA components that have been developed in the IMMEDIATE project; i.e., carbon support from TC, catalyst from ICPF, catalyst from CNRS, GDL from SGL, and membrane and ionomer from FUMA. For these components, price projections were made for cases of annual productions of MEAs for 1,000 up to 500,000 stacks, based on evaluations of the potentials for up-scaling to industrial production levels. From these projected component prices, MEA sales prices at the same stack production volumes were estimated by IRD. The prices generated in this report were used in the D2.2 report on the economic assessments of the up-scaling of MEAs and stacks for the powertrain.

An exploitation plan identifying exploitable results, market opportunities and commercialisation expectations was made according to the project plan, and the project milestone on the exploitation plan was achieved.

IV. POTENTIAL IMPACT

The intensive R&D work on the catalyst support materials (carbons) performed in the project has led to the following results with significant impact:

- Increased knowledge about carbon as catalyst support in fuel cells and specification of commercial products. This has led to special carbons with improved performance that can be marketed for this application.
- Improved know-how on carbon production processes and equipment and related transfer of know-how into operations (optimisation, new technologies). This has led to a product that has significantly improved performance. It has higher costs at product level (carbon support), but lower costs at product user level (catalyst and fuel-cell system); i.e., the product contributes to lower system costs. This brings about the following benefits to fuel-cell catalyst producers: Improved catalyst efficiency and corrosion stability and lower catalyst costs. For the carbon manufacturer (TC) the result means earlier market entry.
- New carbon characterisation techniques and methods and the transfer of know-how into the quality control of the carbon production. This has led to improved quality control possibilities for special carbons for fuel-cell applications. The improved analytical know-how makes it possible to identify key material properties influencing the performance at user level and to supply customers with suitable, high-quality materials. The benefits to the catalyst manufacturers are reliable, high-quality support materials and improved product performance. For the carbon manufacturer (TC) the result means the ability to continuously market high-quality products that are competitive with low-price alternatives supply.
- Better understanding of critical design requirements of GDLs for operation under low-humidity conditions. This is particularly valuable as it has impact on the balance of plant (BoP) of the fuel-cell system. Better MEA performance under such circumstances will substantially decrease the system cost.
- Development of innovative GDL types on the pilot scale which could be fed into qualification at various fuel-cell manufacturers after the project.
- Integration of new catalysts/supports in electrodes, improved product performance for operating at higher temperature and lower humidity
- New ink formulations for improved performance using low PGM electrodes
- Production process that makes the manufacture of low-cost, high-quality MEAs with low PGM content possible on a large scale
- Within the IMMEDIATE project dissemination and outreach activities were done that comprised the participation in 3 workshops and 15 conferences, the presentation of 7 talks and 9 posters, the writing of 6 papers and filing of 1 utility-model application, and the launching of a public project website and a partner share point. All was done in line with the project targets and relevant procedures and guidelines.

Use and dissemination of foreground

I. SECTION A: DISSEMINATION (PUBLIC)

List of scientific (peer-reviewed) publications (A1)

Template A1: List of scientific (peer reviewed) publications										
No.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/will open access be provided to this publication?
1	Mitigation of PEM Fuel Cell Electrolyte Degradation with Metal Oxide/Nafion Nanofiber Interlayers	Zaton, Marta (CNRS)	ECS Transactions	Volume 61, issue 23	ECS	–	2014	15–23	–	No
2	Highly loaded carbon black supported Pt catalysts for fuel cells	Kaluža, Luděk (ICPF)	Catalysis Today	Volume 256	Elsevier	–	2015	375–383	http://hdl.handle.net/11104/0249853; http://dx.doi.org/10.1016/j.cattod.2015.02.016	Yes, by November 2017

3	Fuel Cell Platinum Catalysts Supported on Mediate Surface Area Carbon Black Supports	Kaluža, Luděk (ICPF)	Chemical Engineering Transactions	Volume 43	AIDIC	–	2015	913–918	http://hdl.handle.net/11104/0255890; www.aidic.it/cet/15/43/153.pdf	Yes, open-access journal
4	Synthesis of Pt/C Fuel Cell Electrocatalysts: Residual Content of Chlorine and Activity in Oxygen Reduction	Kaluža, Luděk (ICPF)	Electrocatalysis	DOI 10.1007/s12678-016-0312-3	Springer	–	2016; published online	1–7	http://link.springer.com/article/10.1007%2Fs12678-016-0312-3	Yes, one year after publication
5	Development of tailored high-performance and durable electrocatalysts for advanced PEM fuel cells	Larsen, Mikkel Juul (IRD)	International Journal of Hydrogen Energy	TBD	Elsevier	–	Submitted	TBD	–	No
6	Correlation between the surface characteristics of carbons and their electrochemical stability and proton	Jiménez Morales, Ignacio (CNRS)	TBD	TBD	TBD	–	In preparation	TBD	–	No

	exchange membrane fuel cell performance									

List of all dissemination activities (A2)

Template A2: List of all dissemination activities							
No.	Type of activity	Main leader	Title	Date/period	Place	Type of audience	Size of audience
1	Web	IRD	http://www.immediate.ird.dk/		–	All public	∞
2	Web	IRD	http://immediate.ird.dk/		–	Project partners and FCH JU	< 30
3	Workshop	IRD	FCH JU Programme Review Days	11–12 November 2013	Brussels, B	Scientific community	< 100
4	Workshop	IRD	FCH JU Programme Review Days	10–11 November 2014	Brussels, B	Scientific community	< 100
5	Workshop	IRD	FCH JU Programme Review Days	17–18 November 2015	Brussels, B	Scientific community	< 100
6	Conference	CNRS	225th ECS Meeting,	11–15 May 2014	Orlando, Florida, USA	Scientific community	< 100
7	Presentation	CNRS (M. Zaton)	Development of Nanofiber Ceria-PFSA Interlayers to Mitigate Membrane Chemical Degradation	11–15 May 2014	Orlando, Florida, USA	Scientific community	< 100
8	Publication	CNRS (M. Zaton)	Mitigation of PEM Fuel Cell Electrolyte Degradation with Metal Oxide/Nafion Nanofiber Interlayers	2014	–	Scientific community	∞
9	Conference	CNRS	European Materials Research Society 2014 Spring Meeting	26–30 May 2014	Lille, F	Scientific community	< 100
10	Presentation	CNRS (M. Zaton)	Nanofiber Ceria-PFSA Interlayers to Mitigate Membrane Chemical Degradation	26–30 May 2014	Lille, F	Scientific community	< 100
11	Conference	ICPF	21st International Congress of Chemical and Process Engineering (CHISA 2014)	23–27 August 2014	Prague, CZ	Scientific community	< 100

12	Presentation	ICPF (L. Kaluža)	Highly loaded carbon black supported Pt catalysts for fuel cells	23–27 August 2014	Prague, CZ	Scientific community	< 100
13	Publication	ICPF (L. Kaluža)	Highly loaded carbon black supported Pt catalysts for fuel cells	2015	–	Scientific community	∞
14	Conference	ICPF	46th Symposium on Catalysis	03–05 November 2014	Prague, CZ	Scientific community	< 100
15	Poster	ICPF (D. Gulková)	Highly loaded carbon black supported platinum catalysts for fuel batteries	03–05 November 2014	Prague, CZ	Scientific community	< 100
16	Conference	CNRS	Advances in Polymers for Fuel Cells and Energy Devices	8–11 February 2015	Asilomar, Pacific Grove, California, USA	Scientific community	< 100
17	Poster	CNRS (M. Zaton)	Comparison of fluoride emission rate from SSC and LSC PFSA MEAs during high temperature OCV hold and mitigation of membrane degradation with a mitigation of cerium oxide-nanoparticle-enriched PFSA nanofiber network at the membrane-electrode interface	8–11 February 2015	Asilomar, Pacific Grove, California, USA	Scientific community	< 100
18	Poster	IRD (M. Odgaard)/-CNRS	Innovative automotive MEA development	8–11 February 2015	Asilomar, Pacific Grove, California, USA	Scientific community	< 100
19	Conference	ICPF	12th International Conference on Chemical & Process Engineering (ICheaP12)	19–22 May 2015	Milan, I	Scientific community	< 100
20	Poster	ICPF (D. Gulková)	Fuel cell platinum catalysts supported on mediate surface area carbon black supports	19–22 May 2015	Milan, I	Scientific community	< 100
21	Publication	ICPF (L. Kaluža)	Fuel Cell Platinum Catalysts Supported on Mediate	2015	–	Scientific community	∞

			Surface Area Carbon Black Supports				
22	Conference	CNRS	46ème Journées de Calorimétrie et d'Analyse Thermique (JCAT46)	20–22 May 2015	Montpellier, F	Scientific community	< 100
23	Poster	CNRS (I. Jiménez Morales)	Evaluation of the surface characteristics of carbons using flow calorimetry and their use as electrocatalyst supports for fuel cell application	20–22 May 2015	Montpellier, F	Scientific community	< 100
24	Conference	ICPF	Veletrh vědy	21–23 May 2015	Prague, CZ	Scientific community	?
25	Poster	ICPF (K. Smítalová)	Příprava a charakterizace Mo/C katalyzátorů	21–23 May 2015	Prague, CZ	Scientific community	?
26	Conference	CNRS	ECS Conference on Electrochemical Energy Conversion & Storage with SOFC–XIV	26–31 July 2015	Glasgow, Scotland, UK	Scientific community	< 100
27	Presentation	CNRS (M. Zaton)	Mitigating Membrane Degradation: Investigation of Lifetime and Fluoride Emission Rate from Modified Short-Side-Chain and Long-Side-Chain PFSA Membrane Electrode Assemblies during High Temperature Open Circuit Voltage Hold	26–31 July 2015	Glasgow, Scotland, UK	Scientific community	< 100
28	Conference	CNRS, IRD	Electrolysis & Fuel Cell Discussions (EFCD2015)	13–16 September 2015	La Grande Motte, F	Scientific community	< 100
29	Poster	CNRS (I. Jiménez Morales/M. Zaton)	Evaluation of the Surface Characteristics of Carbons using Flow Microcalorimetry and their Use as Fuel Cell Electrocatalyst Supports	13–16 September 2015	La Grande Motte, F	Scientific community	< 100
30	Conference	ICPF	47th Symposium on Catalysis	02–04 November 2015	Prague, CZ	Scientific community	< 100

31	Poster	ICPF (D. Gulková)	Synthesis of Pt/C fuel cell electrocatalysts: Residual content of chlorine and activity in oxygen reduction	02–04 November 2015	Prague, CZ	Scientific community	< 100
32	Publication	ICPF (L. Kaluža)	Synthesis of Pt/C Fuel Cell Electrocatalysts: Residual Content of Chlorine and Activity in Oxygen Reduction	2016	–	Scientific community	∞
33	Conference	IRD	International Conference on Innovative Electrochemical Energy Materials and Technologies (EEMT2015)	8–12 November 2015	Nanning, CN	Scientific community	< 100
34	Presentation	IRD (M. J. Larsen)	Development of tailored high-performance and durable electrocatalysts for advanced PEM fuel cells	8–12 November 2015	Nanning, CN	Scientific community	< 100
35	Publication	IRD (M. J. Larsen)	Development of tailored high-performance and durable electrocatalysts for advanced PEM fuel cells	Submitted January 2016	–	Scientific community	∞
36	Conference	IRD	International Energy Agency Annex 34 Fuel Cells for Transportation Working Group Meeting	11 November 2015	Vienna, A	Scientific community	< 100
37	Presentation	IRD (M. Odgaard)	Advanced MEAs for Automotive Applications	11 November 2015	Vienna, A	Scientific community	< 100
38	Conference	IRD	Fuel Cell Seminar & Energy Exposition	16–19 November 2015	Los Angeles, California, USA	Scientific community	< 100
39	Poster	IRD (M. Odgaard)	Innovative automotive MEA development	16–19 November 2015	Los Angeles, California, USA	Scientific community	< 100
40	Conference	IRD	33rd Annual International Battery Seminar & Exhibit	21–24 March 2016	Fort Lauderdale, Florida, USA	Scientific community	< 100

41	Presentation	IRD (M. Odgaard)	Advanced MEA Development: Automotive Applications, Low PGM, Durability, Materials by Design Approach	21–24 March 2016	Fort Lauderdale, Florida, USA	Scientific community	< 100

II. SECTION B: EXPLOITATION (PUBLIC)

List of IPR applications (B1)

Template B1: List of applications for patents, trademark, registered designs, etc.						
No.	Type of IP rights	Confidential (yes/no)	Foreseen embargo date	Application reference(s)	Subject or title of application	Applicants(s) (on the application)
1	Utility model, Czech Republic	No	17/03/2015 (registration date)	CZ 27949 U1	Katalyzátor Pt/C pro nízkoteplotní palivové baterie	Kaluža, Luděk (ICPF)

List of exploitable foreground (B2)

Template B2: List of exploitable foreground									
No.	Type of exploitable foreground	Exploitable product(s) or measures	Confidential (yes/no)	Foreseen embargo date	Description of exploitable foreground	Sectors of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & other beneficiaries involved
1	General advancement of knowledge	Industrial production processes	Yes	Implementation in 2016	Improved know how in production processes and equipment and related know how transfer into operations (optimisation, new	C19.2.0 - Manufacture of refined petroleum products	Implementation in 2016	Patent application filed before project start	TC (Imerys)

					technologies)				
2	General advancement of knowledge	Improved quality control techniques for special carbons for fuel cell applications	Yes	Implementation in 2016	New carbon characterisation methods and know-how transfer into quality control of carbon production	C19.2.0 - Manufacture of refined petroleum products	Implementation in 2016	Technical publication of some of the analysis techniques (corrosion data were presented at the Lucerne conference)	TC (Imerys)
3	Commercial exploitation of R&D results	Carbon catalyst support for fuel cells	Yes	Market launch 2018	Knowledge about carbon as catalyst support in fuel cells, definition and specification of commercial products, improved product performance	C20.5.9 - Manufacture of other chemical products n.e.c. (catalyst manufacturer)	Market launch 2018	Patent application filed before project start	TC (Imerys)
4	General advancement of knowledge	Scale-up and production-scale control	No	Implementation in 2016	Electrocatalysts highly loaded with Pt comprisi	C20.5.9 - Manufacture of other chemica	Implementation in 2016	Utility model registrered (CZ 27949 U1);	ICPF

		and quality evaluation			ng 50-70 wt.% of Pt and 50-30 wt.% of carbon with precisely defined content of residual Cl/Br (licence on preparation procedures and control parameters)	l products n.e.c.		other IP protection expected	
5	General advancement of knowledge	Pre-graduate/Doctoral students training	No	Implementation in 2016	New tematic research field opened - Electrocatalysts synthesis and characterisation	P85.5.9 - Other education n.e.c.	Implementation in 2016	Scientific papers/research reports	ICPF
6	General advancement of knowledge	Carbon-supported catalyst for fuel cells	No	Implementation in 2016	Rapid (2 minutes) continuous flow preparation method leading to mondisperse Pt nanoparticles and	C20.5.9 - Manufacture of other chemical products n.e.c. (catalyst manufacturer)	Implementation in 2016	No IP protection ecpected	CNRS

					their deposition in high weight percentage without aggomeration on carbon supports giving carbon supported fuel cell catalysts				
7	General advancement of knowledge	Fuel cell membrane	No	Implementation in 2016	Novel method of incorporation of radical scavengers into a fuel cell membrane	C20.5.9 - Manufacture of other chemical products n.e.c. (membrane producer)	Implementation in 2016	No IP protection ecpected	CNRS
8	Commercial exploitation of R&D results	New GDL/ MPL formulations for improved performance under dry/elevated-temperature	Yes	Implementation in 2016	New GDL/MPL formulations for improved performance under dry/elevated-temperature operation	C13.9.6 - Manufacture of other technical and industrial textiles	Implementation in 2016	Patent application filed before project start; additional IP protection considered	SGL

		operation							
9	General advancement of knowledge	Improved quality control techniques for special GDLs/ MPLs for fuel cell applications	Yes	Implementation in 2016	Better understanding of GDL behaviour in PEMFC operating at higher temperature and lower humidity	C13.9.6 - Manufacture of other technical and industrial textiles	Implementation in 2016	Technical publication (in planning)	SGL
10	Commercial exploitation of R&D results	Industrial production processes	Yes	Implementation in 2016	Production process for new SSC cross-linkable PFSA membrane with fibre reinforement and chemical stabilisation	C20.5.9 - Manufacture of other chemical products (membrane producer)	Implementation in 2016	Patent application filed before project start	FUMA
11	Commercial exploitation of R&D results	Improved quality control techniques for special PFSA membrane for fuel cell	Yes	Implementation in 2016	Process control of reinforcement and double coating	C20.5.9 - Manufacture of other chemical products n.e.c. (membrane	Implementation in 2016	IP protection considered	FUMA

		applications				producer)			
12	General advancement of knowledge	Integration of new catalysts/supports in electrodes, improved product performance for operating at higher temperature and lower humidity	Yes	Implementation in 2016	Knowledge about integration of new catalysts/supports in electrodes, improved product performance for operating at higher temperature and lower humidity	C27.2 - Manufacture of batteries and accumulators	Implementation in 2016	No IP protection ecpected	IRD
13	Commercial exploitation of R&D results	New ink formulations for improved performance using low PGM electrodes	Yes	Implementation in 2016	Ink formulations that give improved performance using low PGM electrodes	C27.2 - Manufacture of batteries and accumulators	Implementation in 2016	No IP protection ecpected	IRD
14	Commercial exploitation of R&D results	Production process for membrane-electro	Yes	Implementation in 2016	Production process that makes the manufac	C27.2 - Manufacture of batteries and accumulators	Implementation in 2016	Existing IPR on fundamental concepts; addition	IRD

		de assemblies (MEAs) with low PGM content			ture of low-cost, high-quality MEAs with low PGM content possible on a large scale			al IP protection considered	
15	additional IP protection considered "	Trends on FC cost and durability performance	Yes		Knowledge on trends in FC cost and durability performance	C29 - Manufacture of motor vehicles, trailers and semi-trailers	Not set	No IP protection ecpected	Volvo
16	General advancement of knowledge	MEA performance and requirments on the system solution	Yes	Not set	Knowhow on MEA performance and requirments on the system solution	C29 - Manufacture of motor vehicles, trailers and semi-trailers	Not set	No IP protection ecpected	Volvo

Details on each of the exploitable results listed above, such as potential, market, etc., as well as the time frame, partners and requirements involved in its exploitation, can be found in the deliverable report *D8.4 Draft exploitation plan* (confidential). See also the Section IV *Potential impact* of the *Final publishable summary report* chapter.

Report on societal implications

A General Information *(completed automatically when **Grant Agreement number** is entered.*

FCH JU Grant Agreement Number:	303466
Title of Project:	**Innovative autoMotive MEa Development – implementation of Iphe-genie Achievements Targeted at Excellence [IMMEDIATE]**
Name and Title of Coordinator:	Madeleine Odgaard, vice president

B Ethics

1. Did you have ethicists or others with specific experience of ethical issues involved in the project?	☐ ☒	**Yes** **No**
2. Please indicate whether your project involved any of the following issues:		
INFORMED CONSENT		
• Did the project involve children?		No
• Did the project involve patients or persons not able to give consent?		No
• Did the project involve adult healthy volunteers?		No
• Did the project involve Human Genetic Material?		No
• Did the project involve Human biological samples?		No
• Did the project involve Human data collection?		No
RESEARCH ON HUMAN EMBRYO/FOETUS		
• Did the project involve Human Embryos?		No
• Did the project involve Human Foetal Tissue / Cells?		No
• Did the project involve Human Embryonic Stem Cells?		No
PRIVACY		
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)		No
• Did the project involve tracking the location or observation of people?		No
RESEARCH ON ANIMALS		
• Did the project involve research on animals?		No
• Were those animals transgenic small laboratory animals?		No
• Were those animals transgenic farm animals?		No
• Were those animals cloning farm animals?		No
• Were those animals non-human primates?		No
RESEARCH INVOLVING DEVELOPING COUNTRIES		
• Use of local resources (genetic, animal, plant etc.)		No
• Benefit to local community (capacity building i.e. access to healthcare, education etc.)		No
DUAL USE		
• Research having potential military / terrorist application		No

C Workforce Statistics

3 Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	1 (IRD)	0
Work package leader	1 (IRD) 1 (CNRS) 1 (TC) ***In total: 3***	1 (IRD) 1 (FUMA) 2 (Volvo) 1 (SGL) ***In total: 5***
Experienced researcher (i.e. PhD holders)	1 (IRD) 4 (CNRS) 1 (SGL) 2 (ICPF) 1 (TC) 1 (SJTU) ***In total: 10***	1 (IRD) 5 (CNRS) 3 (FUMA) 2 (Volvo) 1 (SGL) 4 (ICPF) 1 (TC) 2 (SJTU) 1 (JRC) ***In total: 20***
PhD Students	1 (CNRS) 1 (ICPF) ***In total: 2***	
Other	1 (IRD) 2 (FUMA) 1 (SGL) 1 (ICPF) 2 (SJTU) ***In total: 7***	1 (IRD) 1 (CNRS) 3 (FUMA) 1 (SGL) 2 (TC) 1 (SJTU) 1 (JRC) ***In total: 10***
4 How many additional researchers (in companies and universities) were recruited specifically for this project?		**6**
Of which, indicate the number of men:		2 (FUMA) 1 (CNRS) ***In total: 3***
Of which, indicate the number of women:		3 (CNRS) ***In total: 3***

D Gender Aspects

5 Did you carry out specific Gender Equality Actions under the project?

☒ Yes
☐ No

6 Which of the following actions did you carry out and how effective were they?

	Not at all effective				Very effective
☐ Design and implement an equal opportunity policy	○	○	○	●	○
☐ Set targets to achieve a gender balance in the workforce	○	○	○	○	○
☐ Organise conferences and workshops on gender	○	○	○	○	○
☐ Actions to improve work-life balance	○	○	○	○	○
○ Other:					

7 Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

☐ Yes- please specify
☒ No

E Synergies with Science Education

8 Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

☒ Yes - please specify
- FUMA: Company open day
- ICPF: Co-participation of one pre-graduate research student of Open-Science 4 who presented scientific co-poster at event "Veletrh vìdy" organised by Czech Academy of Science 21-23 May 2015 held in PVA EXPO Prague - Letòany

☐ No

9 Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

☐ Yes- please specify
☒ No

F Interdisciplinarity

10 Which disciplines (see list below) are involved in your project?

☐ Main discipline[1]: 2.3
☐ Associated discipline: 1.3 | ○ | Associated discipline: 1.2

[1] Insert number from list (Frascati Manual)

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

☒ Yes
☐ No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

☒ No
☐ Yes- in determining what research should be performed
☐ Yes - in implementing the research
☐ Yes, in communicating /disseminating / using the results of the project

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?

☐ Yes
☐ No

12 Did you engage with government / public bodies or policy makers (including international organisations)

☐ No
☐ Yes- in framing the research agenda
☐ Yes - in implementing the research agenda
☒ Yes, in communicating /disseminating / using the results of the project. Defining the European automotive PEMFC test protocols.

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

☐ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
☒ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
☐ No

13b If Yes, in which fields?

Agriculture	Energy ✖	Human rights	
Audiovisual and Media	Enlargement	Information Society	
Budget	Enterprise	Institutional affairs	
Competition	Environment ✖	Internal Market	
Consumers	External Relations	Justice, freedom and security	
Culture	External Trade	Public Health	
Customs	Fisheries and Maritime Affairs	Regional Policy	
Development Economic and Monetary Affairs	Food Safety	Research and Innovation	
Education, Training, Youth	Foreign and Security Policy	Space	
Employment and Social Affairs	Fraud	Taxation	
	Humanitarian aid	Transport	

13c If Yes, at which level?

☐ Local / regional levels
☒ National level
☒ European level
☒ International level

H Use and dissemination

14 How many Articles were published/accepted for publication in peer-reviewed journals?		**4**
To how many of these is open access[2] provided?		**3**
How many of these are published in open access journals?		**1**
How many of these are published in open repositories?		**2**
To how many of these is open access not provided?		**1**
Please check all applicable reasons for not providing open access:		
☒ publisher's licensing agreement would not permit publishing in a repository ☐ no suitable repository available ☒ no suitable open access journal available ☐ no funds available to publish in an open access journal ☐ lack of time and resources ☐ lack of information on open access ☐ other: ……		
15 How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**0 patent applications**
16 Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**1 utility model**
17 How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		

18 Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

☐	Increase in employment, or	☐	In small & medium-sized enterprises
☐	Safeguard employment, or	☐	In large companies
☐	Decrease in employment,	☐	None of the above / not relevant to the project
☒	Difficult to estimate / not possible to quantify	☐	

19	**For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:**	*Indicate figure:* ☒ for some partners
Difficult to estimate / not possible to quantify		

[2] Open Access is defined as free of charge access for anyone via the internet.

I Media and Communication to the general public

20 As part of the project, were any of the beneficiaries professionals in communication or media relations?

❑ Yes ☒ No

21 As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

❑ Yes ☒ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

❑	Press Release	❑	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
☒	Brochures /posters / flyers	☒	Website for the general public / internet
❑	DVD /Film /Multimedia	☒	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	☒	English
❑	Other language(s)		