Periodic Reporting for period 2 - GAIA (next Generation Automotive membrane electrode Assemblies)

Reporting period: 2020-07-01 to 2022-06-30

Summary of the context and overall objectives of the project

GAIA had the overall aim of developing high power and high current density automotive membrane electrode assemblies (MEAs) with designs satisfying the operational (beginning of life power density
Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

The two major achievements in terms of project metrics correspond to the FCH JU 2024 performance target for light duty vehicles, first reached in June 2021, and again in June 2022, and on reducing the voltage loss rate with the final MEAs in a short stack to within the target range over the first 600 hours of operation of an automotive drive cycle, including (and in particular) at 105 °C. Cognisant of the challenge of reaching a sufficiently low degradation rate (11-14 µV/h) consistent with reaching the 6,000 hour lifetime target while also, with the same MEAs, achieving the 1.8 W/cm² power density at high current density (3 A/cm²) target, the outcomes of GAIA represent an important step forward for fuel cell transport MEA technology. The results are all the more important that they were obtained with MEAs using materials developed and up-scaled in GAIA.

WP2 dealt with the requirements, test methods, operating conditions and performance benchmarking for a unified approach to the evaluation of GAIA MEAs and MEA components. Fuel cell system simulations showed that operating temperatures of >100 °C are very favourable for system architecture and lower cost. Operating conditions for fuel cell stack operation (including operating points at 105 °C), single cell and stack operating conditions were set up and subsequently revised for improved stack performance while remaining within the boundary conditions of operation of a fuel cell vehicle. Several 4- and 10-cell stacks were built and provided to WP6. The cost analysis of WP2 reached two important conclusions: firstly that recycling (catalyst and ionomer) has the potential to significantly reduce MEA cost, and that, with this, the cost per kW of the final GAIA MEA approaches the 6 €/kW target of the FCH JU 2019 annual working plan.

WP3 developed low EW ionomers with low melt flow index (high molecular weight) for the membrane. The processing and formulation of thermostable electrospun nanofibre reinforcements were optimised, and the target materials throughput rate was achieved. For the first time, an upscaled electrospun reinforcement was employed in the membrane used for the MEA in final stack testing. Multiple rolls of upscaled nanofibre web were produced and delivered for membrane fabrication. Thin (12-15 µm) reinforced fuel cell membranes comprising low equivalent weight (EW) perfluorosulfonic acid (PFSA) ionomer and chemical stabilisation components were produced at scale and characterised ex situ and in situ. A library of high oxygen permeability polymers with variation of the polymer backbone structure, equivalent weight and molecular weight was developed, and the impact of these variables on the oxygen permeation and MEA performance improvement was determined.

WP4 developed high mass activity catalysts supported on highly structured, surface-modified, corrosion resistant supports. Novel carbon supports were surface-modified by nitrogen plasma treatment and calorimetric and thermogravimetric methods were developed to evaluate the strength of the ionomer-support interaction. Novel catalytic entities were prepared, comprising both thin films and structured particles, platinum only and as alloys, in particular with nickel and with rare earth metals. The catalyst mass activity in a fuel cell reached 0.89 A/g Pt (PtNi/C catalyst), exceeding the target of 0.7 A/g Pt. The PtY, PtNd and PtGd alloy catalysts developed provided the highest reported power density at high current density of any fuel cell with Pt-rare-earth cathode catalyst. Systematic study of the effect of catalyst particle location within carbon support micropores and outside of such micropores led to selection of these catalyst types for use in the MEAs developed in WP5.
MEAs comprising novel ionomers from WP3, designed to give increased oxygen permeability, were assessed by analysing the local transport resistances under a range of operating conditions. Thinner membranes were evaluated and integrated respectively into Gen3 and Gen4 MEAs, both of which achieved the 1.8 W/cm² at 0.6 V performance target. WP4 catalyst materials with Pt-location preferentially near the surface of the particles led to MEAs with lower mass transport resistance in particular at low stoichiometries and high current densities, and they were used in the Gen3 and Gen4 MEAs. The Gen4 MEA also achieved the 1.8 W/cm² GAIA performance target in short stack testing and showed substantial improvement in degradation rate, achieving the project target under some of the operating points albeit not under all conditions. Layers with graded Pt loading cathodes were developed and the performance impact of decal transfer processes in terms of contact resistance and changes in porosity of the catalyst layer with transfer conditions was quantified.

In WP6, a GDL with high degree of graphitisation and a more open microporous layer was used in combination with the GAIA Gen3 and Gen4 catalyst coated membranes. The operating conditions were optimised at all the operating points defined at the beginning of the project for improved compatibility with the selection of GDL and catalyst layers. During the first 600 operating hours of an automotive drive cycle with the Gen4 stack, all 65L, 80M+ and 105M (65 °C, low current density, 80 °C intermediate-high current density, 105 °C intermediate current density) operating points demonstrated degradation rates clearly meeting and even exceeding the target of between -11 and -14 µV/h. In particular, the extremely low degradation rate of -4 µV/h at the 105M operating point was remarkable as it demonstrates the very good high temperature stability at 105 °C stack temperature. The calculated degradation rates, handled with care, demonstrate moderate or low degradation if the three of ten cells with remarkably low performance are not considered. This means in a best-case scenario the durability target was reached, even at the high power density operating points.

In WP7, eight articles were published to date in international high quality journals, and many other results are in the course of drafting into publications. A project flyer and three project newsletters were published for more general audiences, and two video clips were produced, one on automotive MEA preparation and a second on fabrication of a nanofibre reinforced membrane.

The target 1.8 W/cm² at 0.6 V seemed an aspirational target at the beginning of the project, but the unachievable was achieved in GAIA with two slightly different MEA constructions, in each case with full-size automotive MEAs in short stacks. The reproducibility is therefore demonstrated. By reaching this high-power density without increasing platinum loading, the Pt-specific power density was reduced from 0.45 g Pt/kW (e.g. VOLUMETRIQ) to 0.25 g Pt/kW.

GAIA had the great honour of being part of the project cluster recognised in the FCH JU Awards 2019 as “Best Success Story” for “driving forward automotive fuel cell technology”.

Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)

GAIA’s excellent project team has driven the project achievements to reach the final performance target, while also making excellent progress towards durability and costs targets.
Achievement of the intermediate performance target of 1.5 W/cm² at 0.6 V in a full size single cell

cell voltage against time on operation during drive cycle testing at four load points

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