**PrimoLyzer (245228)**

# *Project Final Report*

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| FCH JU Grant agreement no.: | 245228 |
| Project acronym: | **PrimoLyzer** |
| Project full title: | **Pr**essur**i**sed PE**M** Electrolyser stack |
| Funding scheme: | Collaborative Project, Small or medium-scale focused research project |

# FINAL PUBLISHABLE SUMMARY REPORT

## EXECUTIVE SUMMARY

The primary objective of the PrimoLyzer project (www.primolyzer.ird.dk) is to develop, construct, and test a cost-minimised, highly efficient and durable PEM-Electrolyser **stack** aimed for integration with domestic µCHPs.

The following six (6) partners have carried out the work (Jan-2010 to Jul-2012): IRD A/S (coordinator), ECN, VTT, FumaTech, Åbo Academi, and Abengoa Hidrógeno[1].

The project work was initiated by an analysis of a PEM electrolyser aimed for integration with surplus wind and solar power. Depending on the weight of the different criteria several types of stacks can be produced. Finally, considering an estimated power of 4 kW for the electrolyser stack and an inlet voltage of 48 $V_{DC}$, it is decided that the electrolyser stack will include 29-cells with a surface of 69 $cm^2$. Considering that the system will be used during 10±2 hours a day, with a production and consumption flow of 1 $Nm^3$/hour, a hydrogen storage of 11 $Nm^3$ should be considered.

Carbon black and multi walled carbon nanotube supported Pt and PtPd catalysts were studied for the hydrogen evolution reaction (HER). 10 wt% noble metal loading was found optimal in liquid $H_2SO_4$ electrolyte and the activity target of 1.5 $A/cm^2$ at – 40 mV (RHE) was met already at room temperature. The OER (Oxygen evolution reaction) reaction was studied by molecular modelling and a new reaction mechanism with surface oxygen molecule $S\text{-}O_2$ as a reaction intermediate is proposed.

As a key component of the PEM water electrolysis cell, a polymer electrolyte membrane with good mechanical, thermal and chemical stability is required. A PFSA-based membrane and composite membranes were developed and characterised. A hydrocarbon-based sPS was also developed with the aim to reduce the gas crossover and cost. The new PFSA and/or composite membranes show the same thermal stability, comparable mechanical properties and lower resistance as well as better water electrolysis performance as the state of the art membranes. The reinforced PFSA membranes bring obviously improved strength, low gas permeability and reduced water permeation, reduced swelling and linear expansion.

The best performing MEAs are equipped with a VTT OER catalyst consisting of mixed Ir-Ru and a rather thin [120 µm] Fumatech PSFA-type membrane. The single cell IR-corrected polarisations of the optimised MEAs show a better performance than the project target [1.64 V @ 1.2 $A/cm^2$] for MEAs with less than the targeted catalyst loadings [actual Anode/Cathode loading: 0.3/0.5 mg per $cm^2$; target: Anode/Cathode loading: 1.0/0.5 mg per $cm^2$]. A membrane comparison study has shown that the performance of MEAs based on the reinforced membrane is poorer due to higher resistance. However, it has been concluded that reinforcement is necessary to accommodate the high differential MEA pressures.

Several MEAs have been tested for longer periods. In total is ≈17,000 h single cell test hours made. The main results from these durability studies are as follows:

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[1] Former legal name: Hynergreen Technologies, S.A.

- The observed degradation rate is $\leq$30 µV/h, best for the MEAs equipped with the FumaTech membrane developed within the PrimoLyzer project
- The VTT developed OER catalyst is more stable than the benchmark anode catalyst
- The BoL performance and the measured degradation rate indicate a lifetime of $\geq$2 years

The stack design work done comprises ex-situ component tests, mechanical property considerations using a safety factor of $\geq$1.3, and manifold & flow field modelling/simulations. Based on the experiments, simulations and calculations a PEM electrolyser stack was designed in accordance with the standard: IEC 62282-2(2005-3) FC technologies-Part 2. The final stack did not perform as targeted mainly due to two reasons: 1) The MEAs are based on rather thick membranes for safety reasons; 2) A high ohmic resistance was noted between the two cathode flow-plates. >1,000 hours of operation has been achieved although with two different stacks. The highlights from these tests are as follows:

- The membrane and the anode catalyst developed within PrimoLyzer proved better than the commercial available reference materials
- A total of 620 $Nm^3$ has been produced using 3,038 kWh (4.9 $kWh/Nm^3$ $H_2$)
- Heat produced for utilisation in central heating systems: ≈2 kWh/h using water cooling
- Hydrogen outlet pressure: 50-100 bar
- An average cell voltage of 2.1 V @ 1.2 $A/cm^2$ was obtained @ $P_{H2}$=50 bar & T=70ºC±10ºC
- The purity of the produced $H_2$ is high (99.996%). A 1.5 kW LT PEM µCHP has without any problems been operated on the produced hydrogen for ≈220 hours

The PEMEC electrolyser has been tested and the following efficiencies measured/calculated:

- PEMEC stack: $P_{AC} \rightarrow H_2$: 60% efficient
- PEMEC system: $P_{AC} \rightarrow H_2$: 53% efficient
- PEMEC system: $P_{AC} \rightarrow H_2 + P_{TH}$: 96% efficient

The up-scale cost analysis focus on the contribution of each different element. The analysis shows that the cost of one electrolyser can be reduced by ≈50% when the total stack production volume is increased from 1 to 100 stack units. In conclusion, the cost of one stack with a 1 $Nm^3/h$ hydrogen production capacity is less than 5,000 € in production of 100 units.

## PROJECT CONTEXT AND OBJECTIVES

The primary objective of the PrimoLyzer project was to develop, construct, and test a cost-minimised highly efficient and durable PEM-Electrolyser stack aimed for integration with domestic µCHPs. This has been achieved through a combination of the following activities:

- Specification done by the end-user [Abengoa Hidrogeno]
- Basic material R&D to increase electrode stability and efficiency, development of new catalyst and materials for lowering costs and improving performance [VTT & Åbo Academi]
- Basic material R&D to develop an efficient, low cost and durable membrane with sufficiently low gas crossover to allow high pressure operation [Fumatech]

- Process development to fabricate high performance MEAs [ECN & IRD]
- Engineering of a durable, reliable, and robust high pressure PEM stack through CFD modelling and design optimisation [IRD]
- Long-time continuous stack test together with a hydrogen fuelled 1.5 kW µCHP [IRD]
- An evaluation headed by the end-user [Abengoa Hidrogeno]

The PrimoLyzer project was focussed on the Electrolyser stack. The concluding tests were done in a spread-out setup together with a 1.5 kW µCHP-system. The specific key-targets for the stack were as follows:

- Hydrogen production capacity: 1 $Nm^3/h$
- Pressure: 10 MPa (100 bar)
- 1.68 V @ 1.2 $A/cm^2$ not only at BoL but also after 2,000 hours of continuous operation
- Cost: <5,000 € per $Nm^3$ $H_2$ production capacity per hour in series production
- Durability: >20,000 hours @ constant load
- Operation of the PEM Electrolyser ($\eta$>75% LHV) stack together with a dead-end µCHP (1.5 $kW_{AC}$); 2,000 hours of test was targeted.

The project has been coordinated by Dr. Laila Grahl-Madsen, IRD A/S (LGM@IRD.dk). A public project website is available at: www.PrimoLyzer.ird.dk.

## MAIN S&T RESULTS/FOREGROUNDS

The technical work has been carried out in the following six (6) work packages: WP1 Specification; WP2 Catalyst; WP3 Membrane; WP4 MEA; WP5 Stack; and WP6 Evaluation. The project was initiated on the 1st of January 2010 and completed on the 30rd of June 2012 (2½ year). The PrimoLyzer consortium consists of the six (6) participants listed below along with their main project responsibilities:

| Partner ID | Business activity | Main project responsibility |
|---|---|---|
| IRD A/S (IRD; DK) | MEA manufacture<br>FC component manufacture<br>PEM FC stack manufacture<br>PEM & DMFC module/system development | Project coordinator<br>Manufacture of MEAs<br>Design, construction and validation of Electrolyser stack<br>Long-term testing of the Electrolyser stack along with a PEM FCHP |
| Stichting Enerieonderzoek Centrum Nederland (ECN) | Research centre: PEM FC & EC development | MEA development<br>Design, and validation of Electrolyser stack |
| Valtion Teknillinen | Research centre: PEM FC & EC | Catalyst development |

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| Tutkimuskeskus (VTT) | development | |
| Fuma-Tech Gesellschaft Fuer Funktionelle Membranen und Anlagentechnologie MBH | Ion-exchange membrane manufacture<br>Production of membrane stacks for electrochemical processes<br>Ionomer, membrane and MEA-producer | Membrane development and supply |
| Abengoa Hidrógeno (AH) | Electricity production utilizing new different RE-technologies | Specification and evaluation |
| Åbo Akademi (AABO) | University: PEM FC & EC development | Microstructural and electrochemical characterisation |

ECN withdrew from the project on the 1st of April 2011 as a consequence of the ECN management decision to terminate their Hydrogen & Fuel Cell program.

The scientific work has been carried out in six (6) technical work packages. The objectives and the main results are summarised below.

### WP1 ANALYSIS AND SPECIFICATIONS (HEADED BY ABENGOA HIDRÓGENO [AH]):

The main objective of WP1 was to define the necessary requirements for the integration of the PEM Electrolyser with wind and solar technologies in a prototype plant. This WP was headed by an end-user. In general, the main results of WP1 are as follows:

- Definition of the requirements of the PEM electrolyser stack. Two renewable power sources (wind and solar) for the integration with the PEM electrolyser have been analysed for characteristics and availability. The outcome was a specification of the electrolyser system for integration with renewable power sources.
- Specification of the requirements of the PEM Electrolyser BoP. The BoP required for the PEM electrolyser stack considered include: Power converter system, Cell voltage monitoring system (CVMS), Control and instrumentation systems (valves, regulators, sensors, and crossover detection), Water supply, Hydrogen purification and Refrigeration & Storage systems.
- Analysis of a PEM Electrolyser aimed for the integration with surplus wind and solar power. The possible configuration of the electrolyser and the renewable sources integration has been analysed.
- Analysis of the integration of the prototype plant (Solar/wind technology device-PEM electrolyser). For each renewable source two possibilities (coupled and decoupled operation with the electrolyser) have been studied, considering decoupled operation as the better option. For this reason, different technologies that could be used to storage hydrogen have been investigated and the advantages and disadvantages of each one have been presented.

AH has furthermore studied the safety requirements that have to be considered in the installation, taking into account the possibility to include hydrogen and oxygen storage. A report that includes the main safety requirements considering the characteristics of the PrimoLyzer installation (high pressure and hazardous gases) has been compiled.

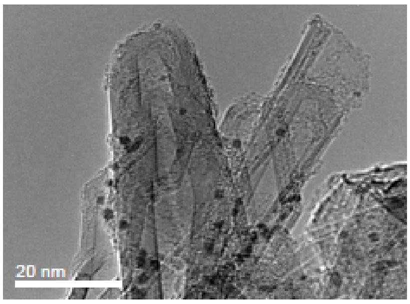

Fig. 1
TEM image of the 10 wt% Pt on MWCNT catalyst.

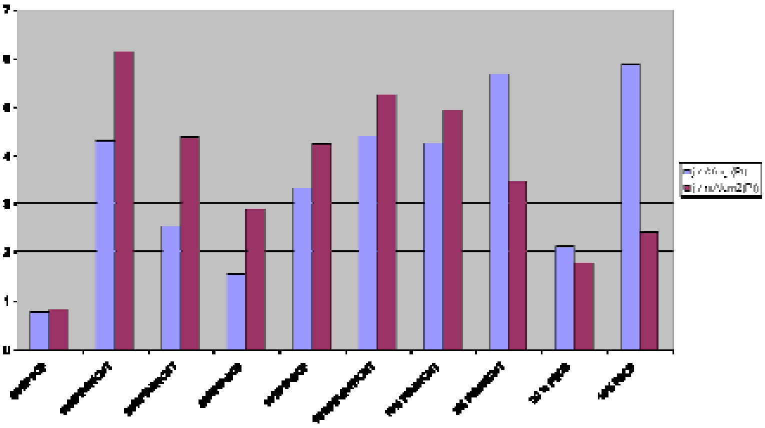

Fig. 2 Cathodic HER catalyst performance at -50 mV (RHE) and room temperature in 0.5 M $H_2SO_4$.

WP2 CATALYST (HEADED BY VTT):

*WP2 Objectives*: The WP objectives were to develop mixed metal oxide (MMO) anode catalyst and CNT supported PtPd cathode catalyst facilitating MEA performance of 1.2 A/cm$^2$ at 1.64 $V_{DC}$ and extrapolated durability of 20,000 h. The performance target for the anode catalyst was 1.2 A/cm$^2$ at 1.45 V (RHE) and for the cathode catalyst 1.2 A/cm$^2$ at – 40 mV (RHE).

*WP2 Results*: Pt and Pd were deposited on carbon black (CB) and graphitized multi-walled carbon nanotubes (MWCNT) by a well-established impregnation method for the cathodic hydrogen evolution reaction (HER) catalyst. The crystal sizes of the catalysts were characterized by TEM (Fig. 1), EDS and XRD. The crystal size was in the range of 4-6 nm. Pd formed larger aggregates than Pt. The performance of these catalysts was measured on a rotating disc electrode (RDE) at room temperature and -50 mV (RHE) in 0.5 M $H_2SO_4$. The electrochemical surface area was measured by the CO desorption method. Optimum noble metal loading on carbon appeared to be 10 wt% Pt or PtPd (Fig. 2). At this loading the Pt/CB, PtPd/CB, Pt/MWCNT and PtPd/MWCNT catalysts reached current outputs above 3 A/mg at – 40 mV (RHE) corresponding to 1.5 A/cm$^2$ at the target loading of 0.5 mg/cm$^2$. The activity target was reached in $H_2SO_4$ at room temperature and the best catalyst synthesized in the project was five (5) times as active as the commercial 60 wt% Pt/CB reference catalyst.

The catalyst performance was further verified at MEA level combining the HER cathode with a fuel cell type of 60 wt% Pt/CB hydrogen anode in a hydrogen pump mode. The experiments were carried out using a fully humidified anode and liquid water circulation at the cathode at 80°C. The results showed that the high specific activity of the 10 wt% Pt/CB or Pt/MWCNT catalysts is lost due to the increase in the thickness of the cathode catalyst layer in comparison to the 60 wt% Pt/CB catalyst and therefore 20 wt% Pt/MWCNT catalyst was selected as the final composition for the MEAs. As the fuel cell anodes did not exhibit long-term stability at the measurement conditions, the electrolyser cathode stability was further verified at MEA and stack level.

Mixed metal oxide (MMO) catalysts were developed for the anodic oxygen evolution reaction (OER) using three different approaches: Adams fusion, sol-gel and flame spray pyrolysis (FSP). The experimental work was supported by a molecular modelling work on oxygen evolution on rutile type of MMOs.

Binary oxides of Ir with Ru, Sn, Ta, Ti, Co and Mn as well as tertiary oxides with Ru and Sn were prepared by the Adams method. The oxides were characterized by TEM (Fig. 3), EDS and XRD for the crystal size. The performance was measured on an RDE at room temperature in 0.5 M $H_2SO_4$. The OER onset potential was estimated by fitting tangents to galvanostatic polarization curves and the current output was measured at 1.8 V (RHE) (Fig. 4 & 5). The most active compositions were Ir-Ru, Ir-Sn and Ir-Ru-Sn MMOs. $IrRu_3O_8$ was selected for further studies. As the OER activity is very temperature dependent, the target values could not be reached at room temperature. However, the superior activity of the selected catalyst was confirmed at MEA level in WP4.

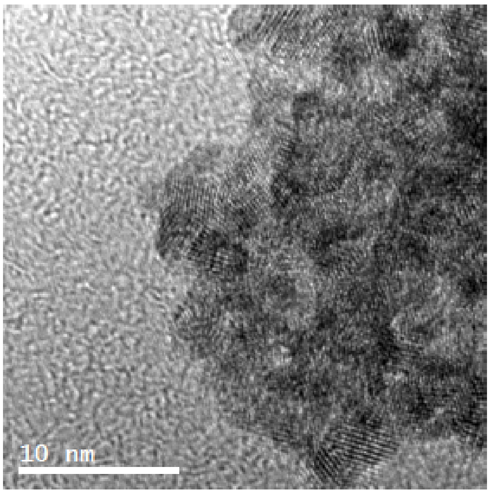

Fig. 3
TEM image of the $IrO_2$ catalyst.

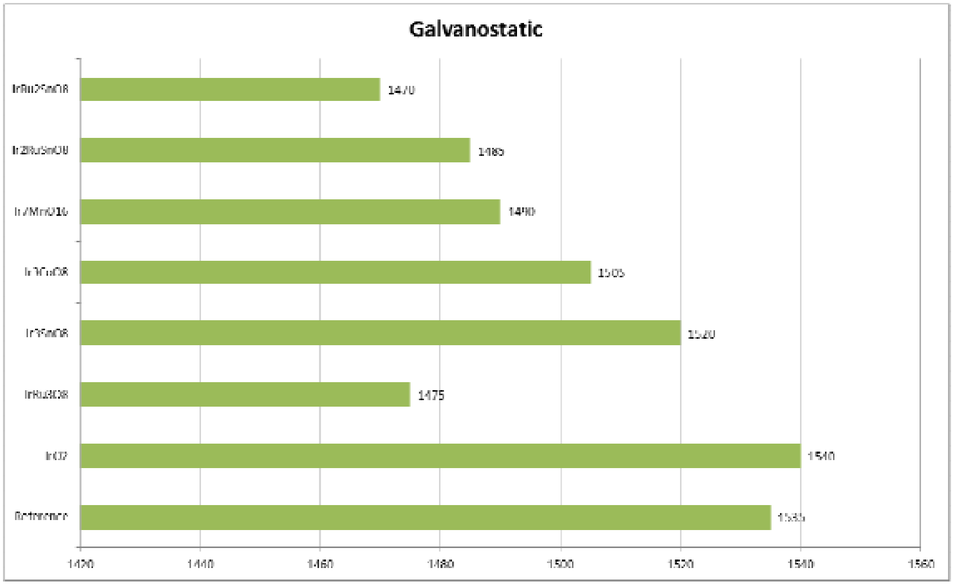

Fig. 4 Onset potential (RHE) of the OER reaction at room temperature in 0.5 M $H_2SO_4$.

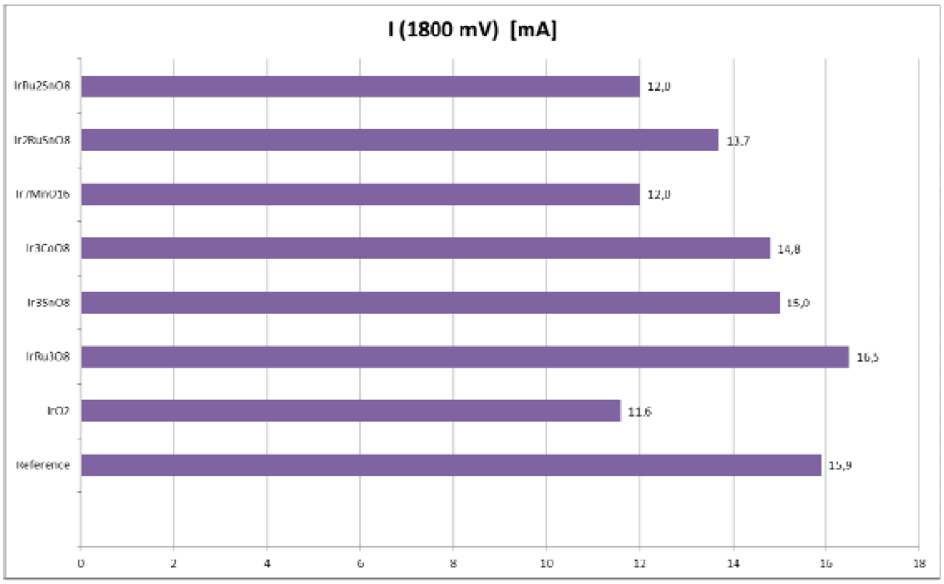

Fig. 5 Current output of 10 µg samples of OER catalyst at 1.8 V (RHE) and room temperature in 0.5 M $H_2SO_4$.

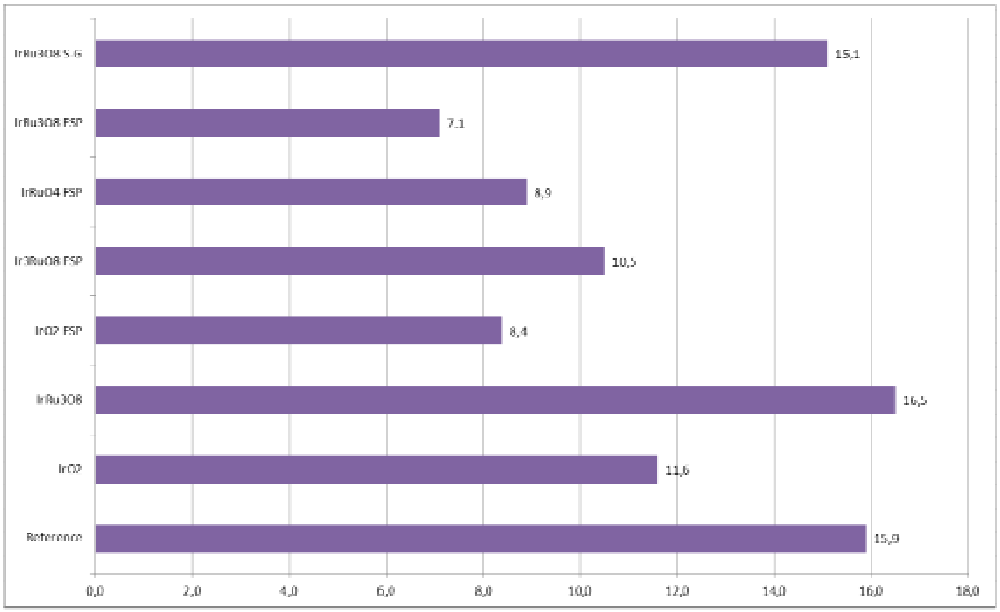

Fig. 6 Current output of Ir-Ru MMOs by different preparation methods at 1.8 V (RHE) and room temperature in 0.5 M $H_2SO_4$.

The mixed Ir-Ru oxides were prepared also by sol-gel and FSP methods. The sol-gel catalysts were almost as active as those based on the Adams method. The FSP catalysts were produced in powder form and deposited on Ti felt. In both cases the crystal size was somewhat larger than achieved by the other methods and the activity thus lower, as seen in Fig. 6.

The short-term stability of the mixed Ir-Ru oxides was measured in a thermostated flow cell at 1.85 V (RHE) and 80°C in 0.5 M $H_2SO_4$. The leached metal ions were analysed by ICP-MS in the electrolyte. The results confirmed the well-known fact that addition of iridium stabilises $RuO_2$ under these conditions. The mixed oxide appeared stable in the three-day experiment. Further catalyst stability was measured at MEA level in WP4.

The modelling work comprised studying the mechanism of the oxygen evolution reaction on the surfaces of pure, binary and tertiary metal oxides, e.g. $IrO_2$, $IrRuO_4$ and $Ir_2RuSnO_8$, with rutile or rutile-like structures. The catalyst composition was optimized by theoretical quantum mechanical calculations of mixed oxide crystal and surface structures and their interactions with water and oxygen. The crystal and surface structures of the catalysts were investigated using density functional methods. All the calculations were performed with the CASTEP (CAmbridge Serial Total Energy Package) code implemented into Materials Studio version 5.0 (Accelrys, 2009). In these calculations, the total electronic energy and overall electronic density distribution were solved in order to define the energetically stable surface structures and surfaces with reagents. The electrochemical potential was accounted for by a fixed positive charge on the surface.

A new OER mechanism shown in Fig. 7 is proposed based on the calculations. The main difference in comparison to earlier work found in the literature is that the reaction appears to proceed via a surface oxygen molecule S-$O_2$ as a reaction intermediate instead of a peroxide S-OOH.

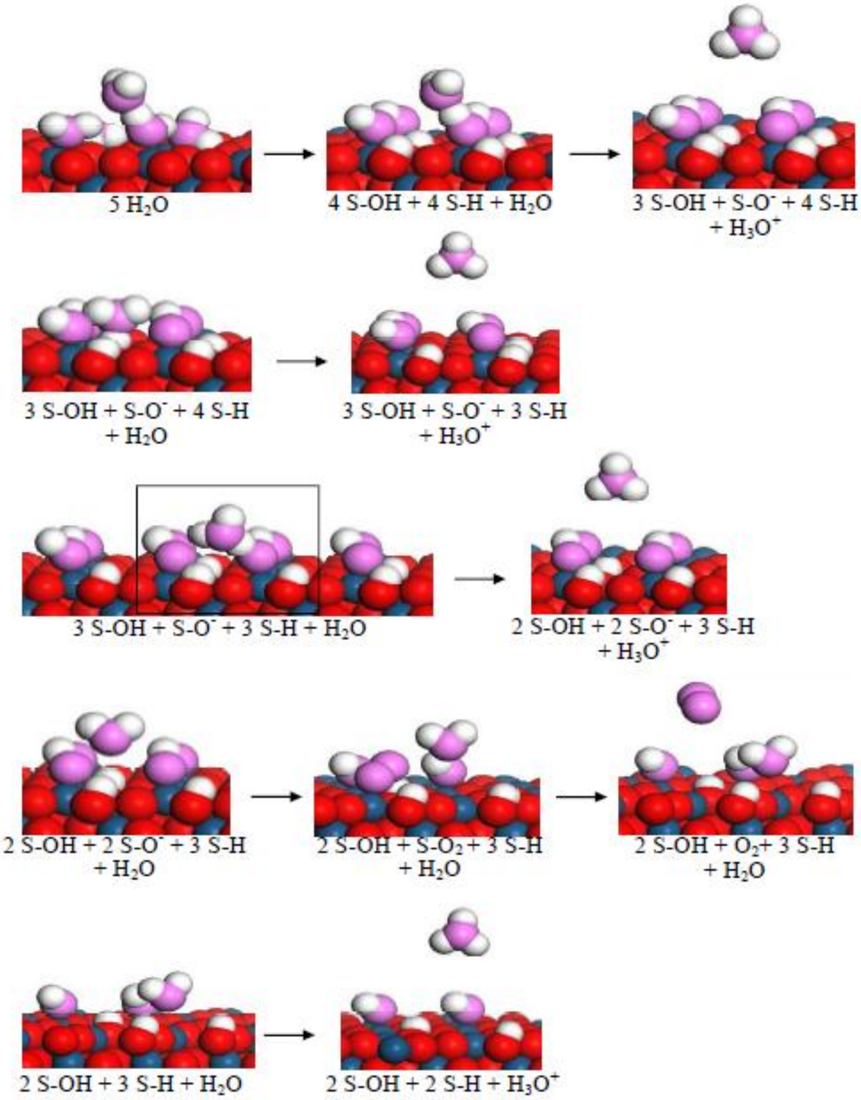

Fig. 7 Proposed OER reaction mechanism on $IrO_2$ and $IrRuO_4$.

WP3 Membrane (headed by FumaTech):

The main objective of WP3 was to develop an efficient, low cost and durable membrane with sufficiently low gas crossover to allow high-pressure operation. The main results are as follows:

- Evaluation of the *State-of-Art* PFSA membranes. Commercially available PFSA membranes as benchmark for the MEA development were evaluated. N117 and F10120 were chosen for benchmark and characterised in detail and compared with the membranes developed in this project. These evaluation results were provided to the MEA development in WP4.
- Development of improved membranes. Membranes from extrusion and casting processes were prepared. Different methods were used to match the purpose of good mechanical property, low gas permeability, lower area resistance and low cost. The PFSA membranes with different thickness were reinforced with PTFE and glass fibres and also composited with ZrP. The hydrocarbon polymer and membranes with different EWs were synthesised and prepared. The reinforcement was also used in the hydrocarbon membrane to improve the mechanical strength.
- Characterisation of improved membranes. The prepared membranes were characterised for mechanical, chemical and thermal properties with particular focus on the water transport, gas permeation, and electrochemical properties. All membranes have been tested for performance in a single cell with FumaTech standard electrolyser electrodes. The mechanical properties as well as low gas permeation and low water transport were improved through reinforcement. Lower water transport was achieved through composition. The hydrocarbon membranes could offer very high conductivity and good oxidation stability. The improved membranes manufactured are very competitive to the benchmark membranes.
- Fabrication of improved PFSA membranes. The PFSA membrane with reinforcement was considered as the promising candidate for the stack and fabricated for the project partner in sufficient quantities for the single cell test and the final stack test.

WP4 MEA (headed by ECN/IRD):

*WP4 Objectives*: The overall objective of WP4 was to develop a MEA with a performance better than 1.64 V @ 1.2 A/cm$^2$. The anode loading should be below 1 mg/cm$^2$ and cathode loading below 0.5 mg/cm$^2$. The degradation rate should be low enough to reach 20,000 h durability ($\leq$30 µV/h).

*WP4 results*: The MEA development was initiated with a benchmark study where commercial MEA precursors were used to verify the optimised MEA manufacturing technique and establish the *State-of-the-Art* MEA performance. The PrimoLyzer catalysts and membranes have been tested on a single component basis together with selected benchmark materials (Fig. 8). Good results were obtained even with lower catalyst loadings than targeted. The results showed that the IR corrected performance was well within the targeted performance (Fig. 9), but the results also revealed that the Ohmic resistances are significant.

The longer-term single cell tests comprise tests up to 5,350 hours. The degradation rate calculated in the initial tests varies from <30 µV/h to >250 µV/h, and reflects most of all different experimental events e.g. feed water purity. Two longer-term single cell tests where the most critical parameters have been well in-control are shown in Fig. 10. The degradation rate of both MEAs is acceptable and within

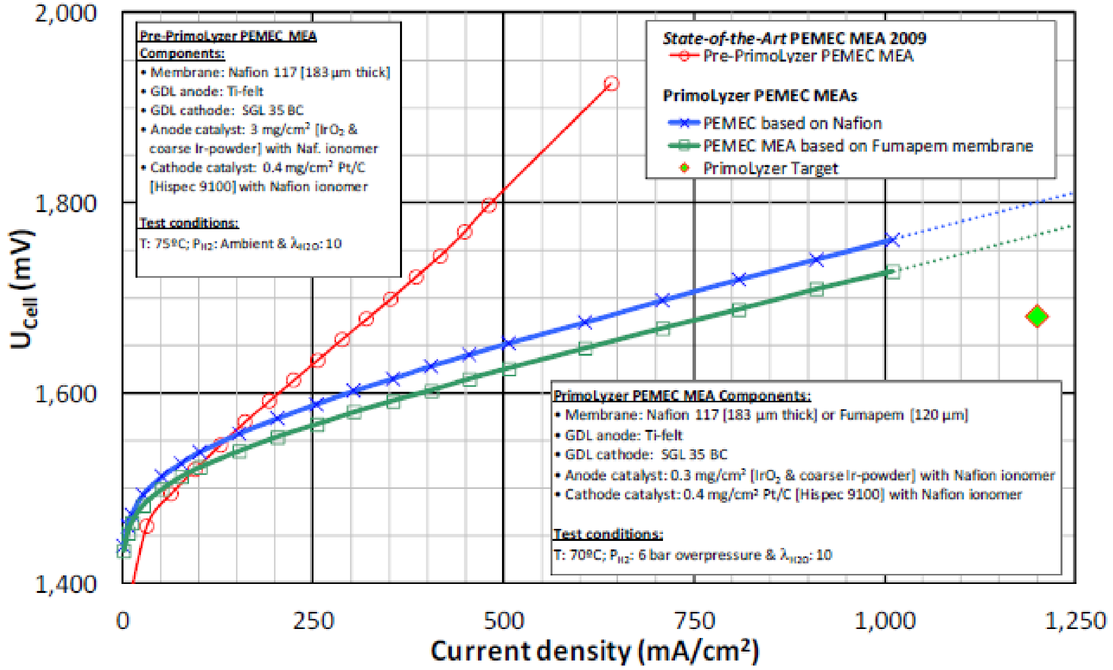

Fig. 8 Polarization curves of the *SoA* PrimoLyzer MEA's based on commercial precursors.

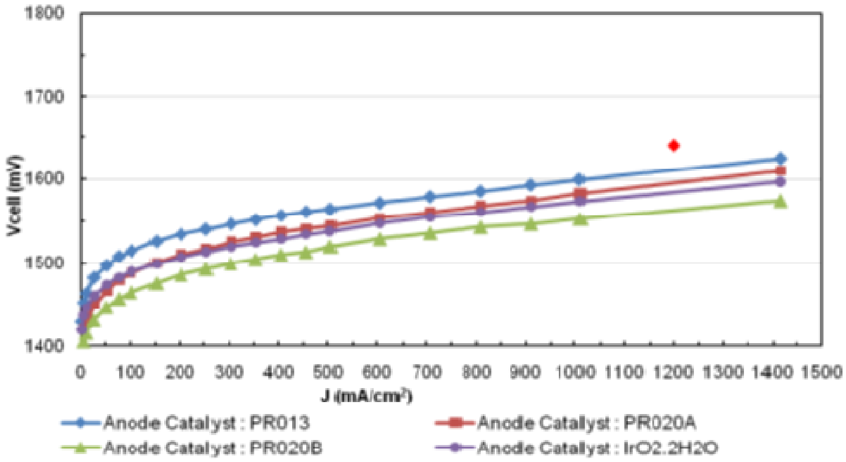

Fig. 9 IR-corrected polarization curve measured at 6 bar, 70°C, $\lambda_{H2O}=10$. The MEAs are prepared with commercial cathode catalyst (JM HiSpec 9100) and Nafion 117.

the PrimoLyzer target. The lowest degradation is obtained for the MEA based on the PrimoLyzer developed membrane (Fig. 10B). However, this is in part related to the lack of membrane activation prior to the test, which also is mirrored in the relative low performance.

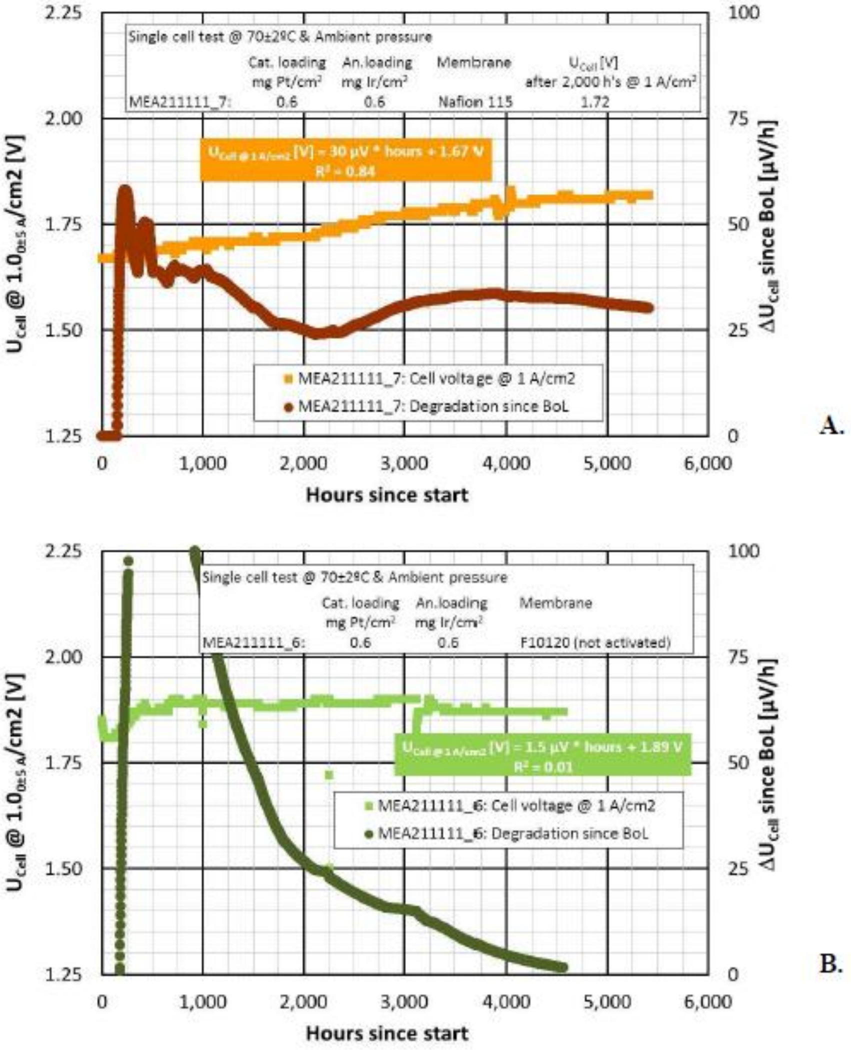

Fig. 10 Long-term single cell test of two MEAs both based on 120 µm thick membranes.

WP5 Electrolyser stack (headed by IRD): A stack capable of producing 1 $Nm^3$ $H_2$ per hour is specified to consist of 29-cells each with an active area of 69 $cm^2$. The design work done comprises ex-situ component tests, mechanical property considerations using a safety factor of $\geq$1.3, and manifold & flow field modelling/simulations. Based on the experiments, simulations and calculations a PEM electrolyser stack was designed in accordance with the standard: IEC 62282-2(2005-3) FC technologies-Part 2.

Below the main results are summarised:

- The stack (Fig. 11) has been successfully leakage tested up to 130 bar
- The mechanical stack design has proven to work very well. The following two (2) points have to be highlighted:
  - The mechanical design allows a high-pressure difference (>90 bar) across the MEA
  - The stack is relatively easy to assemble
- The combination of water supply for electrolysis and cooling has worked very well
- The final stack did not perform as targeted mainly due to two reasons:
  1) The MEAs are based on rather thick membranes for safety reasons
  2) A high ohmic resistance was noted between the two cathode flow-plates (has to be improved)
- The quality of the produced $H_2$ is high (99.996%)
- >1,000 hours of operation has been achieved although with two different sets of MEAs, the key numbers from the stack tests are as follows:
  - A total of 620 $Nm^3$ has been produced using 3,038 kWh (4.9 kWh/$Nm^3$ $H_2$)
  - Heat produced for utilisation in central heating systems: ≈2 kWh/h using water cooling
  - Hydrogen outlet pressure: 50-100 bar
  - An average cell voltage of 2.12 V @ 1.2 A/$cm^2$ was obtained after 200 h of operation @ 70°C±10°C
- A 1.5 kW LT PEM µCHP has without any problems been operated on the produced hydrogen for ≈220 hours

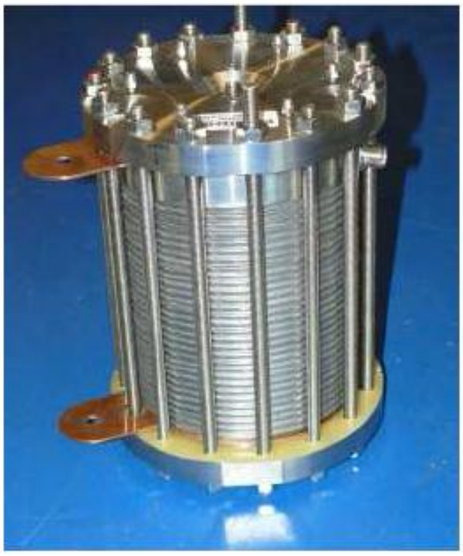

Fig. 11
Picture of a full 29-cell PrimoLyzer stack.

WP6 Evaluation (headed by AH): The aim of WP6 is to analyse the results obtained in the previous WP and to extrapolate and report the prototype results. As the aim of PrimoLyzer is to develop a high pressure PEM electrolyser to be integrated with RES (photovoltaic and wind) in order to produce hydrogen with clean energy to be used on a domestic µCHP, test protocols for the different elements and the whole plant integrated have been prepared. In summary, the tests protocols that have been developed are:

- Test protocols of wind and solar energy installations
- Tests protocols of the BoP of the PEM Electrolyser.
- Test protocols for the stack, which must be subjected to several tests to verify that the design specifications are fulfilled for compliance with the International ISO 22734-1:2008 (E). There are two groups of test for the stack, the preliminary test methods and the routine test protocols.
- Tests protocols of the whole plant integrated. Three (3) important events have been considered: Start-up, Shutdown and Emergency shutdown.

The evaluation of the PEM electrolyser has resulted in the following efficiencies:

- PEMEC stack: $P_{AC} \rightarrow H_2$: 60% efficient
- PEMEC system: $P_{AC} \rightarrow H_2$: 53% efficient
- PEMEC system: $P_{AC} \rightarrow H_2 + P_{TH}$: 96% efficient

An extrapolation of the test results has been done to predict that the durability and lifetime of a PEM electrolyser is $\geq$2 years.

In this evaluation task, the electrolyser system has been the object of an up-scale cost analysis, focusing on the contribution of each different elements cost. It should be highlight that the cost of one electrolyser could be reduced approximately 50% if the total stack production volume is increased from 1 to 100 stack units. In conclusion, the cost of one stack of 1 $Nm^3/h$ hydrogen production capacity is less than the targeted 5,000 € in production of 100 units.

## POTENTIAL IMPACT AND DISSEMINATION AND EXPLOITATION OF RESULTS

Global hydrogen production stands at around 448 billion m3/yr (40 billion kg/yr)[2]. Reforming natural gas is still cost effective and accounts currently for ≈48% of the hydrogen produced worldwide, while only a smaller amount is produced by electrolysis [up cit.]. As the price of natural gas increases, electrolysis becomes a viable option for competition in the hydrogen market. In the future hydrogen economy, an added benefit of electrolytic hydrogen production is that it offers a stable and secure energy future together with renewable energy sources. The commercial marked potential for low cost, efficient PEM electrolysers as aimed in PrimoLyzer is therefore huge. The present market for industrial electrolysers is already operated by several companies, which sell small electrolysers as a more convenient alternative to buying bottled gas. However, the number of competitors is limited and the market is characterised by a high price level. Proton Energy presently covers 70% of the PEM electrolyser market with an estimated potential turnover of 250 million euros.

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[2] Kroposki, B.; Levene, J.; Harrison, K.; Sen, P.K. & Novachek, F. (2006): Electrolyzis: Information and Opportunities for Electric Power Utilities. US Department of Energy, Technical Report NREL/TP-581-40605. pp. 1-33.

The developed membrane, catalysts, MEAs, stack components, and stack can be commercialised. The knowledge on components such as membrane, and catalyst can also be used in congener technologies. The catalysts systems and the reinforced membrane developed are at an advanced maturity level and could probably be used at an industrial level within a few years. Other materials developed are at a lower maturity level and need further R&D e.g. the hydrocarbon membrane.

IRD aims to exploit the results through the production of PEMEC MEAs and systems. Further R&D must be carried out, particular on stack and system before this goal can be achieved. The experience gained through PrimoLyzer has formed a valuable contribution to IRD's long-term strategy for FC exploitation.

For AH, PrimoLyzer project has as a potential impact in their designs of renewable hydrogen production plants by means of electrolysis. During the project, AH has increase its knowledge on high pressure PEM electrolysers, safety and regulations, and these facts has as a consequence an improvement in the integration and operation of its plants. Furthermore, during the project, AH has developed its skills on efficiency and costs analysis, what will be an advantage in its evaluation as end-user.

On the whole, the PrimoLyzer project results will assist EU to reach their short- to medium term target on sustainable hydrogen production and supply chains. The PrimoLyzer consortium aims to continue the development in a PrimoLyzer phase II comprising system development and field test together with RES.