elyntegration

Grid Integrated Multi Megawatt High Pressure Alkaline Electrolysers for Energy Applications

FINAL PROJECT REPORT

DELIVERABLE 1.3

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1 EXECUTIVE SUMMARY

This report includes a summary of all ELYntegration activities, tasks and main results.

2 SUMMARY OF THE CONTEXT AND OVERALL OBJECTIVES OF THE ACTION

The strategic goal of the ELYNTEGRATION Project (Grid Integrated Multi Megawatt High Pressure Alkaline Electrolysers for Energy Applications) is the design and engineering of a robust, flexible, efficient and cost-competitive single stack Multi Megawatt High Pressure Alkaline Water Electrolysis (AWE) of 4,5 T H_2/day capable to provide cutting-edge operational capabilities under highly dynamic power supplies expected in the frame of generation/ transmission/ distribution scenarios integrating high renewable energies (RE) shares.

The final design of the MW HP AWE has been achieved on the basis of the development, validation and demonstration of a HP AWE industrial prototype comprising:

- Cylindrical stack consisting of industrial size elementary cells, balance of plant (BOP)
- Power electronics
- Advanced communication & control system

In the early phase of the development process, great attention is brought to the identification of end-user's needs and relevant/critical operational requirements.

A set of specific objectives has been defined for the project, both at functional capabilities level and value proposition for AWE, and include

- High system efficiency and high current density
- Flexibility
- Durability in steady state and dynamic conditions
- Enhanced communication and control capabilities
- Regulatory frameworks, standards, tariffs, scenarios and end-users
- Business scenarios and business models

ELYNTEGRATION project has been carried out by a multi-disciplinary consortium, coordinated by FHA, well-balanced and with complementary expertise, which will aim at achieving the project objectives. The consortium includes an alkaline electrolyser manufacturer (IHT), research organizations to develop the new designs and components (FHA, VITO, IFAM, IAEW) and an engineering and technology provider (INYCOM).

3 WORK PERFORMED FROM THE BEGINNING OF THE ACTION TO THE END OF THE PERIOD COVERED BY THE REPORT AND MAIN RESULTS ACHIEVED SO FAR

The main results and project outcome are listed by work package in the following:

WP2

In Task 2.1 a review of the regulatory framework for the integration of electrolysers into electric power grids was conducted. It was identified, that prescribed technical requirements for grid connection are not expected to be critical. It could be shown, that end-user prices for electricity are highly dependent on regulatory frameworks thus impacting the economic efficiency of electrolysers. This task was mainly conducted by IAEW.

The second task of WP2 focused on re-evaluating the technical targets for the final design of the electrolyser. Emphasis was given to parameters that have direct impact on the acceptance of the system in potential future markets for electrolyser. The main parameters identified of significant importance are related to response time and maximum and minimum capacity. This task was mainly conducted by FHA.

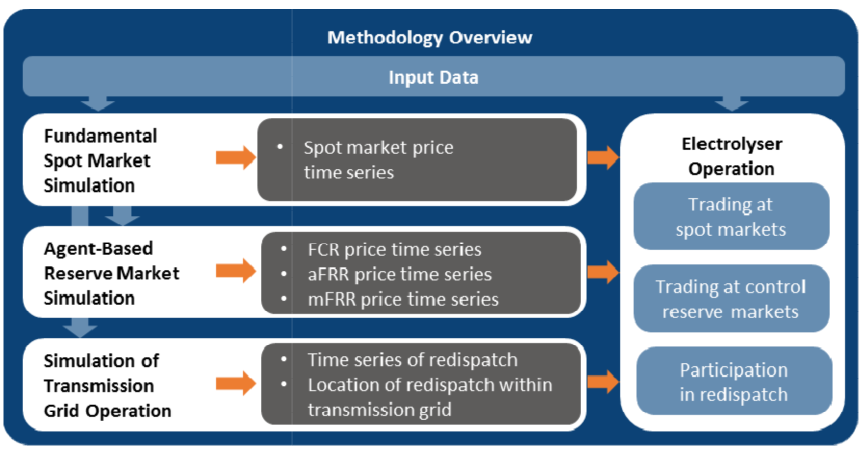

Figure 1. Overview of methdology for business model evaluation.

Within Task 2.3 potential new business models (BM) for electrolysers within the context of power systems with high shares of renewable energies were investigated. These BM include cross-commodity arbitrage trading between spot markets for electricity and hydrogen markets, provision of control reserve products and of grid services. Different simulation approaches were used in order to calculate the operational costs for electrolyser integration into the European power system. Taking into account a detailed breakdown of electrolyser investment and operational costs, potential future net margins were calculated in order to assess the profitability of each electrolyser BM. The results show, that in case of hydrogen mobility as target sector, a profitable electrolyser operation can be achieved both for BM with cross-commodity arbitrage trading and provision of control reserve (especially provision of positive automatic and manual frequency restoration reserve). It is shown that especially those power markets are promising, which are subjected to high shares of renewable energies in future scenarios. Crucial for profitable operation is a high hydrogen price, potential exemptions from end-user charges for electricity and the dynamic performance of electrolyser operation. Results of this task are presented in deliverable 2.3. Deliverable 6.4 of task 6.1 gives a detailed sensitivity analysis of the simulation results for BM evaluation. This task was mainly conducted by IAEW.

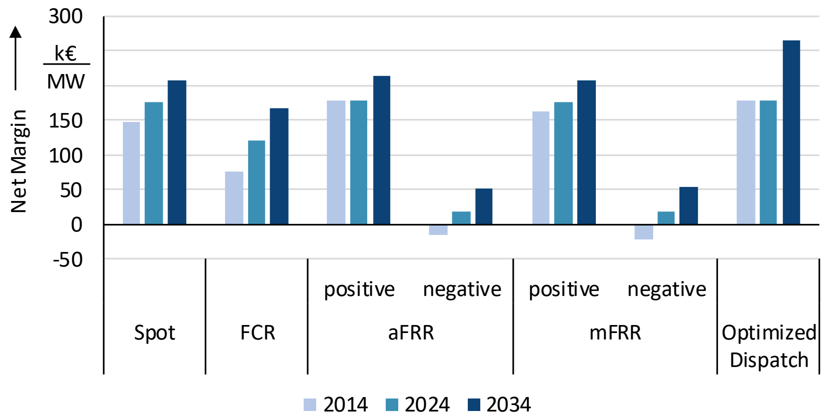

Figure 2. Net margins for a 10 MW electrolyser.

Task 2.4 was focused on the development of a Life Cycle Cost (LCC) analysis. The main goal was to achieve the following steps that ensure commercial deployment of HP AWE:

- Reduce Multi Megawatt HP AWE Total Costs of Ownership
- Achieve highly competitive CAPEX (below central SMR)

The LCC of a Multi Megawatt HP AWE is the total cost occurred for its exploitation during its whole lifetime, including the cost to produce and purchase, install, operate, maintain and dispose of all relevant equipment. Cost breakdown analysis for different electrolysis plants was evaluated, including the project developments implemented in the project in different technical fields.

A LCC sensitivity analysis was carried out, analysing the effect of major parameters into the final value of hydrogen production cost along the whole period analysed. As known, electricity cost has the major impact in MW installations, especially in those business cases with high capacity factor. Therefore, it is considered that if MWs installations are intended to be deployed to match with a growing hydrogen demand in mobility, industry and energy (P2G) markets, it is crucial to have access to low electricity prices in order to reach the hydrogen production costs in the range of 2 €/kg.

WP3

WP3 covered the development and testing of major technical developments carried out in the project, namely membrane, electrode and new cell assembly implementation.

Membrane development and testing was carried out in three different sizes, from lab and pilot scale size up to market size.

Compressible Zirfon® based membranes (with 2D textile reinforcement) which should get their gas tightness thanks to the compression when mounted in the electrochemical cell.

Membrane development has been tackled through modifications in the formulation, the microstructure and the thickness of the separator membranes. At this respect, VITO developed a total of eight different membranes, three using pore template particles of 60 nm and 5 using pore template particles of 3000 nm.

The membranes were characterised for their total porosity, pore size distribution and bubble-point (using Capillary Flow Porosimetry), water permeability, ionic resistance (both areal and specific resistance) in 30 wt% KOH electrolyte solutions at 30 °C. The bubble point was higher for Zirfon®PERL than for the new membranes; it should be noted here however that the novel developed membranes were designed considering that they would be substantially compressed when mounted in the electrolyser, situation in which the pores should be compressed and reduced in size.

The results suggest that properties for types 2 were mostly dominated by the pores and extra porosity created thanks to 3000 nm template. It is noteworthy the low resistance of these types when compared to Zirfon® PERL, despite of being 1.5 to 2.5 times thicker. SEM pictures also evidence the highly open morphology realised for this new type 2. In the case of types 1, the equilibria solvent /non solvent during the coagulation process seem the most determining for membrane morphology, with large finger-shaped pores- and hence for membrane properties.

The two most promising membranes (type 1 and type 2) were selected for testing in pilot scale stack and accelerated stress tests (AST) development. Seven pieces of each were post treated to eliminate the pore former and shipped to IHT, where they were assembled in the stack from which samples were cut for characterisation.

Additionally, the most promising membrane was produced at industrial scale for demonstration testing. Membrane production by casting at industrial scale was realised at AGFA however, membrane post treatment to remove the particle template had to be carried out at VITO. Following post-treatment, samples were taken of different membranes and micro XRF was implemented in order to confirm that the whole template had been leached out, and the membranes were packaged flat and shipped to IHT. The usual characterisations (liquid permeability, ionic resistance, CFP, porosity) were carried out as well on samples of these membranes.

Electrode development was carried out from lab up to pilot scale (intermediate size). The first step was the decision of the best substrate material. The decision was made on the basis of costs, availability, porosity and electrochemical activity. In a second step, the substrate was modified with a catalytically active surface layer, using a powder metallurgical route. For the lab, small samples (2 cm x 1 cm) were produced in order to optimize the electrochemical properties. The main parameter was the overpotential value at -300 mA/cm² (η_{300}). The iterative approach (production and electrochemical tests) was successful to improve the activity as well as the long term stability of the electrodes, resulting in an overpotential value of η_{300} = 50 mV. The production of the larger electrodes was conducted in two steps. Electrodes for the micropilot stack were produced in the first place and the electrodes for the pilot scale stack in a second step. For each step the process parameters had to be adjusted, which was accompanied by some modification measures and completely new construction of the leaching device as well as the furnace (see Figure 3). The industrial upscaling and manufacturing was also tested and analysed in cooperation with a subcontractor. The ELY-tests for the larger electrodes demonstrated the outstanding high activity and stability of the developed electrodes.

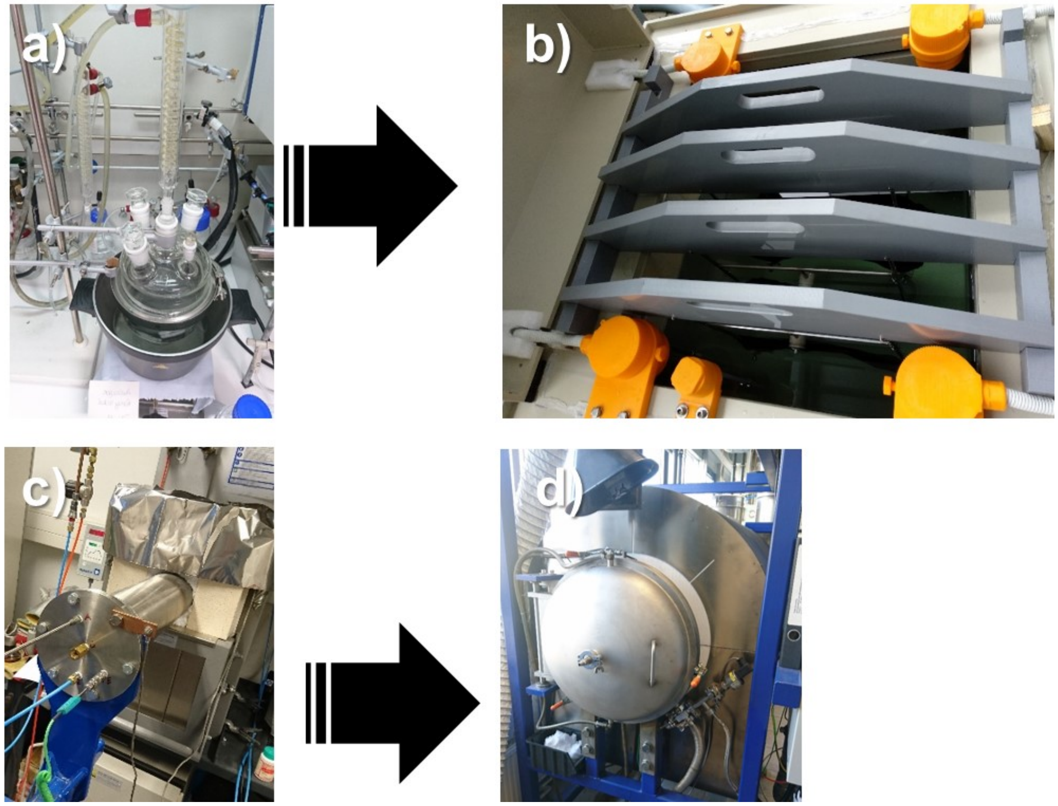

Figure 3. Leaching device fot the (a) micropilot scale and the (b) pilot scale electrodes; furnace for the heat treatment for the (c) micropilot scale electrodes and (d) for the pilot scale electrodes.

At intermediate size (pilot scale), a total of 5 different stacks were tested at FHa. In order to assess the durability of the stacks under high dynamic power profiles Accelerated Stress Test protocol (AST) for alkaline water electrolyzers was developed by FHa. This protocol mimics the operation of an electrolyser providing grid services provision. A test bench (Figure 4) for carrying out the stacks characterization under dynamic behaviour was set up at FHa. The test bench is available to work up to 60 bar and 95 ºC, a hydrogen production of 3.5 Nm^3/h and up to 25 kW. It is monitorized and remote controlled. The performance of stacks assembled with novel membranes (two types) or advanced electrodes (Ni-Mo and Raney-Ni) were evaluated and the degradation under high dynamic conditions assessed. Once the AST protocol (Figure 5) was applied for each stack, the long-term voltage degradation under the studied conditions was assessed.

Figure 4. Test bench (pilot scale) at FHa.

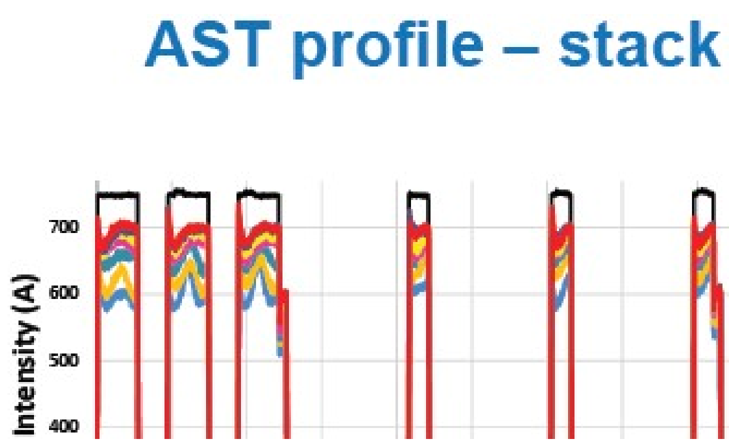

Figure 5. Accelerated stress test protocol applied. Stack performance over the time.

In general, a voltage degradation percentage was observed when the stack was working under very high dynamic current densities conditions ranking from 4 up to 9% however, it depends on the cell, in the temperature profile of the cell and the intensity applied. For some cells it has been as low as 1.83% and others as high as 13.8%. The increase is bigger at higher intensities.

The stacks assembled with the new membranes (type 1 and type 2) and standard electrodes, kept the gas purities along the tests and in special at low current density values. The membranes were characterised by VITO after AST, and the results were compared to those obtained for samples of unused membranes, in order to elucidate if membrane degradation has taken place as a result of AST experiments. SEM- EDS and ICP-MS were implemented as well to investigate changes in the membrane after AST. The deposition of inorganic foulants (identified with SEM-EDS) seemed the cause of many of the changes observed, whereas no loss of ZrO_2 happened, according to ICP-MS.

In regards of the electrodes, after the electrolyser tests at IHT and FHA, advanced Ni-Mo and Raney Ni electrodes were ex-situ analysed by IFAM using electrochemical methods, light microscopy and SEM. The analysis of the cross section revealed that no delamination or decomposition of the catalyst layer occurred during the ELY tests (see Figure 6). The overpotential value (at -300 mA/cm²) for the electrodes after the ELY-tests was nearly as high as before the tests and in some cases even higher. The results clearly reveal that a powder metallurgical route is suited for the industrial production of electrodes with high quality. The quality is referred to a high electrochemical activity, long term stability, homogeneity of the deposited catalyst layer and a highly reproducible production process. The powder metallurgical route can be applied to a broad range of catalyst systems which are attached stable to a porous or flat metallic substrate.

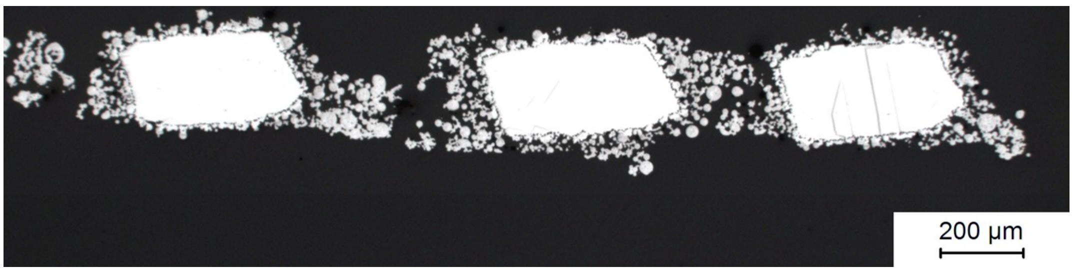

Figure 6. Cross-section (light microscopy) of a promising electrode after the tests at IHT.

There has been work related to new cell assembly implementation with the goal of adapting the electrolyser technology to new energy markets providing grid services. A modelling task has been carried out also to support and guide the analysis of this activity. Different cell assemblies have been proposed and adjusted to be tested in the frame of this WP.

The last important part of this WP was the manufacturing of the stacks used at different sizes in the project. Different stacks have been designed and implemented from scratch at intermediate level. During this WP, it has been analysed from technical point of view also the effect of new materials and assemblies in the manufacturing process.

WP4

This WP was devoted to the development of a C&CS able to simulate the reception of requests from grid operators to provide grid services (tasks 4.1 and 4.2) and to the design and modelling of a BOP suited for dynamic operation of the AWE including its cost assessment and manufacturing optimization (tasks 4.3 and 4.4).

In relation to the C&CS, the first task focused on scanning the possibilities for electrolysers to provide grid services related to frequency regulation. In this respect, the interruptibility grid service of the Spanish TSO (REE) was selected for implementation, as documentation was open and available and the service was available to be offered in 5 MW reduction packs which fits with the assumption done in deliverable 2.3, which models grid services remuneration with 10 MW electrolysers. However, the C&CS includes an interface to perform other tests including: (a) customized power curves introduction to emulate grid services provision, (b) AST and (c) other.

To facilitate remote and control of the AWE, an user friendly SCADA was designed with the following features: (a) P&ID diagram representation including real time values, (b) Historical data visualization, (c) Customize graphics for study on evolution of parameters, (d) Configuration of tests (allowing the design of customized power inputs to the electrolyser), and (e) REE menu (related to interruptibility grid service).

FHa carried out the development of a computer model capable of simulating partial loads and dynamic operation conditions for a wide range of balances of plant for alkaline water electrolysers. The work was initially focused on defining appropriate simulation scenarios taking inputs from business models assessment previously performed in the project.

Work in WP4 continued with the optimization of the system for a Multi Mega Watt High Pressure Alkaline Water Electrolyser (MW HP AWE). It has been taken into account different sizing strategies to identify the one which leads to good performance under grid services and also implies some reduction in CAPEX. It was also analysed other technological scenarios (e.g. materials, equipment efficiency) and manufacturing aspects (economy of scale, transport or modular design) as measures to achieve a cost reduction of the whole system.

The last part of the work focused on making an assessment of the external processes that can be valorised, as the oxygen stream or the waste heat from electrolysis.

As a general outcome and based on simulation results, it was achieved a good performance of the BOP designed operating under grid services conditions, including standardized power profiles defined in QualyGridS project.

WP5

WP5 was dedicated to the test at market size different stacks assembled in WP3.

An updated C&CS was the first technical development tested, being the possibility of operation under grid services provision the major novel characteristic implemented. A first implementation was based on the Spanish grid service provision in the tertiary reserve market, but some adjustments were executed to test the electrolyser under a broader option of grid services conditions.

Novel membrane, new cell assemblies and standard materials used as baseline were tested during this WP. Major technical parameters were gathered and monitored during the operation. From all those technical information, gas purities and voltage per cell were the key parameters analysed in detail to assess the performance of the different developments tested.

As well as to operate the test bench on steady conditions to prove the technical developments operated in real conditions (temperature, pressure and KOH concentration), the test bench operated under some grid services protocols defined in QualyGridS project (FCH-JU project).

As a general outcome, it was validated that the different technical developments were tested successfully at market size and some promising results in terms of gas purities, dynamics and operation profile range were obtained.

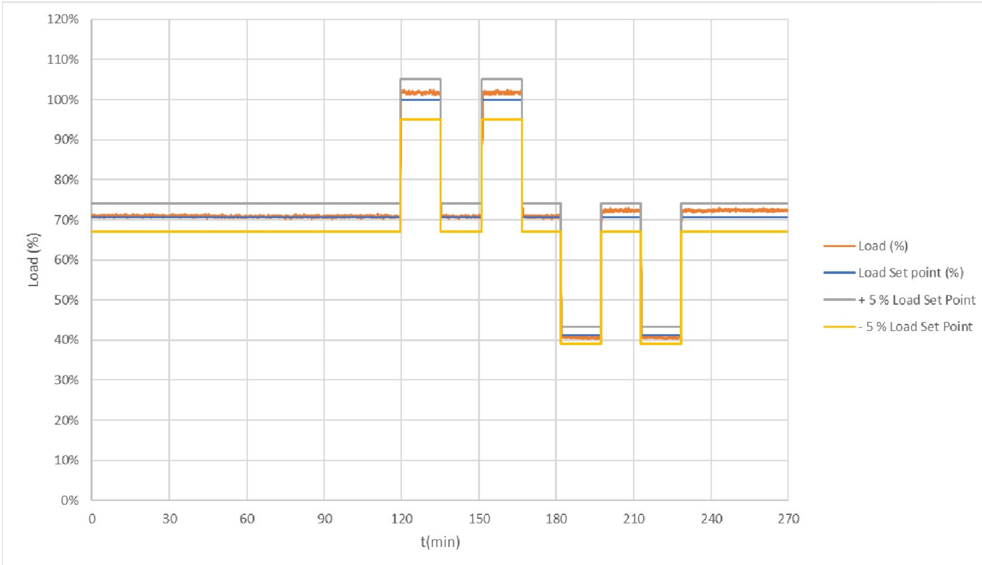

Figure 7. Example of high dynamic profile.

Figure 8. Industrial scale test bench at FHa.

In order to demonstrate the different 1600mm stacks at an industrial prototype level, the FHA balance of plant was upgraded (Figure 7). The upgrade focused on rise different capabilities which allow testing higher hydrogen productions.

WP6

First three tasks of WP6 were dedicated to the analysis of market prospections, exploitation activities and business cases.

In terms of hydrogen demand and potential markets, countries that show large amount of potential industry customers, especially within ammonia production and crude refining industry are most promising. These include Germany, the Netherlands, France, the UK and Poland. Countries for which a significant increase of hydrogen mobility is estimated in future, especially show highly promising business potential not only because of the additional hydrogen demand but also because for these applications the hydrogen price is expected to be significantly higher than for industry applications.

Electricity price is seen like the major key parameter affecting the deployment of MWs electrolysis plant, accounting major cost breakdown factor along the project life cycle. The revenues obtained giving grid services can entail an add-value for the overall business case profitability, but a constant market of hydrogen must be the major income source for MWs installations.

Exploitation activities have been carried out during the second part of the project, in cooperation with different partners in the consortium. An exploitation strategy has been issued and IPR conversations between partners have been produced.

IAEW published results of WP2 within public deliverables 2.1 and 2.3 as well as in a contribution to international journal “Renewable Energy” (DOI: 10.1016/j.renene.2018.02.074).

INYCOM, on the other side, assessed the possibilities for multi MW electrolysers to provide grid services related to frequency adjustment in Spain, studying the required demands for sustainable business cases, publishing the results in IJHE (doi.org/10.1016/j.ijhydene.2019.05.092).

IFAM published some of the results on the advanced electrodes development in the Journal of the Electrochemical Society (DOI:10.1149/2.0851904jes). A patent and/or additional scientific publications are under consideration regarding the most promising electrodes developed in the frame of WP3.

Additionally three proceedings have been published in connection to the participation in the EHEC 2018 and Iberconappice 2017.

At least 3 more scientific publications regarding AST tests carried out on advanced stacks assembled with novel materials are under progress.

More than 5 press releases were launched, in total 35 oral presentations and 2 posters in more than 20 conferences and 6 workshops. Including one invited talk in WHEC 2018, 3 invited talks at different events and the contribution to WHEC 2016 and WHTC2019.

The following table summarizes all the events, congresses and symposiums or fairs where the ELYntegration results and the project were presented.

.Conference, congress, etc.	Title (type)	Date of issue	Place	Author(s)
Aragon Hydrogen Foundation Board Meeting	General Elyntegration Presentation (oral)	December 2015	Zaragoza, Spain	*FHA*
Congreso Iberoamericano de Hidrógeno y Pilas de Combustible (Iberconappice)	Grid Integrated Multi Megawatt High Pressure Alkaline Electrolysers for Energy Applications (oral)	April 2016	Málaga, Spain	*FHA*
Hannover Fair, 2016	General Elyntegration Presentation (oral)	April 2016	Hannover, Germany	*FHA*
Workshop Harmonization of testing protocols for electrolysis applications within the FCHJU projects	General Elyntegration Presentation (oral)	May 2016	Brussels, Belgium	*FHA*
World Hydrogen Energy Conference 2016 (WHEC2016)	Grid Integrated Multi Megawatt High Pressure Alkaline Electrolysers for Energy Applications: ELYntegration (oral)	June 2016	Zaragoza, Spain	*FHA*
World Hydrogen and Energy Conference 2016 (WHEC2016)	The Electrochemical Activity Of Porous Electrodes For The Alkaline Electrolysis Of Water (oral)	June 2016	Zaragoza, Spain	*IFAM*
5th Symsosium of Bavarian Hydrogen Center	General Elyntegration Presentation (oral)	July 2016	Waischenfeld, Germany	*FHA*
BCH Symposium	Green H2 Production From Electrolysis: A Review Of The Experience Of The Fha In The Region Of Aragón oral)	September 2016		*FHA*
Program Review Days	General Elyntegration Presentation (poster)	November 2016, 2017, 2018	Brussels, Belgium	*Consortium*
Hydrogen Trade Mission to Aragon	General Elyntegration Presentation (oral)	February 2017	Huesca, Spain	*FHA*
Technical Forum of the Hydrogen and Fuel Cell exhibition	Electrocatalysts: A Key Component For Power-To-X Technology (oral)	April 2017	Hannover Fair, Hannover	*IFAM*
1st International Conference on Electrolysis (ICE 2017)	New Separator Concepts For A Radical Improvement Of The Gas Quality In Alkaline Water Electrolysis (poster)	June 2017	Copenhagen, Denmark	*VITO*
1st International Conference on Electrolysis (ICE 2017)	Raney-Ni Electrodes For The Alkaline Electrolysis Of Water (poster)	June 2017	Copenhagen, Denmark	*IFAM*
EEM 2017	Economic Potential Of Water Electrolysis Within Future Electricity Markets (oral)	June 2017	Dresden, Germany	*IAEW*

Hypothesis XII	Potential Of New Business Models For Grid Integrated Water Electrolysis (oral)	June 2017	Syracuse, Italy	*IAEW*
European Grid Service Markets Symposium	Opportunities Of Water Electrolysers In The European Flexibility Markets (oral)	July 2017	Lucerne, Switzerland	*IAEW*
QualyGridS workshop	General Elyntegration Presentation (oral)	June 2017	Lucerne, Switzerland	*FHA*
Seminar at Kurt-Schwabe Institut	General Elyntegration Presentation (oral)	July 2017	Waldheim, Germany	*IFAM*
Congreso Iberoamericano de Hidrógeno y Pilas de Combustible (Iberconappice 2017)	Diseño De Protocolos De Testeo Acelerados Para Un electrolizador Alcalino (oral)	October 2017	Huesca, Spain	*FHA*
Congreso Iberoamericano de Hidrógeno y Pilas de Combustible (Iberconappice 2017)	Desarrollo En Phyton De Un Modelo Dinámico De Balance De Planta De Un lectrolizador Alcalino Para Su Integración En Servicios De Red (oral)	October 2017	Huesca, Spain	*FHA*
Congreso Iberoamericano de Hidrógeno y Pilas de Combustible (Iberconappice 2017)	Desarrollo De Un Sistema De Control Y Comunicación Con Funciones De Mantenimiento Avanzado Y Operación Inteligente Para La Provisión De Servicios De Red Por Un Electrolizador Alcalino (oral)	October 2017	Huesca, Spain	*INYCOM*
European Hydrogen Energy Conference (EHEC 2018)	Test protocols for accelerated in situ degradation of alkaline water electrolysis under dynamic operating conditions (oral)	March 2018	Malaga, Spain	*FHA*
VUELTAH Project	Electrolizadores para Balance De La Red Eléctrica (oral)	March 2018	Huesca, Spain	*FHA*
ICOME 2018	**INVITED** Case Study: Water Electrolysis For Grid Balancing (oral)	May 2018	San Sebastian, Spain	*FHA*
International Hydrogen and Fuel Cells Conference	Impact Of Dynamic Operation In The Degradation Of Alkaline Water Electrolysis Stack Providing Grid Services (oral)	May 2018	Trondheim, Norway	*FHA*
World Hydrogen and Energy Conference *(WHEC 2018)*	**KEYNOTE** Lifetime Assessment Of Novel Membranes For Water Electrolysis Technology Providing Grid Services (oral)	June 2018	Rio de Janeiro, Brazil	*FHA*
Elyntegration workshop 2018	Water electrolysis to provide grid services (oral)	September 2018	Dresden, Germany	*INYCOM*
Elyntegration workshop 2018	Tests protocols for accelerated in situ degradation of alkaline water electrolysis under dynamic operation conditions (oral)	September 2018	Dresde, Germany	*FHA*

Elyntegration workshop 2018	Electrode development within Elyntegration (oral)	September 2018	Dresde, Germany	*IFAM*
Elyntegration workshop 2018	Economic potential of ancillary service provision by water electrolysers (oral)	September 2018	Dresden, Germany	*IAEW*
ACI's H&FC Summit	**INVITED** Alkaline water electrolysis technology operating dynamically. Case study: Elyntegration project (oral)	February 2019	Madrid, Spain	*FHA*
H2020 project E-LAND on smart grids in which INYCOM is partner	Elyntegration case of study (oral)	April 2019	Zaragoza, Spain	*INYCOM*
Presentation to students of Degree on Electrical Engineering at University of Zaragoza on demand side flexibility	Interrumpibility Grid Service and the Possibilities for Multi Mw Loads to Participate in balancing services In the EU (oral)	May 2019	Zaragoza, Spain	*INYCOM*
World Hydrogen Technologies Convention (WHTC 2019)	Perspectives And Challenges Of Advanced Alkaline Water Electrolysers Providing Grid Services– Lifetime Assessment Of Novel Materials And Components (oral)	June 2019	Tokyo, Japan	*FHA*
Program Review Days	General Elyntegration Presentation (poster)	November 2016 November 2017 November 2018	Brussels, Belgium	*Consortium*

Table 1. Summary of all the events.

4 PROGRESS BEYOND THE STATE OF THE ART AND EXPECTED POTENTIAL IMPACT (INCLUDING THE SOCIO-ECONOMIC IMPACT AND THE WIDER SOCIETAL IMPLICATIONS OF THE ACTION SO FAR)

The project had a clearly oriented to market approach, so the expected potential impact of the results was focused on satisfying the potential needs of new markets and business models while complying with the existent requirements for connection to grid and provision of balancing or grid services. It is expected that market and business model results from WP2 and WP6, which have been made public through three deliverables, pave the way towards a set of recommendations for policy makers and regulators. The project shows, that with its improvements in terms of dynamic electrolyser performance, new and potentially profitable business models are available to investors and operators of alkaline electrolyser in future. Only high ramping and hot start capability of electrolyser enable a flexible electrolyser operation at spot markets and control reserve markets for electricity. The project results also emphasize the importance of appropriate hydrogen target sectors for early applications requiring high hydrogen prices as can be expected within mobility sector. In terms of regulation, the project showed that potential exemptions from end-user prices for electricity such as RES surcharges or network charges can be significant for profitable electrolyser integration into power systems.

The industrial partner (IHT) has the capability of manufacturing high pressure alkaline electrolysers in the range of MW. Nowadays, one big unit of this technology (3.5 MW) can produce up to 760 Nm^3/h of hydrogen at 32 bar. ELYNTEGRATION results and improvements, both in materials and in cell, balance of plant design and C&CS will increase the competitiveness of this kind of systems (Multi Megawatt production with a single stack), providing services to the grid operators as potential improvement to be considered as additional aspect of the business model.

These improvements are aligned with the specific objectives of the Multi Annual Work plan (MAWP 2014-2020) for electrolysers producing hydrogen from renewable electricity for energy storage and grid balancing.

	MAWP target 2020	ELYNTEGRATION Results
Energy consumption (kWh/kg)	52 @1000+kg/d	Achieved during the project under certain operation conditions
CAPEX	2.0 M€/(t/d)	Achieved during the project for MW installation

Table 2. Objectives in ELYNTEGRATION and project achievements.

The works done in cell improvement, regarding membranes and electrodes have contributed to increase the knowledge on capabilities for development of AWE. Some of the materials developed in the project could be upscaled and manufactured to match the market requirements. It would help to increase the purchase opportunities of some key components, improving the overall procurement and total cost.

The results on dynamic testing and protocols have contributed to the development of test designs, in order to establish the requirements for dynamic operation and AST for AWE providing grid balancing services.

In relation to the C&CS developed by INYCOM, the concept developed in ELYntegration to allow connectivity with grid operators is the basis to add features based on data analytics such as optimized operation (with energy efficiency and robustness criteria) or predictive maintenance which are demanded by electrolysis industry today.

Finally, the project is very oriented to integrate the electrolysers in the electricity grid providing grid balancing. The results have shown that the most promising markets would be those with a very low electricity price which could be linked to the high penetration of RES. Therefore, the results obtained could pave the way to the deployment of RES in the electricity mix in Europe.