INSIGHT

"ImplementatioN in real SOFC Systems of monItoring and diaGnostic tools using signal analysis to increase tHeir lifeTime"

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Research and Innovation Project

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Dissemination and exploitation plan (final update)

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Document Abstract

This deliverable is part of WP7 which is the main interface between the project and the outside world, academics, and industrials playing a role in the value network underpinning the scientific breakthrough in stationary fuel cells systems.

Towards this goal, the tasks aim to make the project work widely known, establishing links with related ongoing research initiatives, managing the foreground knowledge and protecting it as appropriate, exploring and assessing emerging application areas, and setting the foundations for future commercial exploitation and opportunities.

This deliverable gives an updated overview on the actual dissemination and exploitation actions within the INSIGHT project.

The deliverable describes the progress on the dissemination materials and exploitation plan- and the reporting for the activities performed all along the 36 months of project.

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1. Introduction

The Dissemination and Exploitation activities have been implemented within WP7 "Dissemination and exploitation activities" which aims to ensure scientific, social and economic impacts based on the results of the INSIGHT project.

We will present firstly the update on dissemination activities in comparison to the second Dissemination plan D7.3 and then, the same with the exploitation plan.

2. Dissemination activities

The INSIGHT project gives a particular importance to dissemination activities to facilitate the communication between the partners and the stakeholders. The latter have been informed continuously about progress and results that will allow the project to get all the necessary feedback and visibility at the international level.

The figure below describes the updated general strategy for both external dissemination and exploitation activities during the INSIGHT project, and the accomplished activities. As a reminder, the key dissemination stakeholders of INSIGHT project are:

- Scientists, Education communities;
- Industrials and SME's;
- Public funding bodies.

A. Dissemination Targets

The following table lists the targets given for objectives at the beginning of the project. The dissemination targets have been achieved and in next paragraph tables will present the activities.

Activities	Indicators for measuring the effectiveness of the approach	Targets set by the Project	Achieved at M36
Flyers	Distribution of flyers	30/partner/event	600
Poster	Distributed during Conferences, workshop, exhibition	1/event	4
Website	Average number website visitors/day	10/day	1093 visitors
Events/ Conferences	Number of participations to conferences	5	27 + 3 planned in 2020
Workshops	A workshop will be organized during an international event (M18 – M36)	2	1 2nd to be arranged jointly with RUBY after INSIGHT end
Scientific publications	Number of scientific publications addressed to Fuel Cell Communities	5/ Project	13
Non-scientific publications	Number of non-scientific publications (articles, press releases, …)	2/Project	2
Summer school	Number of participants	16 (including 6 from industry)	44
Patents	none	none	2

Table 1 : communication targets

B. Flyer/poster

A first flyer was prepared in last November 2017 for the FCH-JU PRD and a second one will be prepared for the end of 2018 with main results.
An update of the visual identity was done.

Figure 1: INSIGHT visual identity

First INSIGHT Flyer

That first Flyers have been distributed at the PRD 2017, at EFCF 2018 and during the Hannover Messe (2017 and 2018).

Figure 2 : 1st Flyer front side

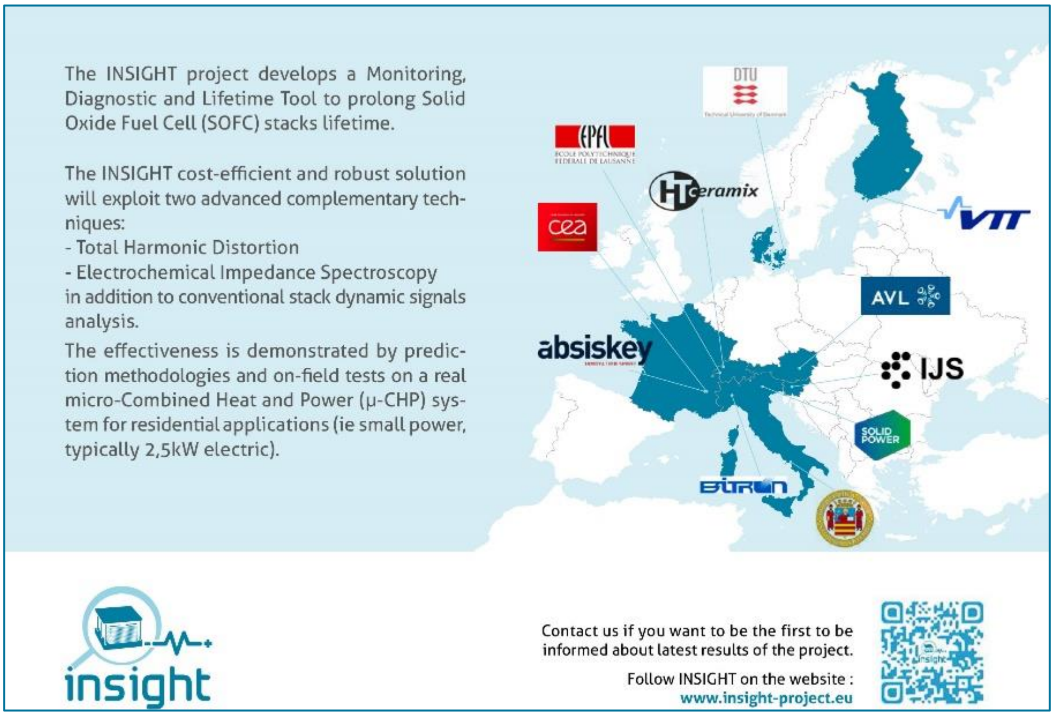


Figure 3 : 1st Flyer back side

Second INSIGHT Flyer

A second flyer was prepared with main results in last November 2019 for the PR Days in Brussels, on 19th November 2019.

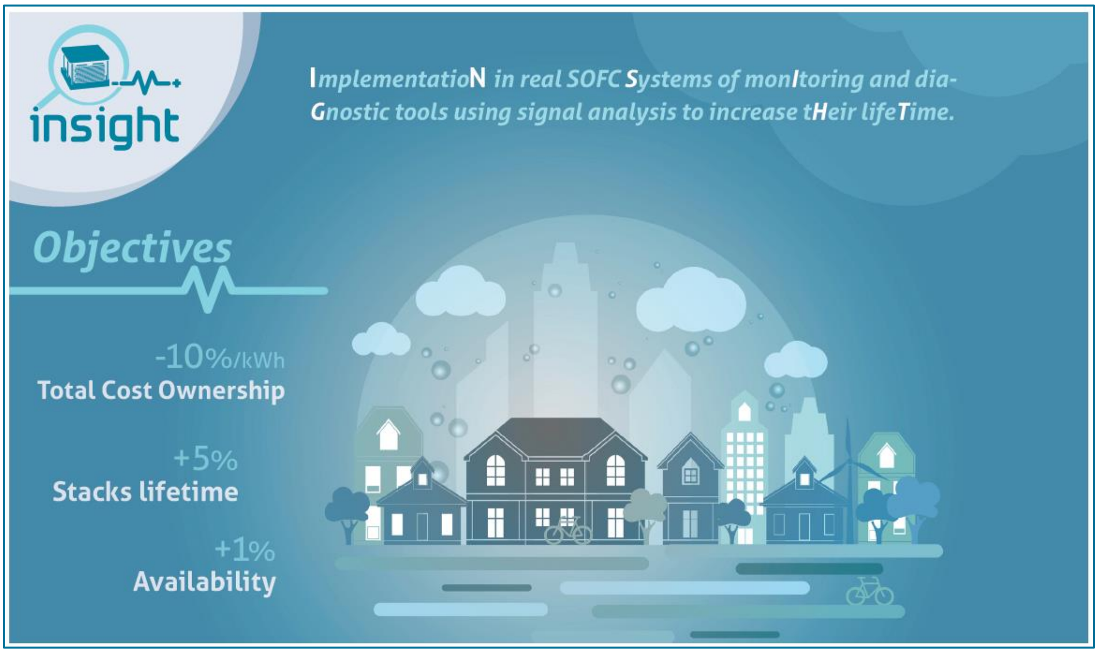


Figure 4 : 2nd Flyer front side

Figure 5 : 2nd Flyer back side

First INSIGHT Poster

A first poster was prepared, in order to present the project at the Hannover fair on DTU booth on April 2017.

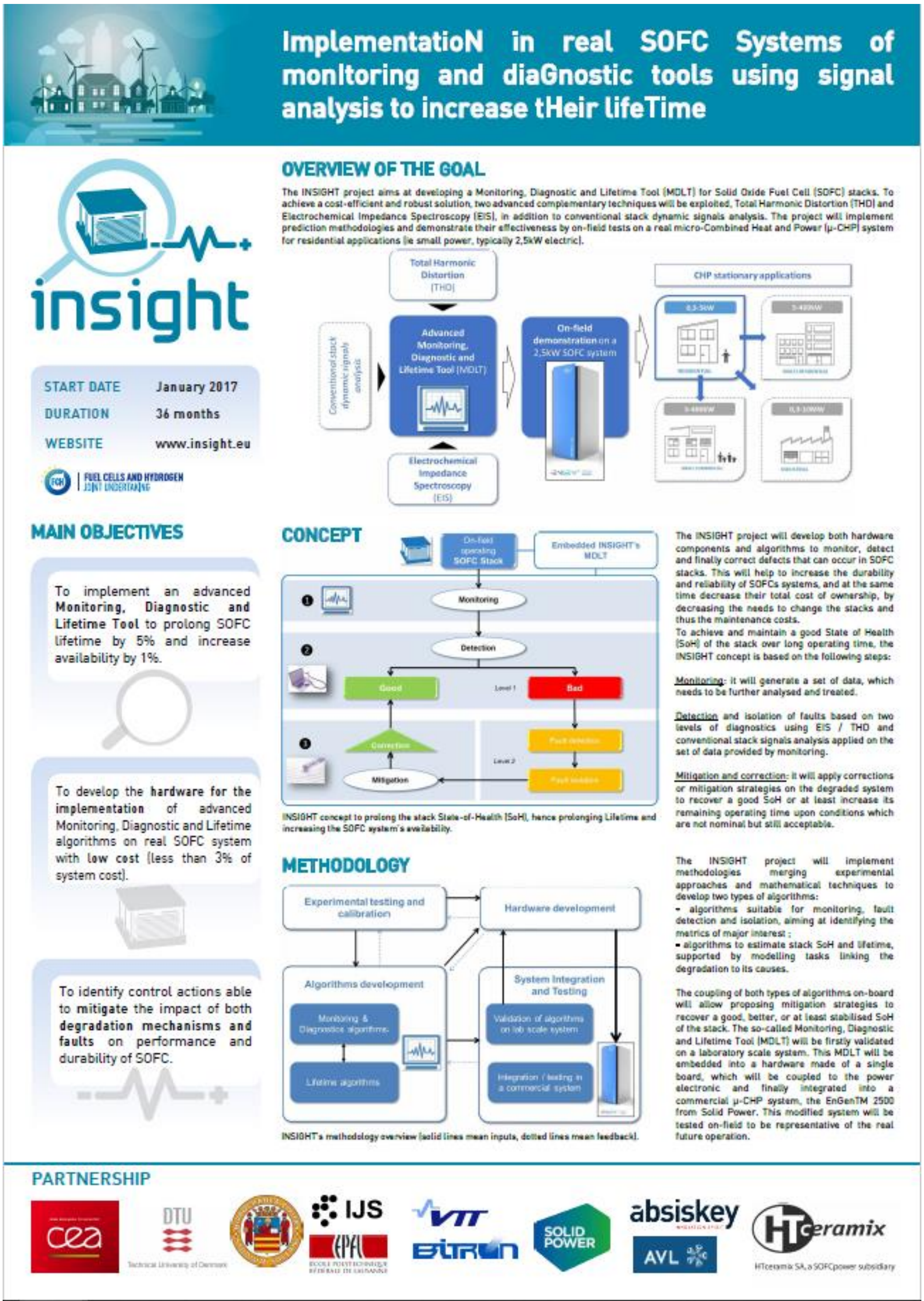


Figure 6 : First poster, Hannover Messe 2017 on DTU booth

Second INSIGHT Poster

A second poster has been done for the Hannover Fair 2018 to illustrate and promote the firsts results.

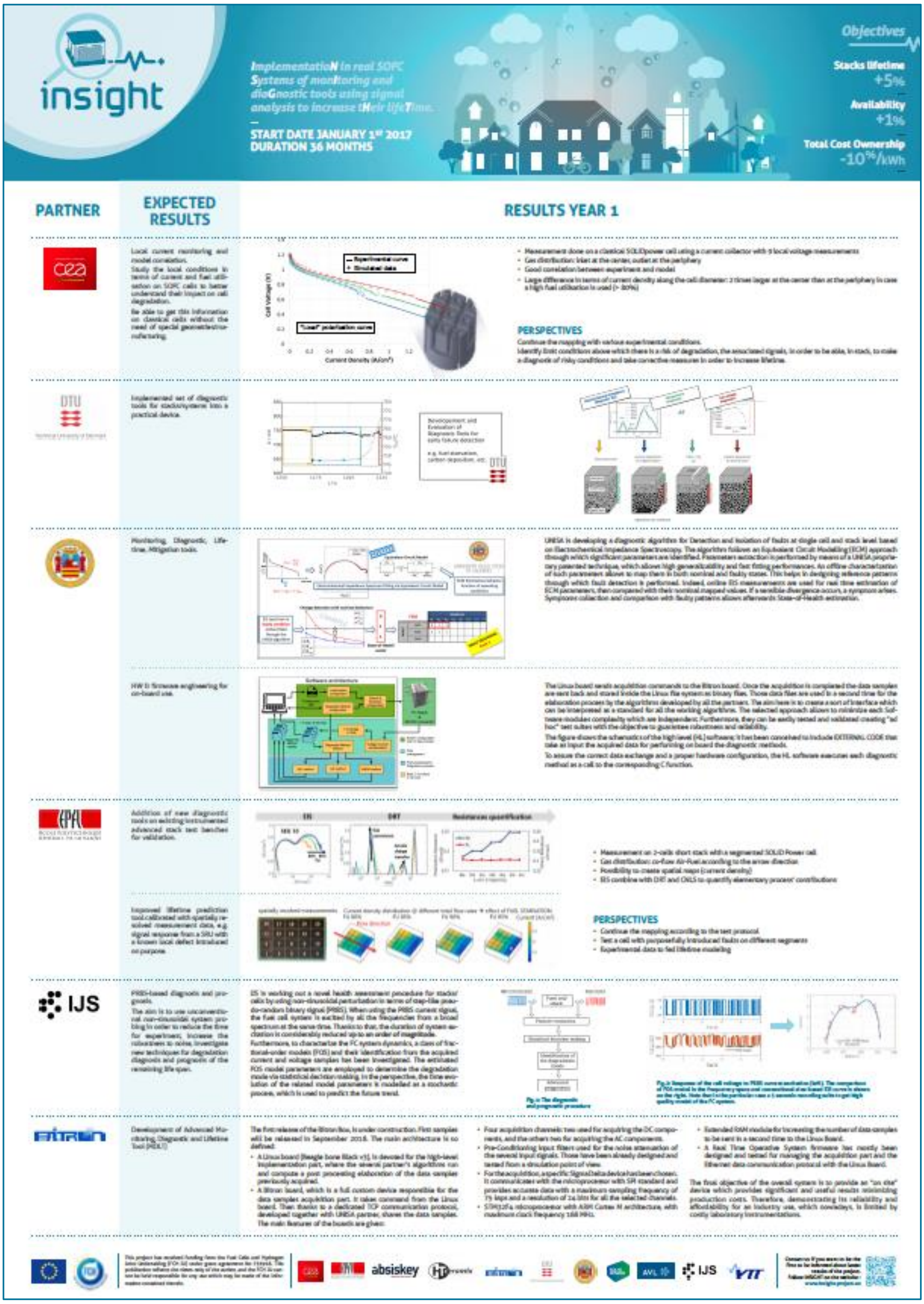


Figure 7 : Second poster, Hannover Messe 2018 on DTU booth

Third INSIGHT Poster

A third poster has been done for the European Fuel Cell Forum Conference (EFCF) in Luzern (Switzerland) held in 3-6 July 2018.

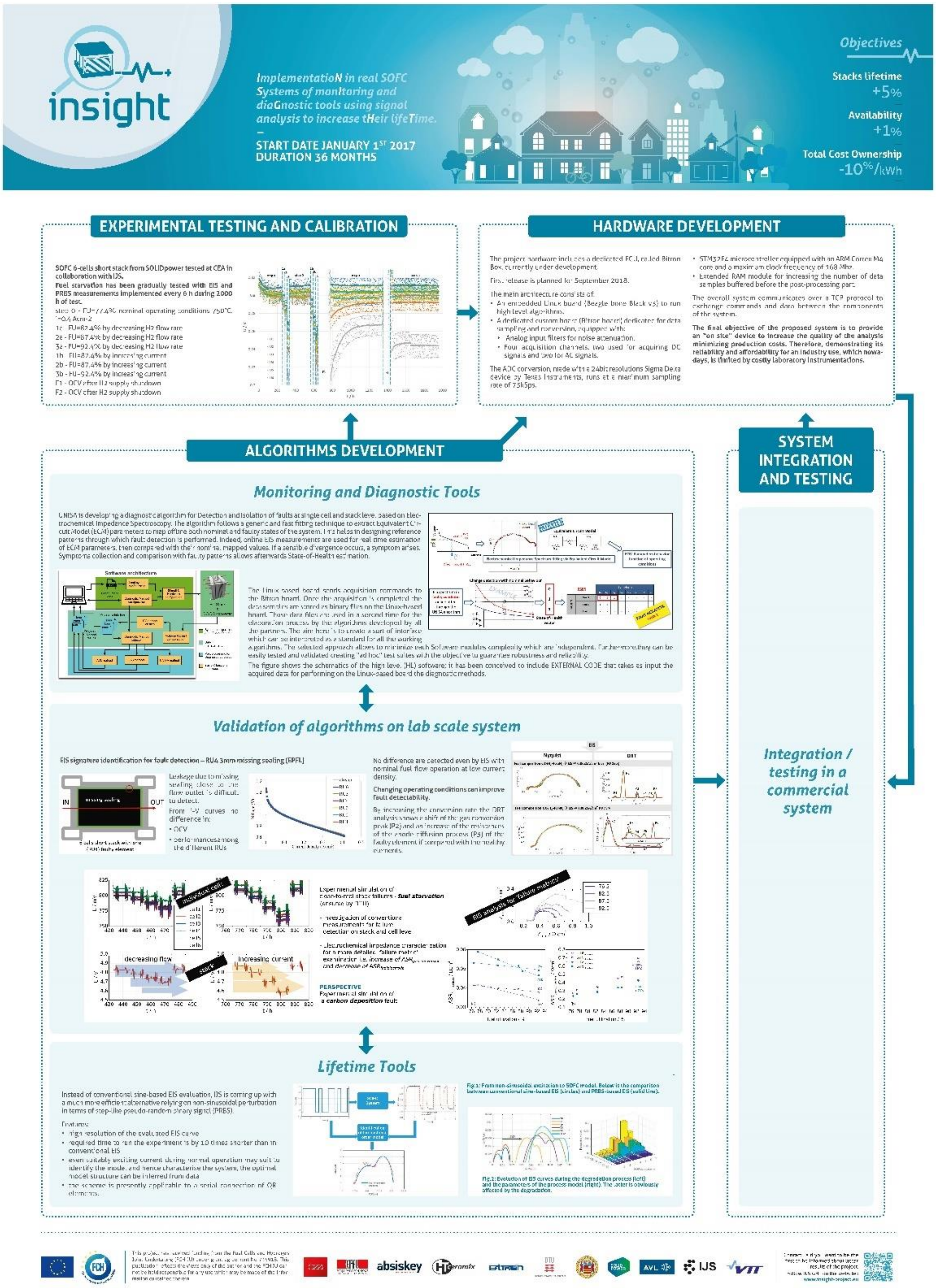


Figure 8 : Third poster: EFCF 2018 Luzern

Fourth INSIGHT Poster

A fourth poster has been created for IEEE 4th International Forum on Research and Technologies for Society and Industry "Innovation to shape the future" - Palermo, Italy, September 10-13 2018.

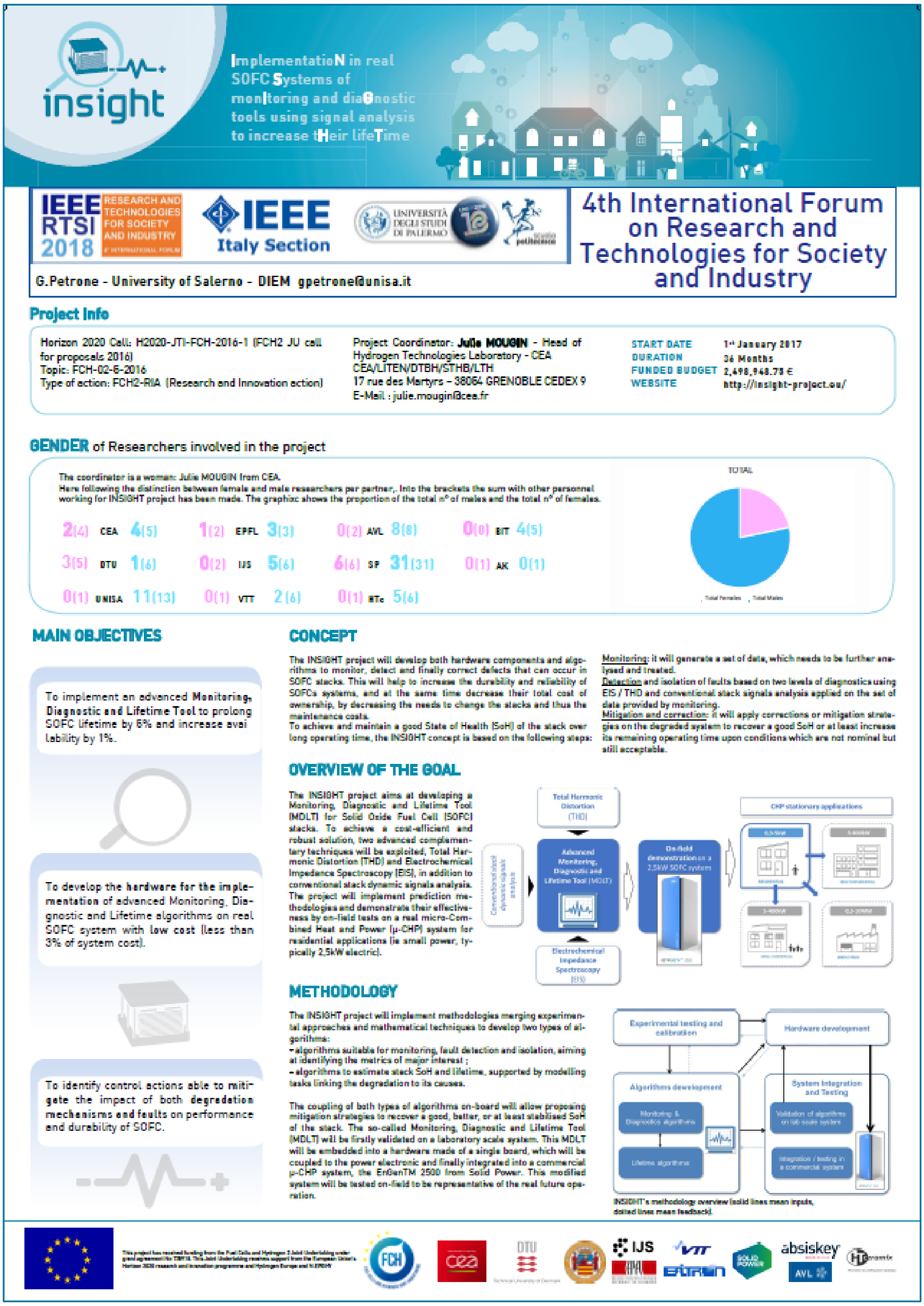


Figure 9 : Fourth poster: IEEE 4th International Forum on Research and Technologies for Society and Industry

The flyers and posters are available on the INSIGHT website.

C. Website

Google analytics service is used to provide statistics on the number of visitors of the website and geographical locations.

Frequentation (2017/01/01 – 2019/12/02) :

The objectives for the launch of the project were to obtain a significant and increasing frequentation of the website. They are reached considering the number of sessions (since the official launch of the website : around **1093 visitors** and **1477 sessions**) and the high proportion of new visitors.
10,6% of them are returning visitors.

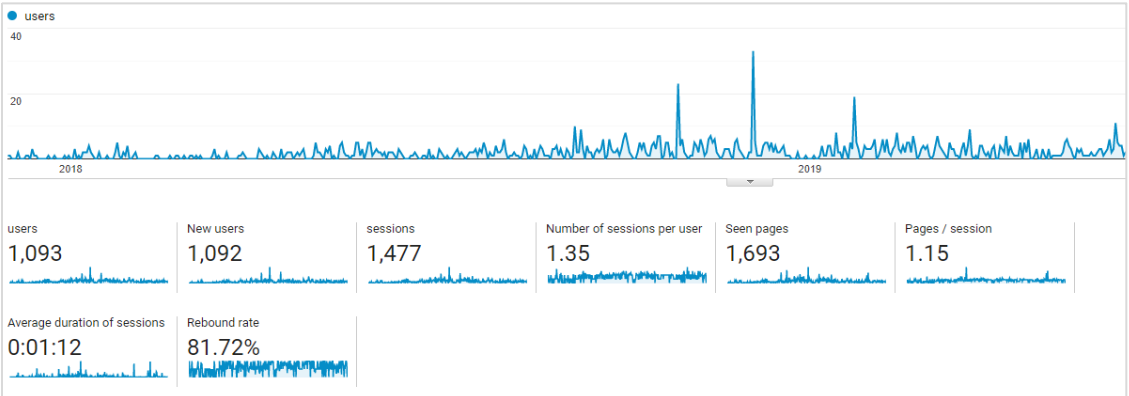


Figure 10 : Website frequentation statistics – since the beginning of the project

Geographical distribution (2017/01/01 – 2019/12/02) :

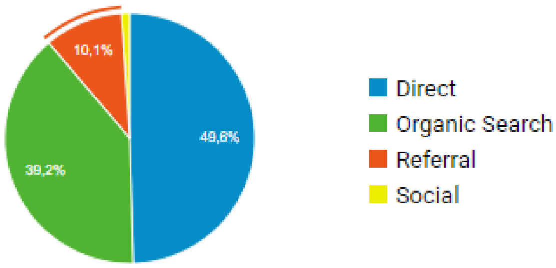
The breakdown per country is provided below :
14,5% of visitors are from Italy, then 13,1% from USA and 12,4% form China.

Country	users	users
	1,093 % of total: 100.00% (1,093)	1,093 % of total: 100.00% (1,093)
1. Italy	162	14.50%
2. United States	146	13.07%
3. China	139	12.44%
4. la France	94	8.42%
5. Germany	80	7.16%
6. United Kingdom	39	3.49%
7. Belgium	38	3.40%
8. Switzerland	38	3.40%
9. Spain	32	2.86%
10. India	28	2.51%

Figure 11: Website frequentation statistics – since the beginning of the project

Traffic acquisition (2017/01/01 – 2019/12/02) :

the visitors mainly find the website by direct entry of the url address (49,6%), then by typing key words in the search engine (39,2%), which demonstrate the efficiency of communication materials (flyer, poster,Social Media).



Direct entry of the url address
Taping key words in search engine
Acquisition via links on other websites
Acquisition viaSocial Media

Figure 12: Website frequentation statistics – since the beginning of the project

D. Events

The following table lists the conferences or public events relevant for the project in which partners participated with a contribution and/or a presentation of INSIGHT. This table is used to follow up the events related to the project (and in blue other events for the target group: cluster and associations).

	Description: title of the Event	Audience (type, size)	Dates (year and Day/month if known) and Place	Contribution, materials, partner's short name
2017	**Hannover fair**	Industrials, researchers	April 2017 Hannover, Germany	Poster & booth, DTU
	FCH-JU Review days	Industrials, researchers	November, 2017 Brussels, Belgium	Poster & flyer, CEA, AK
2018	**Hannover fair**	Industrials, researchers	April 2018 Hannover, Germany	Poster & booth, DTU
	233rd ECS Meeting	Industrials, researchers	May 13th-17th 2018 Seattle, USA	Paper, DTU
	DSL2018 14th International Conference on Diffusion in Solids and Liquids –	Industrials, researchers	June 25-29, 2018 Amsterdam, The Netherlands	Oral presentation, DTU. M. Chen, L. Zhang, A. Hagen, Modeling Diffusion Induced Microstructure Degradation in Solid Oxide Cells
	European Fuel Cell Forum Conference	Industrials, researchers	July 2018 Luzern, Switzerland	Posters and flyers, CEA Oral presentation, EPFL: Paper: A1403 Thermo-mechanical reliability of SOFC stacks: impact of component tolerances and operating conditions. Oral presentation, EPFL, Paper B0304: Characterization of the local morphology at triple-phase boundaries after SOFC/SOEC operation Poster, EPFL: A1307 Model-assisted identification of DRT peaks by varying operating conditions
	10th IFAC Symposium (International Federation of Automatic Control) 10th Safeprocess	Industrials, researchers	August 29-31, 2018 Warsaw	Oral presentation, IJS Fractional-order model identification for state of health assessment of solid-oxide fuel cells
	IEEE 4th International Forum on Research and Technologies for Society and Industry "Innovation to shape the future"	Industrials, researchers	September 10th-13th, 2018 Palermo, Italy	Poster, UNISA
	ETAI Conference	Industrials, researchers	September 20th -22th, 2018, Struga, Nord Macedonia	Plenary talk, IJS Prognostics and Health Management of Modern Systems and Components: Recent Developments and Perspectives

	11th International Workshop on Impedance Spectroscopy	Industrials, researchers	September 25 th-28 th 2018, Chemnitz, Germany	- Oral presentation, IJS EIS through time-domain fractional order identification - Oral presentation IJS Multivariate statistical fault detection based on wavelet transform with an application on fuel cells
	FCH-JU Review days	Industrials, researchers	November 14th-16th, 2018 Brussels, Belgium	Poster & flyers CEA, AK
	Workshop on Monitoring and Diagnostics of Fuel Cells	Industrials, researchers	November 13th, 2018 Brussels, Belgium	Oral presentations, Poster and flyers CEA, UNISA, AK, IJS
2019	**Hannover fair**	Industrials, researchers	April 2019 Hannover, Germany	Poster and booth DTU
	ELECTRIMACS 2019 - The 13th international conference of the IMACS TC1 Committee	Industrials, researchers	May 21th-23^{th,} 2019 Salerno, Italy	Oral presentation IJS, paper IJS, CEA Probabilistic deconvolution of solid oxide fuel cell impedance spectra
	Thermo-Calc User Group meeting	Invited talk. DTU. Modeling Diffusion Induced Phase Transformation in Oxide Systems	April 15th 16th , Leoben, Austria	DTU
	ESI 2019	350	June 2th-7 th ,2019	Oral, IJS: Statistical Analysis of Impedance Data the talk is about the complete signal processing chain from PRBS up to ECM parameter identification using fractional order systems Exhibitor, AVL
	Joint European Summer School on fuel cell, electrolyser, and battery technologies	PhD students and industry employees (16 participants)	September 2019, Athens, Greece	Integration into section: High Temperature Fuel Cells and Electrolysers (SOFC and SOE)
	SOFC XVI 16th International Symposium on Solid Oxide Fuel Cel	Industrials, researchers	September, 8th 13^{th,} 2019 Kyoto, Japan	Oral Presentation, CEA : Effects of polarization on the microstructural changes at the YSZ/Ni-YSZ interface Oral presentation, Jointly written paper, presented by CEA (Julie Mougin): Monitoring and Diagnostics of SOFC Stacks and Systems
	ICAE 2019 **11 th International Conference on Applied Energy**	Industrial, researchers	August 12-15, 2019, Västerås, Sweden.	Oral presentation, UNISA: Comprehensive model-based methodology for fault detection, isolation and mitigation of fuel cell powered systems.
	EFC19 **8 th European Fuel Cell Technology & Applications Piero** **Lunghi Conference**	Industrial, researchers	December 9-11, 2019, Naples, Italy.	Oral presentation, UNISA: Advanced model-based aging estimation of solid oxide fuel cell stacks. Full length article to be published in IJHE in 2020

	FCH-JU Review days	Industrials, researchers	November 2019 Belgium	Poster session, flyers distribution
2020	**European Fuel Cell Forum 2020**	Industrials, researchers	July 2020 Luzern, Switzerland	Abstract submitted, EPFL: Measurement of the effective mechanical properties of SOC oxygen contact layers by computational homogenization and effects on contact pressure during stack operation.
	European Fuel Cell Forum 2020	Industrials, researchers	July 2020 Luzern, Switzerland	Abstract submitted, IJS, CEA: On-line diagnosis of a solid oxide fuel cell stack by means of uncertain equivalent circuit models
	European Fuel Cell Forum 2020	Industrials, researchers	July 2020 Luzern, Switzerland	Abstract submitted, Solidpower: SOFC In-Field Test of an Advanced Monitoring and Diagnostics Tool

Table 2 : Participation to identified events

E. Scientific publications

The following table lists actual publications relevant for the project. This table will be used to follow up the publications related to the project.

Description, title of the journal etc…	Address of journal	Dates	Status	DOI	Open access: Green or gold	Repository Link (of publication)
Journal of Power Sources	http://www.journals.elsevier.com/journal-of-power-sources/	2018	1 publication CEA, 2018, « Impact of Nickel agglomeration on Solid Oxide Cell operated in fuel cell and electrolysis modes »	https://doi.org/10.1016/j.jpowsour.2018.06.097	Green	https://doi.org/10.1016/j.jpowsour.2018.06.097
PhD thesis EPFL Priscilla Caliandro	https://infoscience.epfl.ch/record/255087	2018	1 publication, EPFL Identification of Solid Oxide Cell Elementary Processes by Electrochemical Impedance Spectroscopy	10.5075/epfl-thesis-8389	Green	https://infoscience.epfl.ch/record/255087
Solid State Ionics	https://www.journals.elsevier.com/solid-state-ionics	2018	1 CEA publication, « Experimental validation of a LSCF electrode model operated in electrolysis mode: understanding the reaction pathway under anodic polarization", Solid State Ionics 319 (2018) 234-246	https://doi.org/10.1016/j.ssi.2018.02.012	Green	https://doi.org/10.1016/j.ssi.2018.02.012
Journal of Power Sources	https://www.journals.elsevier.com/journal-of-power-sources/	2019	1 publication, DTU, 2019. "Interdiffusion between gadolinia doped ceria and yttria stabilized zirconia in solid oxide fuel cells: Experimental, investigation and kinetic modeling"	https://doi.org/10.1016/j.jpowsour.2019.227152	Green	https://arxiv.org/abs/1910.11947
Philosophical Transactions of the Royal Society A	https://royalsocietypublishing.org/doi/pdf/10.1098/rsta.2019.0006	2019	1 publication IJS "Identification of the coupling functions between the process and the degradation dynamics by means of the variational Bayesian inference: an application to the solid-oxide fuel cells", Volume 377, Issue 2160	https://doi.org/10.1098/rsta.2019.0086	Green Open Access	https://doi.org/10.1098/rsta.2019.0086
Journal of Power Sources	https://www.journals.elsevier.com/journal-of-power-sources	2019	1 Publication, EPFL Model-assisted identification solid oxide cell elementary processes by electrochemical impedance spectroscopy measurements Priscilla Caliandro, Arata Nakajo, Stefan Diethelm, Jan van Herle	https://doi.org/10.1016/j.jpowsour.2019.226838	Gold open access	https://doi.org/10.1016/j.jpowsour.2019.226838

Journal of power sources	http://www.journals.elsevier.com/journal-of-power-sources/	2019	1 publication, CEA Microstructural correlations for specific surface area and triple phase boundary length for composite electrodes of solid oxide cells, H. Moussaoui et al., Volume 412, 1 February 2019, Pages 736-748	https://doi.org/10.1016/j.jpowsour.2018.11.095	Green	https://doi.org/10.1016/j.jpowsour.2018.11.095
Acta Materialia	https://www.journals.elsevier.com/acta-materialia	2019	1 publication, EPFL Characterization of local morphology and availability of triple-phase boundaries in solid oxide cell electrodes	https://doi.org/10.1016/j.actamat.2019.07.027	Gold open access	https://doi.org/10.1016/j.actamat.2019.07.027
ECS Transactions	http://ecst.ecsdl.org/content/91/1/641	2019	1 publication, EPFL Effects of Polarization on the Microstructural Changes at the YSZ/Ni-YSZ Interface.	https://doi.org/10.1149/09101.0641ecst	Green	https://iopscience.iop.org/article/10.1149/09101.0641ecst
Journal of Electrochemical Energy Conversion and Storage	https://asmedigitalcollection.asme.org/electrochemical	2019	1 Publication EPFL, Accepted Evolution of the morphology near triple-phase boundaries in Ni-YSZ electrodes upon cathodic polarization	https://doi.org/10.1115/1.4046478	Green	https://asmedigitalcollection.asme.org/electrochemical/article/17/4/041102/1074944/Evolution-of-the-Morphology-Near-Triple-Phase
J. Electrochem. Society	https://www.electrochem.org/publications/jes	2020	1 publication CEA Degradation of Ni-YSZ Electrodes in Solid Oxide Cells: Impact of Polarization and Initial Microstructure on the Ni Evolution.	https://doi.org/10.1149/2.1261915jes	Green	https://doi.org/10.1149/2.1261915jes
Journal of power sources	http://www.journals.elsevier.com/journal-of-power-sources/	2020	1 publication, CEA, submitted, Particle-based model for functional and diffusion layers of Solid Oxide Cells electrodes	https://doi.org/10.1016/j.powtec.2020.03.040	Green	https://hal.archives-ouvertes.fr/hal-02520003/

Table 3 : Publications

F. Patents

The following table lists actual patents filed in the frame of the project Insight.

Patent Topic	Partner	Dates	Status
Stack monitoring by means of stack segments	AVL	2019	Filed, under examination
Monitoring by periodic non-sinusoidal excitation, multi frequency based metric approach	AVL	2018	Approved

Table 4 : Patents

3. Exploitation plan

A set of tools was established in order to follow up the strategy as described above and to support the meetings:

1. The knowledge assessment to analyze the evolution of the results during the project compared with what was expected at first, (Table 6);
2. The Intellectual Property Management scheme, (Table 7);

   The exploitation roadmap to follow the evolution of the results in terms of exploitable items. The aim of this table is to determine exploitable items/products that could be commercialized. Thus, we will define the technology readiness progress, the competitive context and the exploitation plan (Table 8).

Exploitation Strategy Seminar

The consortium of INSIGHT followed the recommendation of FCH for developing the exploitation plan to attend a workshop with Meta Services, the Exploitation Strategy Seminar Report, held in Salerno – Italy on the 31st of January 2019.

At the seminar, the first part focused on key exploitable results (KER), their use, and how the exploitation plan needs to aim at a sustainable use of the KERs after the end of the project. Differences between exploitation and dissemination were then presented and discussed together with the tables to be used for the characterisation of KERs. Afterwards participants worked in groups, supported by the expert, discussing the needs the result is addressing, the solution for that needs and why the value of the proposed solution is higher than what is currently available (UVP).

The expert stated in the report of the seminar that INSIGHT has strong potentials if the envisaged results are put in use exploiting their "value chain" dimension (algorithms, BitronBox, micro co-generator, suite of services). This dimension should be addressed by partners to find the best set up to pave the way for further collaborations.

The following KERs have been discussed by the partners during the seminar.

No.	Name of the KER
1	BitronBox - Electronic device for SOFC Online Diagnosis
2	Small size high efficiency micro-cogenerator SOFC based systems, for small commercial and residential markets
3	Diagnostic Algorithm
5	Know-how in characterizing customer solutions for fuel cell diagnostics

Table 5 : Key Exploitable Results

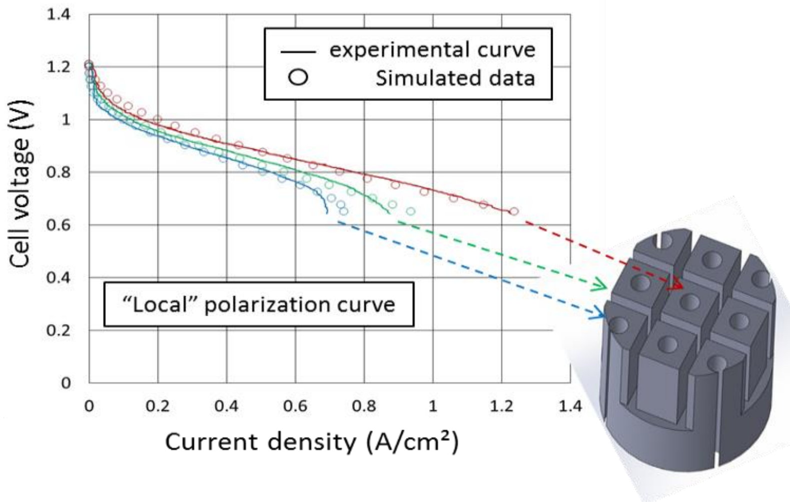
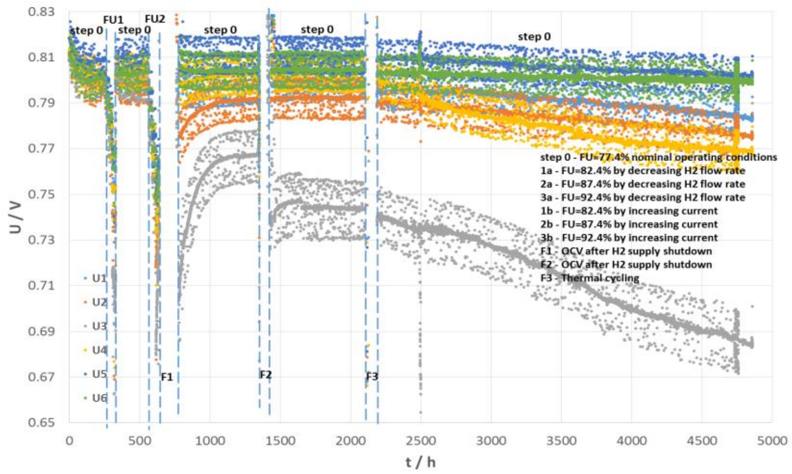
The following table will report the characterization of the KER, which detailed descriptions will be kept on file for confidential issues.

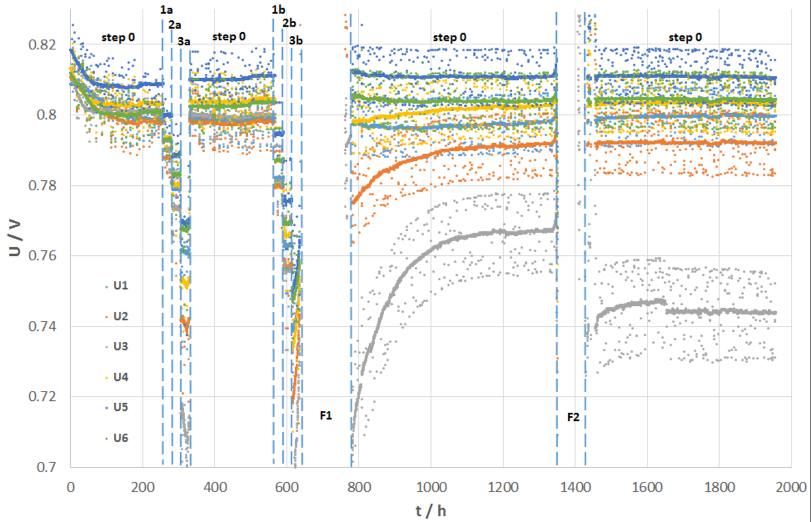
KER #1 - Electronic device for Solid Oxide Fuel Cell (SOFC) Systems online Monitoring and Diagnosis	
Description	The Electronic device (called BitronBox in the scope of the project) is an advanced all-in-one compact equipment devoted to the online diagnosis of SOFC systems. The BitronBox allows fault detection by means of EIS (Electrochemical Impedance Spectroscopy), PRBS (Pseudo-Random Binary Spectroscopy) and THD (Total Harmonic Distortion) characterization. This characterization does not affect the nominal operation of the system and guarantees quasi-real time outcomes in terms of fault isolation. This device will subsequently propose the best mitigation strategy to the SOFC controller.
Problem	The main problem is to increase the lifetime of a SOFC system. In a real system, the available sensors are usually not able to detect faults (like carbon deposition) early enough to allow mitigation strategies. Moreover, monitoring systems often require to add further equipments which are not easy to bring for in-field use.
Alternative solution	To bring additional equipments which are not easy to bring for in-field use. Combining different systems from different manufacturers can lead to interfacing and synchronization issues.
Unique Selling Point USP - Unique Value Proposition UVP	- providing the best trade-off between quality of the analysis and cost of the solution - all in one solution that guarantees excellent interfacing and synchronization - customer-oriented solution
KER #2 : Small size high efficiency micro-cogenerator SOFC based systems with integrated advanced monitoring that results in lifetime improvement	
Description	The new type of co-generator based on a Solid Oxid Fuel Cell (SOFC) systems integrating the fault detection technology (Bitron Box) is developed in INSIGHT project and will be integrated into a commercial system to improve the lifetime as well as the maintenance procedures
Problem	Current co-generators suffer from performance degradation. Maintenance service is reactive rather than predictive. Customers feel that the product requires a lot of maintenance and it is not reliable
Alternative solution	Currently the problems are solved by short maintenance intervals and by adjusting operation conditions with decreased performances
Unique Selling Point USP - Unique Value Proposition UVP	Improved product performance and availability. Increased maintenance service intervals and switch to a predictive maintenance strategy
KER #3: Algorithms	
Description	Diagnostic algorithms for detection of State of Health and State of Operation of Solid Oxide Fuel Cells, with related patents and scientific papers. Algorithm can be used as bases for providing services on monitoring and maintenance. Mitigation actions can be identified thanks to the algorithm, taking into account faults occurring at stack level. Along with the algorithm, customer projects to implement the algorithm according to the customer applications.
Problem	Suitably detect in time several faults to improve SOFC stack lifetime and reliability. Optimizing the working operations to avoid too much system shut-downs. Provide suggestions on different mitigation strategies to be applied according to the current state of health. Improve overall efficiency, durability, Time To Failure, Time Between Failures, and Time to Recovery
Alternative solution	Lifetime: system are usually operated in conservative manner, to prevent stack failure before expected time (with reduced efficiency); Reliability: only advanced faults are detected, with reduced stack reliability, and maintenance strategies are based on periodic intervention and system shut-down under faulty state; Accelerated Tests Protocols can be used so for to gain understanding on lifetime perspective.

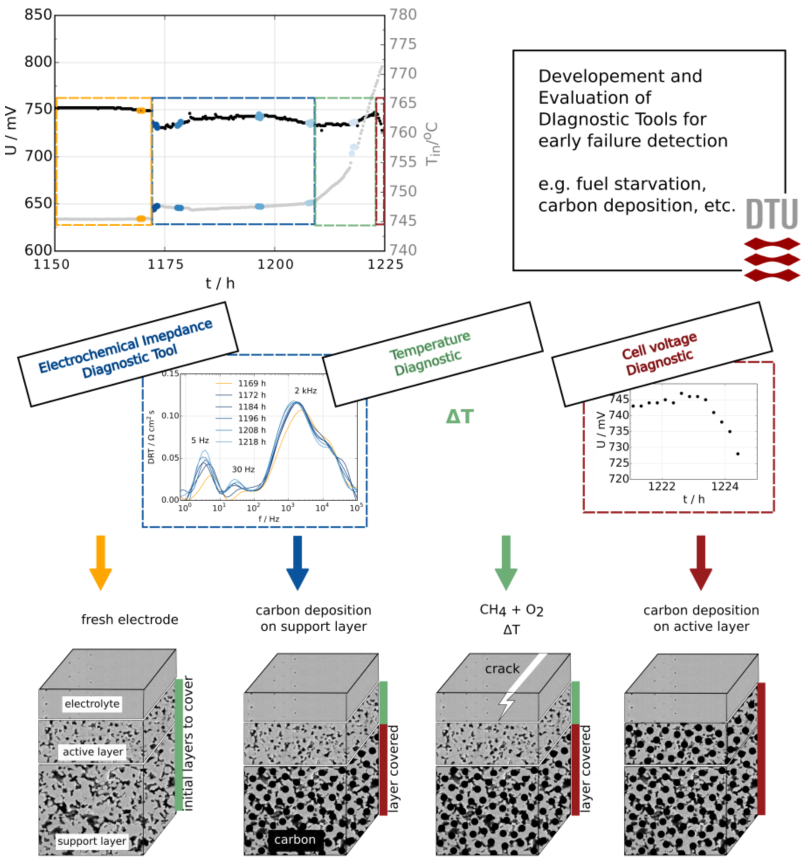
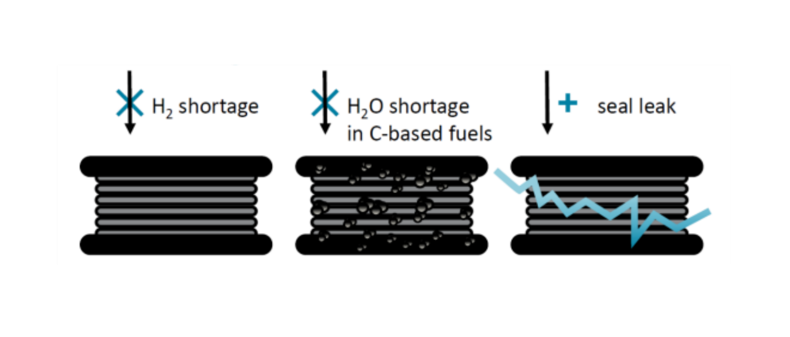
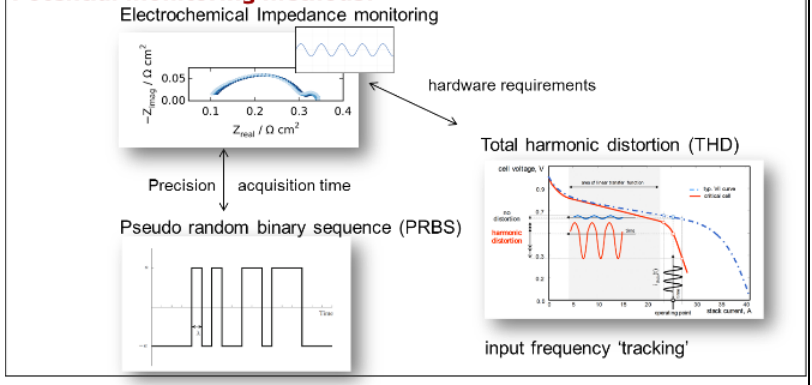
Unique Selling Point USP - Unique Value Proposition UVP	The diagnostic algorithms can detect and isolate several stack faults also at early stage, allowing the controller to recover or move towards a safer operation (i.e., fault tolerant control), avoiding system shut-down and improving maintenance processes (i.e., predictive maintenance). This is allowed thanks to the different mitigation strategies that are identified by the mitigation algorithm. Therefore, the customer can use the stack also under some faulty operations for longer time, with increased lifetime and efficiency. From companies' point of view, they will improve maintenance strategies costs as well as customer care. Moreover, the Total Cost of Ownership will may reduce accordingly.
KER #4: Know-how to develop customised solution	
Description	Know-how to be used to provide advice on developing and characterizing customer solutions for fuel cell diagnostics. The expertise made available in the form of a service, allows to support SOFC system integrators in getting ahead start and a more controllable approach when developing novel solutions. The service incorporates hardware devices and expert advice.
Problem	The customer wants to make their fuel cell systems run longer, be more reliable and better under control during long-term operation. The customer wishes to have more and better information of the performance and behaviour their system, without introducing significant new hardware (and thus costs) to the system. § Need to integrate new hardware to collect more and better information on the performance and behaviour of systems; § Costs for accessing information for the design of new solutions; § Reliability of data to optimise life of fuel cell systems; § Reliability and controls during long-term operation.
Alternative solution	Stack voltage measurements and comparison to reference values. Problem of this method, it is difficult to find the root cause of unexpected performance deviations. Post-mortem analytics, extensive testing… generally the problem has not been addressed until so far – this is a new development. So far system integrators are using "post-mortem" analytics, with extensive testing costs.
Unique Selling Point USP - Unique Value Proposition UVP	The KER – i.e. the developed competence – allows for us to provide this service / to support the customer in getting a head start and more controllable approach to developing the intended solutions. In practice, this translates to costs savings in R&D expenditure and faster reach of results. § Flexibility, with customised solutions, to access information; § Reduction of R&D expenditure and faster reach of results.

Table 6 : Key Exploitable Results descriptions

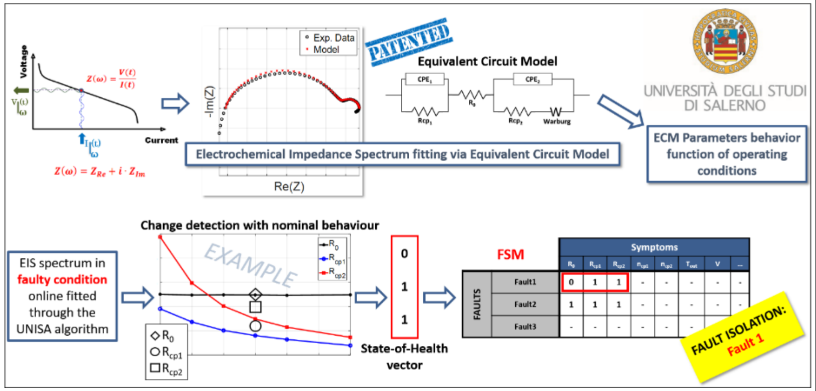
A. Knowledge assessment:

Partner	Expected Results	Results first period	Results at the end of the project
CEA	**Local current monitoring and model correlation** Study the local conditions in terms of current and fuel utilisation on SOFC cells to better understand their impact on cell degradation. Be able to get this information on classical cells without the need of special geometries/manufacturing	Measurement done on a classical SOLIDpower cell using a current collector with 9 local voltage measurements, Gas distribution: inlet at the center, outlet at the periphery Good correlation between experiment and model Large difference in terms of current density along the cell diameter: 2 times larger at the center than at the periphery in case a high fuel utilisation is used (> 80%)  PERSPECTIVES Continue the mapping with various experimental conditions. Identify limit conditions above which there is a risk of degradation, the associated signals, in order to be able, in stack, to make a diagnosis of risky conditions and take corrective measures in order to increase lifetime.	continuation of the long term test on SP 6-cell stack  Evaluation of the impact of high FU steps on stack degradation and on PRBS-type EIS signal, as well as effect of H2 shortage. THD analysis and identification of THD index increase upon high FU steps. Test of leaky stack, and highlight of interest of conventional signals, associated to deviation trials around nominal conditions, as useful methods to highlight issues Validation of the method on a large scale stack (32 cells)

	Implementation of EIS/PRBS every 6 h during 2000 h of a short stack test in order to use it as a diagnostic and lifetime evaluation tool	SOFC 6-cells short stack from SOLIDpower tested at CEA in collaboration with IJS. Fuel starvation has been gradually tested with EIS and PRBS measurements implemented every 6 h during 2000 h of test.  step 0 - FU=77.4% nominal operating conditions 750°C, i=0.4 Acm^{-2} 1a - FU=82.4% by decreasing H2 flow rate 2a - FU=87.4% by decreasing H2 flow rate 3a - FU=92.4% by decreasing H2 flow rate 1b - FU=82.4% by increasing current 2b - FU=87.4% by increasing current 3b - FU=92.4% by increasing current F1 - OCV after H2 supply shutdown F2 - OCV after H2 supply shutdown	

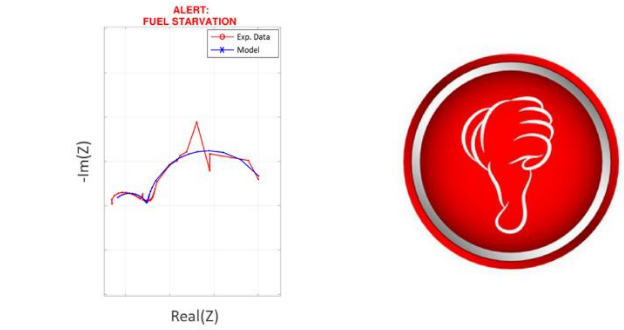
DTU	Implemented set of diagnostic tools for stacks/systems into a practical device		**Realistic faults for operation of combined heat & power systems operating with natural gas fuel:**  **Potential monitoring methods:** 
UNISA	Monitoring, Diagnostic, Lifetime, Mitigation tools	UNISA is developing a diagnostic algorithm for Detection and Isolation of faults at single cell and stack level based on Electrochemical Impedance Spectroscopy. The algorithm follows an Equivalent Circuit Modelling (ECM) approach through which significant parameters are identified. Parameters extraction is performed by means of a UNISA proprietary patented technique, which allows high generalizability and fast fitting performances. An offline characterization of such parameters allows to map them in	The approach has been validated for the detection of the fuel starvation for different technologies and layout. Indeed, the isolation of the fuel starvation has been achieved via EIS-based features analysis extracted via UNISA algorithm for a segmented cell at 90% F.U., for a 6-cell short stack (measured via sinusoidal stimulus) at 85% F.U., for 6-cells short stack (measured via PRBS stimulus) at 82% F.U., for a 64-cells full stack in a laboratory

<table>
<tr><td></td><td></td><td>both nominal and faulty states. This helps in designing reference patterns through which fault detection is performed. Indeed, online EIS measurements are used for real time estimation of ECM parameters, then compared with their nominal mapped values. If a sensible divergence occurs, a symptom arises. Symptoms collection and comparison with faulty patterns allows afterwards State-of-Health estimation.

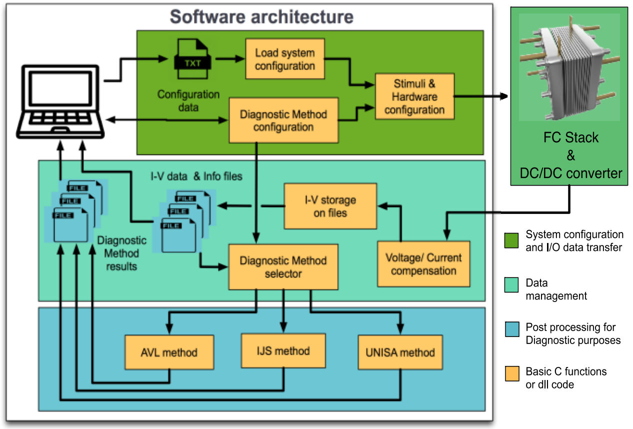
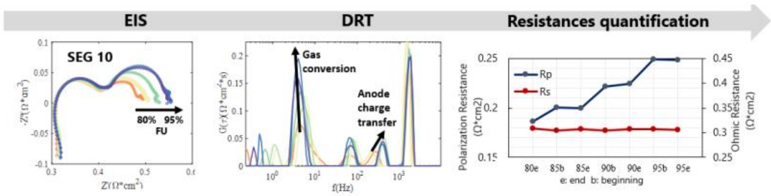
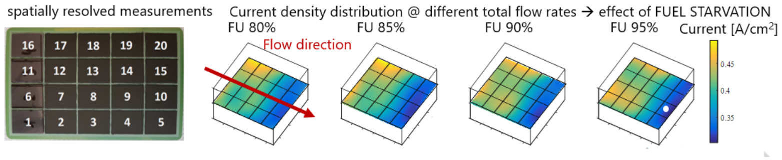


</td><td>environment for a 75% F.U. and for a 64-cells full stack in a real environment (On-Field test) for a 70% F.U.

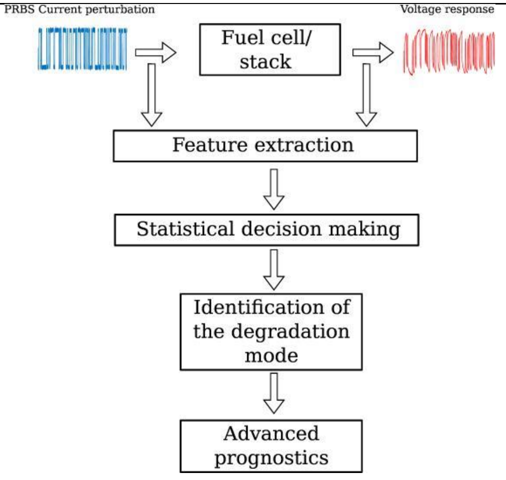
The diagnostic algorithm proved to be suitable for on board applications and the inductive problem that highly affects the EIS spectrum at high frequencies has been overcome with a partial analysis application of the method isolating the low frequency related information.

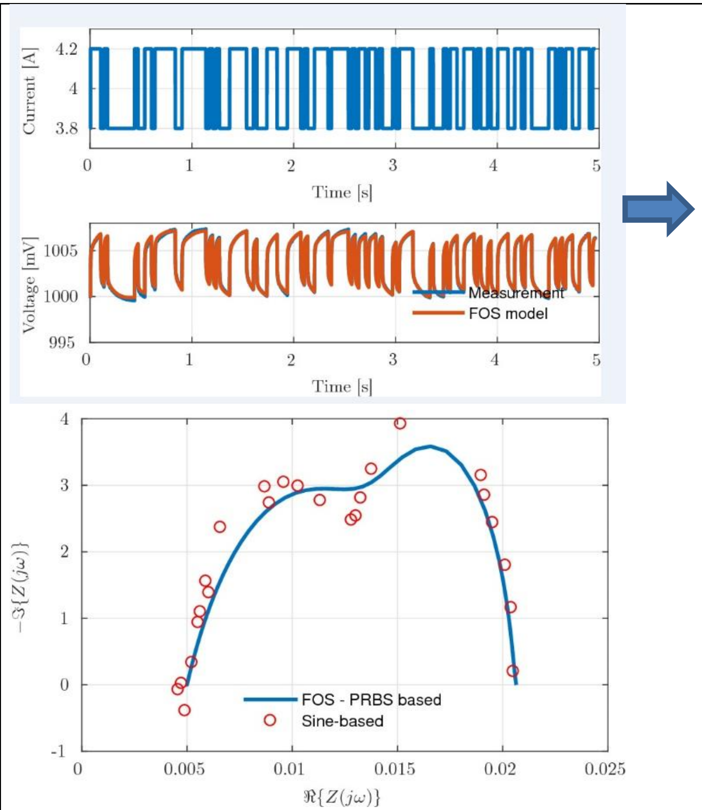


</td></tr>
<tr><td></td><td>HW & firmware engineering for on-board use.</td><td>The figure shows the schematics of the high level (HL) software; it has been conceived to include EXTERNAL CODE that take as input the acquired data for performing on board the diagnostic methods. To assure the correct data exchange and a proper hardware configuration, the HL software executes each diagnostic method as a call to the corresponding C function.</td><td></td></tr>
</table>

			
EPFL	Addition of new diagnostic tools on existing instrumented advanced stack test benches for validation		Conclusions: - The defect "gap in the sealing close to the stack inlet" can be more easily detected than a gap located close to the outlet of the stack. - It can most clearly be observed in the OCV. At the RU level its signature is related to the increase in steam content, which results in a reduction of the polarization resistance as measured by EIS. - DRT analysis reveals that it is the gas conversion peak (P2) that is reduced, whereas peak P3, which is attributed to gas diffusion in the porous anode structure, is shifted towards higher frequencies. - Finally, at the cluster level, this signature cannot be detected anymore due to averaging with defect-free RUs.
	Improved lifetime prediction tool calibrated with spatially resolved measurement data, e.g. signal response from a SRU with a known local defect introduced on purpose	 CURRENT STATUS Measurement on 2-cells short stack with a segmented SOLIDPower cell Gas distribution: co-flow Air-Fuel according to the arrow direction Possibility to create spatial maps (current density) EIS combine with DRT and CNLS to quantify elementary process' contributions PERSPECTIVES Continue the mapping according to the test protocol Test a cell with purposefully introduced faults on different segments	

		Experimental data to fed lifetime modeling	
IJS	**PRBS-based diagnosis and prognosis** The aim is to use unconventional non-sinusoidal system probing in order to reduce the time for experiment, increase the robustness to noise, investigate new techniques for degradation diagnosis and prognosis of the remaining life span	IJS is working out a novel health assessment procedure for stacks/cells by using non-sinusoidal perturbation in terms of step-like pseudo-random binary signal (PRBS). When using the PRBS current signal, the fuel cell system is excited by all the frequencies from a broad spectrum at the same time. Thanks to that, the duration of system excitation is considerably reduced **up to an order of magnitude**. Furthermore, to characterize the FC system dynamics, a class of fractional-order models (FOS) and their identification from the acquired current and voltage samples has been investigated. The estimated FOS model parameters are employed to determine the degradation mode via statistical decision making. In the perspective, the time evolution of the related model parameters is modelled as a stochastic process, which is used to predict the future trend.	The approach has been validated on a 6-cell short stack periodically probed by means of the PRBS. The stack was subjected to high fuel utilisation changed from 77.5% to 92.5% and starvation. Based on the PRBS excitation and wavelet analysis the parameters of the FOS model are identified. Increase fuel utilisation introduces significant changes in the FOS parameters, hence constituting a rather specific, reliably identifiable pattern. Also, degradation mechanisms are identified through the monotonous increase of the serial resistance. An upgrade of the FOS identification algorithm based on Markov Chain Monte Carlo that evaluates the uncertainty of the FOS model parameters by means of the probability density distributions is also developed and validated. Hereby a diagnostic algorithm that accounts for the uncertainty of the model parameters and reveals changes in their time evolution by using entropy indices is derived. An important property of this algorithm is that the diagnostic threshold selection reduces to the selection of the false alarm rate.

		 Figure 13: The diagnostic and prognostic procedure	

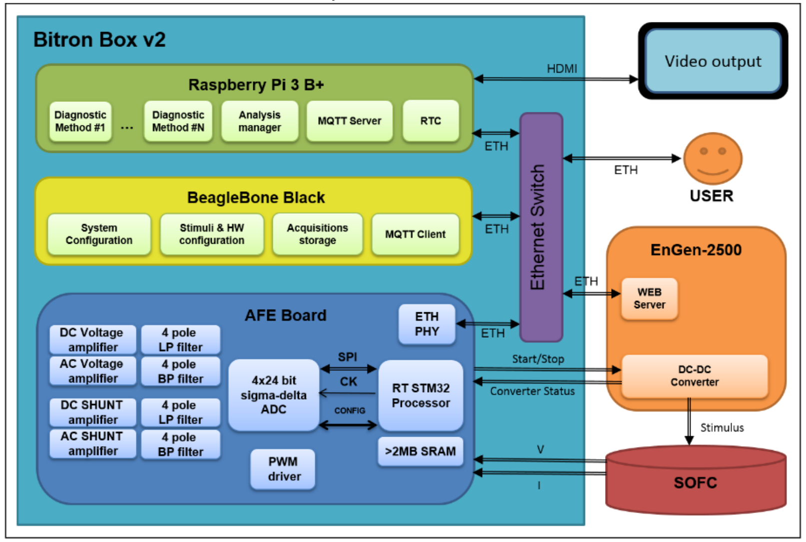
		 Figure 14: Response of the cell voltage to PRBS current excitation (left). The comparison of FOS model in the frequerncy space and conventional sine-based EIS curve is shown on the right. Note that in the particular case a 5 seconds recording suits to get high quality model of the FC system.	
BIT	MDLT HW device.	The first release of the Bitron Box, is under construction. First samples will be released in September 2018. The main architecture is so defined: • A Linux board (Beagle bone Black v3), is devoted for the high-level implementation part, where the several partner's	The new release of the BitronBox was produced in 7 samples:

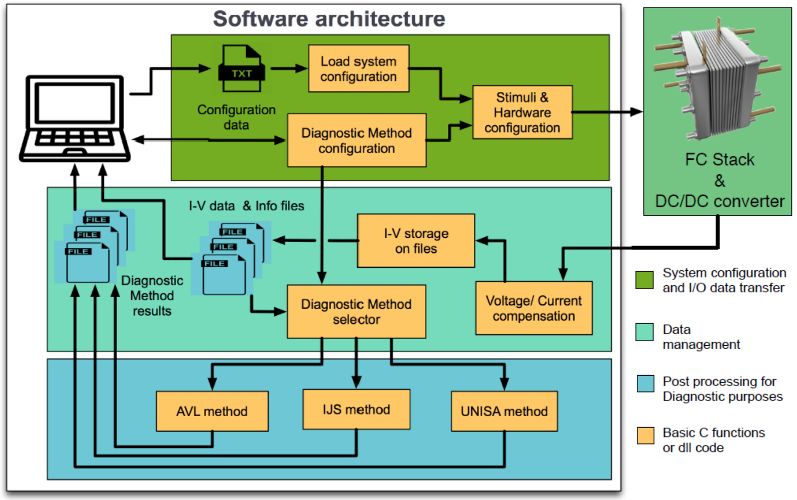
algorithms run and compute a post processing elaboration of the data samples previously acquired.

- A Bitron board, which is a full custom device responsible for the data samples acquisition part. It takes command from the Linux board. Then thanks to a dedicated TCP communication protocol, developed together with UNISA partner, shares the data samples. The main features of the boards are given:
    - Four acquisition channels: two used for acquiring the DC components, and the others two for acquiring the AC components.
    - Pre-Conditioning input filters used for the noise attenuation of the several input signals. Those have been already designed and tested from a simulation point of view.
    - For the acquisition, a specific Sigma Delta device has been chosen. It communicates with the microprocessor with SPI standard and provides accurate data with a maximum sampling frequency of 75 ksps and a resolution of 24 bits for all the selected channels.
    - STM32F4 microprocessor with ARM Cortex M architecture, with maximum clock frequency 168 MHz.
    - Extended RAM module for increasing the number of data samples to be sent in a second time to the Linux Board.
    - A Real Time Operative System firmware has mostly been designed and tested for managing the acquisition part and the Ethernet data communication protocol with the Linux Board.

A more complete and detailed scheme of the Software architecture provided by UNISA, is reported and described below.

In the following figure a more comprehensive architecture of the BitronBox v2 internals is depicted:





The Linux board sends acquisition commands to the Bitron board. Once the acquisition is completed the data samples are sent back and stored inside the Linux file system as binary files. Those data files are used in a second time for the elaboration process by the algorithms developed by all the partners. The aim here is to create a sort of interface which can be interpreted as a standard for all the working algorithms. The selected approach allows to minimize each Software modules complexity which are independent. Furthermore, they can be easily tested and validated creating "ad hoc" test suites with the objective to guarantee robustness and reliability.

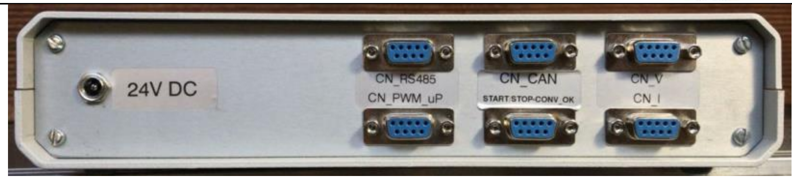
The final objective of the overall system is to provide an "on site" device which provides significant and useful results minimizing production costs. Therefore, demonstrating its reliability and affordability for an industry use, which nowadays, is limited by costly laboratory instrumentations.

BitronBox is composed by 3 elements, AFE, BBB and RB:

- the user interacts with the BitronBox (BBB and RB) via Ethernet cable (through SSH);
- the user can receive visual output thanks to an optional HDMI interface;
- the SOLIDpower EnGen-2500 system interfaces with the BitronBox through a two level interface: a high level web server interface for configuration and a low level digital channel for starting and stopping the DC/DC converter.

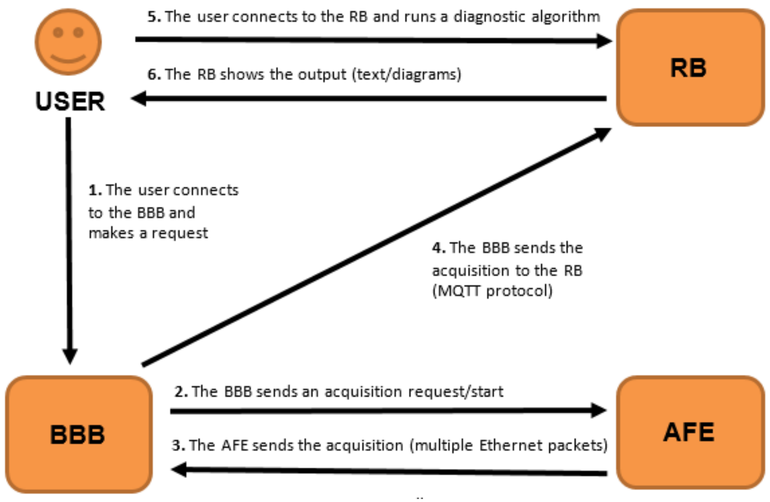
A number of interfaces is exposed by the BitronBox enclosure (see also the figures below, taken from a pre-prototype realization):

- ETH 1: user interface
- ETH 2: interface to the EnGen-2500 system web server
- HDMI: video output
- CN_V: input voltage of the SOFC
- CN_I: input current of the SOFC
- START/STOP-CONV_OK: Digital Input and Digital Output to communicate with the converter
- CN_CAN: CAN interface (not used – only for debug)
- CN_PWM_ µP: PWM of the AFE microcontroller (not used)
- CN_RS485: RS485 interface (not used)



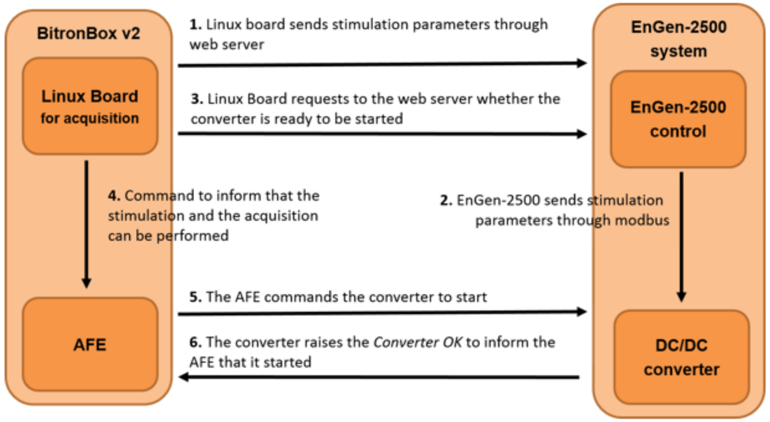
A generic user can connect to the BitronBox (via SSH through Ethernet connection) and command either the BBB and the RB. In this way, he or she can perform an acquisition and then perform the diagnostics.

In the figure below, the high level workflow is described.



The picture below shows a typical sequence of operations to be performed before an acquisition.

The BitronBox and the EnGen-2500 are connected through an Ethernet cable (for the web server interface) and through two digital pins (for the DC/DC converter connection).

			 In conclusion, the board already developed in the HEALTH-CODE project has been improved by removing the limitations of the application field as per the current state-of-the-art. The renewed and improved board has been then integrated in the final design of the BitronBox v2 along with the needed interfaces and functionalities.
SP & HTc	Small size high efficiency micro-cogenerator SOFC based systems, for small commercial and residential markets	Modified DC/DC converter for INSIGHT project are custom modifications of the existing DC/DC converters already installed into EnGen-2500tm SOLIDpower's product. The requirements of the converter were written to fulfill project's needs. Hence the parameters of the perturbation will satisfy what is needed for the project to correctly influence the stack electrical current. One of the key features of this component is to have a MDLT generator signal integrated into a commercial DC/DC converter. External dimensions have been planned to be the same as the normal converter, to allow a perfect integration into the chassis of the micro-cogenerator. Easy integration is also important from the software point of view, where the protocol was extended to manage generation of EIS and PRBS signals and the communication with the acquisition and analysis board.	The integration of the BitronBox in the EnGen-2500 system required great effort but finally showed good reliability and functionality over the six months' test period. The normal operation of the system has not been compromised and it is possible to use the system both in normal configuration and in MDLT configuration mode. The integration of the work has been successfully carried out, also in terms of mechanical and electrical design, and the final installation has been performed now in real environment configuration (see picture below (Figure 13). By using the MDLT device it's now possible to perturbate the system with EIS/PRBS signals and then to launch the diagnosis algorithms installed on board the system. An outcome of the diagnosis algorithm is provided on-screen after the period of the perturbation-measure-analysis and provide a clear overview of the test results.

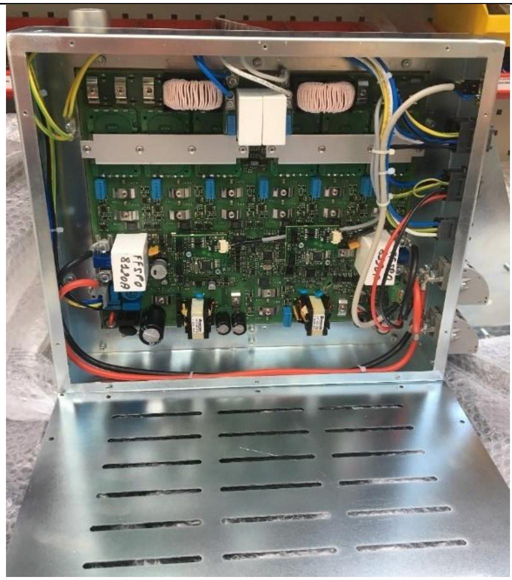


Figure 15 - Modified DC/DC converter for INSIGHT project.

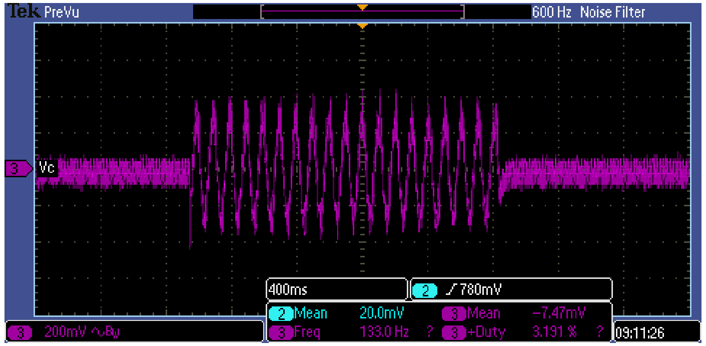
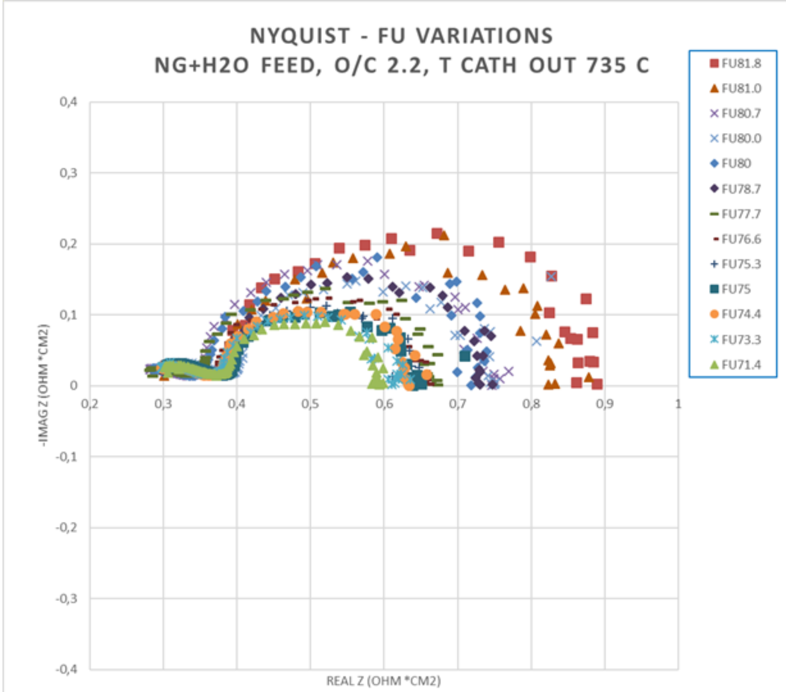


Figure 16 - Generation of EIS perturbation on stack current.

Results on tests performed on DC/DC converters show the possibilty to integrate a perturbations generator into a commercial DC/DC converter. Possibility to change parameters as frequency, amplitude and durations of perturbations will allow many different perturbations and different diagnosis analysis tests. Expectations

Figure 17- Final system installed on field.

		will come also from the next tests on field and from the possible outcome for the cost, hence the possibility to include this solution into a commercial micro-cogenerator.	
VTT	Procedure for developing MDLT algorithms Computational hardware for SOFC systems	VTT will carry out testing and validation of the MDLT tools developed in the project. To this end it will conduct test planning necessary to empirically validate the developed tools. This, and the eventual implementation of the tests, will significantly promote VTT's capacity in supporting companies and organizations in the development of MDLT algorithms by strengthening our capacity to tell which features are necessary and what kind of testing will be useful for validating the algorithms' proper functionality. This will directly guide their development. Furthermore, carrying out such experiments needed for the MDLT tools' validation will necessitate VTT to bring its test facility (e.g. in Figure below), in particular on behalf of its analytics and automation features, up to par with the requirements of such highly complex experiments. This will yield long-lasting laboratory facility capacity as well as relevant knowhow to support reaching the said exploitable outcome. As part of this effort VTT will obtain computational hardware, such as impedance analysis electronics as well as self-programmed algorithms in embedded hardware, which are necessary to carry out said experiments. These "by-products" of the INSIGHT project will be directly exploitable in future research projects as well as in customer collaboration projects for further SOFC system development.	VTT's ability for reliable and good-quality high-frequency measurements improved significantly. This includes better understanding and know-how in all levels of measurements, meaning from enhanced wiring to better usage of measurement sensors, devices and equipment. Thus, capability to support companies and organizations in demanding SOFC tests and measurements was increased. This was shown in providing and sharing good-quality data within the consortium that was used for algorithm development. This was a significant contribution for main results of the project.

		 Figure 18 - The INSIGHT test rig for MDLT tool validation located at VTT fuel cell labs.	 Figure 19. Example of EIS-measurement data measured during the project.

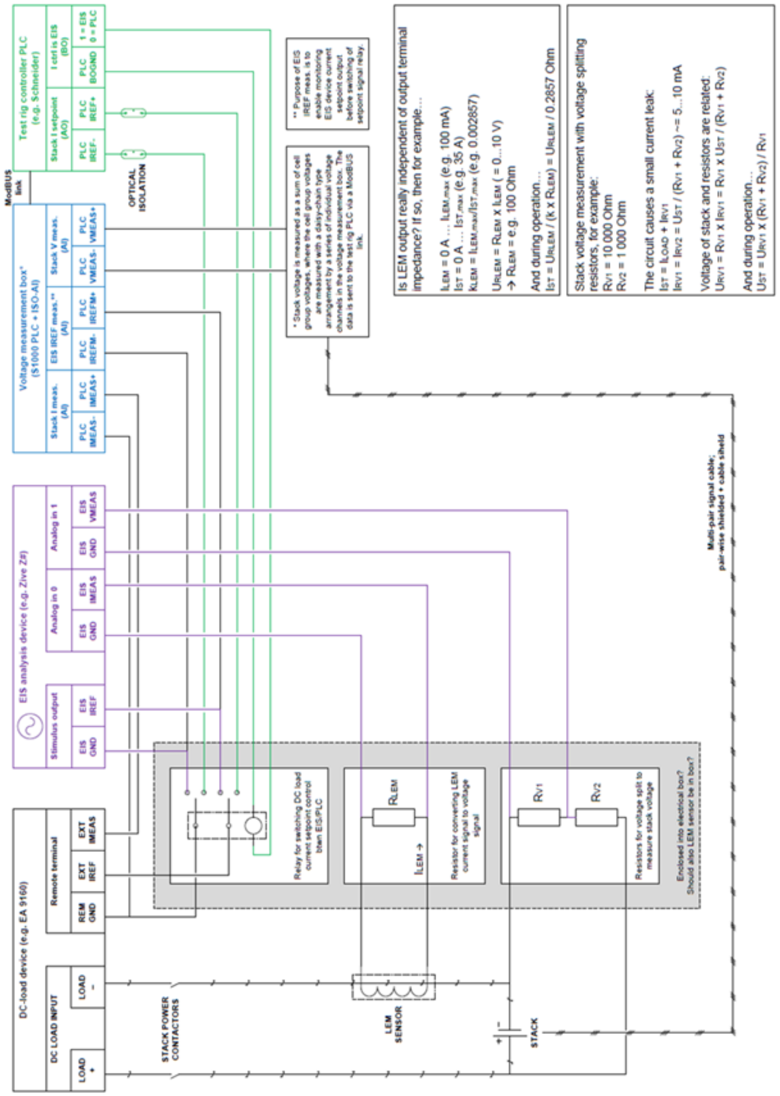
			 Figure 20. Wiring diagram of improved EIS-measurements.

Table 7: Knowledge assessment tool

B. Intellectual Property Management

The knowledge management is dedicated to the management of the knowledge created during the project (Results) and the existing knowledge needed to achieve the work (background) by either the participating institutions or any other parties that might influence the conduct of the project.

Project netboard is used as a daily collaborative web tool to collect relevant information (Background, Results) structured according to the Deliverables. The author of a Deliverable will be responsible for collecting, organizing and archiving all information in relation to his/her Deliverable(s) including the bibliography and web links.

Using the information entered in Project netboard, the partners discuss IP management with the table below.

		Who generates ?		IP protection measures intended (and where)		Licensing model(s)	Financial compensation expected (for commercial exploitation)	Scope of the exploitation ? Any barrier?	Legal service contact point (name, email)
Main Partner	**Exploitable Item name**	**Single ownership**	**Joint ownership**	**Copyright**	**Patent**				
CEA	Local current monitoring	X		NO	NO	No, internal knowhow	Follow up projects (either collaborative or bilateral with industrials)	Scientific articles, understanding of degradation Follow up projects (either collaborative or bilateral with industrials)	Bertrand Morel
	Fault testing protocol		x	NO	NO	No, knowhow			
	Physically based degradation law	X		NO	NO	No, internal model and methodology			
DTU	- Model for cathode degradation during cell production and testing - Fault testing protocols for stacks		X	NO	NO	No, internal knowhow.	- Projects and collaborations (either academic or industrial) - Integration in further national and international projects	- Scientific articles, understanding of degradation - Progressing the technology through enhanced understanding of critical degradation issues	Ming Chen Anke Hagen
UNISA	Diagnostic, lifetime and mitigation algorithms	X		UNISA (DIIN)	NO	Free use of executable algorithm for diagnostic uses, under	Projects and collaborations (either academic or industrial)	Scientific publications, projects and collaborations (either academic or industrial).	Prof. Cesare Pianese (pianese@unisa.it) UNISA Trasferimento tecnologico (traferimentotecnologico@unisa.it)

						UNISA supervision.			
EPFL	Segmented cell for spatially resolved measurements	X	X (with HTc)	NO (?)	NO (?)	No, internal knowhow		Scientific articles, understanding of degradation	Jan Van herle
	Distribution of relaxation of time constants method			YES	NO		Follow up projects (either collaborative or bilateral with industrials)		
IJS	PRBS based health assessment system	X	-	Yes to project partners	Not apllied so far as significant part of hidden knowledge takes part in the system	Not defined yet	yes	Laboratory use well as monitoring of commercial systems; barrier might be in the commercialisation phase in case a global player is not assigned to the action	IJS, Marta.slokan@ijs.si
VTT	Knowhow and experience in conducting complex measurements with mid-size SOFC stacks and modules.	X		NO	NO	No, internal knowhow	Follow-up projects (either collaborative or bilateral with industrials)	Scientific articles, understanding of necessary testing and measurement approaches.	Aki Nieminen aki.nieminen@vtt.fi

	Knowhow and experience in testing and validation of complex SOFC monitoring and lifetime tools.								
AVL	Patent	Yes	-		Two patents filed	Yes, Per unit license in combination with annual license fees.	Unclear, patent not yet approved. New customer projects.	New customers. Implementation in commercial SW.	Stefan.pofahl@avl.com
	Software	Yes	-	yes	no	Purchase price plus SW-maintenance fee	Additional revenues for test station HW.	New customers. AVL will improve its visibility in the domain of EIS HW supplier.	Stefan.pofahl@avl.com
SP&HTc	Small size high efficiency micro-cogenerator SOFC based systems, for small commercial and residential markets	X		YES	NO	YES	Increasing life-time of SOFC stack and reliability of system	Application of MDLT techniques to an industrial micro cogenerator.	Massimo Bertoldi
BIT	Data acquisition board for SOFC systems	x		YES	NO	No, internal know-how	Follow up projects, either with research centers and industrial partners	Follow up projects, either with research centers and industrial partners	Giuseppe Catona@gru.bitron-ind.com

Table 8 : IP management tool

C. Exploitation of Results: management tool

			Technology readiness progress					Competitive context		Exploitation plan			
Partner	**Exploitable Item/product name**	**Exploitable Item short description**	**Current status (input TRL when applicable)**	**Project progress beyond the current status (output TRL)**	**TRL Y1**	**TRL Y2**	**TRL Y3**	**Competitors**	**Added value of exploitable item**	**How? Routes for Exploitation**	**When?**	**By Whom? Potential users**	**Where? Scope : EU and/or other countries**
CEA	Local current monitoring; Fault testing protocol; Physically based degradation law	See above	NA		1 2 2	2	3 3	Other academic partners	Understanding of degradation; fault detection and mitigation strategies	Scientific articles, understanding of degradation Follow up projects (either collaborative or bilateral with industrials)	During or after the completion of the project	Industrial stacks and system manufacturers in SOFC, but also SOEC or SOC	Mainly EU
DTU	Stack testing integrating faults, detailed probing and diagnostics	See above	NA					Other academic partners	Identification of relevant faults and means of diagnostics at stack level	Scientific output (articles), which is available to the SOC community	During and after the project	SOFC technology providers	Mainly EU
UNISA	Diagnostic, lifetime and mitigation algorithms	Algorithms for fault diagnosis, degradation modelling and mitigation strategies	TRL4	TRL6	4	5	6	Other academic and industrial partners	Advanced faut detection and isolation based on EIS; simplified degradation modelling for lifetime inference; mitigation strategies definition for lifetime improvement	Scientific publications, projections and collaborations (either academic or industrial)	During and after project closure	SOFC system integrators and users	Mainly EU

	EIS board firmware	EIS impedance analysis firmware and on-line parameters identification	NA					NA	Embedded diagnostic system	Develop HW and SW aspects of the product	End of the project	Any FC producer and system integrator	
EPFL	Segmented cell for spatially resolved measurements; Distribution of relaxation of time constants method to analyse EIS data							Other academic partners	Understanding of degradation; fault detection and mitigation strategies	Scientific articles, understanding of degradation; Follow up projects (either collaborative or bilateral with industrials)	During/after completion of project	Industrial stacks & system manufacturer in SOFC, but also SOEC or SOC	Mainly EU
JSI	PRBS based health assessment system	A pseudo-random binary signal is used for SOFC probing followed by model identification in time domain from a class of fractional-order models	Input TRL2-3, current 4-5	Expected output TRL 5-6	2	3	4	Current EIS equipment manufacturers	Significantly shorter probing sessions compared to the conventional sine-based techniques; Efficient parameter estimation	Scientific articles, follow up projects (collaborative or bilateral with industrials)	By the end of the project	The bulk of activities will be performed by the IJS team. Potential users span R&D units involved in SOFC technology sector, the upcoming end-users of the SOFC installations ans system integrators appointed to SOFC management and	worldwide

												predictive maintenance	
VTT	Knowhow and experience in conducting complex measurements with mid-size SOFC stacks and modules Knowhow and experience in testing and validation of complex SOFC monitoring and lifetime tools	See above	NA					Other technical and scientific actors	Being capable to conduct more relevant testing in less time, with less effort and producing more accurate and reliable results	Scientific articles, understanding of necessary testing and measurement approaches. Follow up projects (either collaborative or bilateral with industrials) Sales promotional material for VTT corporate sales	During/after completion of project	In particular SOFC system integrators, but also their customers looking for 3rd party verification of claimed capacity of existing solutions	Current customer base spans Europe and Eastern Asia
SP&HTc	Small size high efficiency micro-cogenerator SOFC based systems, for small commercial and residential markets	See above	NA					Other industrial SOFC system producers	Understand application on industrial scale of MDLT diagnosis onSOFC stacks system	Test of final system on-field	During second period of projects, when onfiels test will start	Normal final customer of EnGen 2500 microcogenerator	world
BIT	Data acquisition board fro SOFC systems	Large bandwidth acquisition board with 4 high resolution channels thanks to Sigma-Delta 24 bits converters	mature	mature	9	NA	NA	Other industrial board manufacturers	Large bandwidth acquisition board with 4 high resolution channels thanks to Sigma-Delta 24 bits converters	Follow-up of project, either with research centers and industrial partners	During or after the completion of the project	Systemmanufacturers working in the fiels of the fuel cells	Mainly EU
AVL	Indicom AddOn	SW to anable advanced EIS	3	4	3	4	4	Zahner, Gamry, Metrohm, FuelCon	Validation of SW on SOFC under collaboration of scientific partners	Customer contacts (B2B), conferences, trade fairs	2019 (selected customers)	Stack manufacturers (End-of-Line Testing),	Worldwide

												Stack Integrators, Scientific Institutions	

Table 9 : Exploitation of results