D7.5 – Update PEDR

PROJECT INFORMATION

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PROJECT FULL TITLE	Low Cost Interconnects with highly improved Contact Strength for SOC Applications
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PROJECT WEBSITE	www.lowcost-ic.eu

DELIVERABLE INFORMATION

WP NO.	D7.5
WP LEADER	Henrik Lund Frandsen
CONTRIBUTING PARTNERS	All
NATURE	Report
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DISSEMINATION LEVEL

PU	Public	X
PP	Restricted to other programme participants (incl. Commission Services)	
RE	Restricted to a group specified by the consortium (incl. Commission Services)	
CO	Confidential, only for the members of the consortium (incl. Commission Services)	

LOWCOST-IC

1 Scope of deliverable

This document is an amendment to the Plan for the Exploitation and Dissemination of Results (PEDR), which was submitted in D7.1 in M3. For an outline of the general strategy for the dissemination and exploitation of results in LOWCOST-IC, the reader is referred to this previous report. Here, we have made an overview of the dissemination activities carried out in 2019, and the activities planned for 2020.

2 Dissemination activities in 2019

The LOWCOST-IC project and results generated so far was presented at one technology fair (Hannover Messe) and one conference (SOFC XVI) in 2019. An overview of all presentations is given in Table 1. Most of the presentations were oral, and were well attended by the scientific community as well as the SOFC/SOEC industry.

Five papers with results from LOWCOST-IC were published in 2019, among which four were conference proceedings and one was a full journal paper (published open access). An overview of the papers is given in Table 2.

Table 1 Presentations given in 2019

Date(s)	Type of activity	Name and place of event	Presenter	Title of presentation
1/4/2019-5/4/2019	Presentation of poster at fair	Hannover Messe	Hendrik Langnickel	LOWCOST-IC project
11/9/2019	Oral presentation at conference	SOFC XVI, Kyoto	Henrik Lund Frandsen	Enhancing the Robustness of Brittle Solid Oxide Cell Stack Components
9/9/2019	Oral presentation at conference	SOFC XVI, Kyoto	Christian Walter	Stack Development and Industrial Scale-up
10/92019	Oral presentation at conference	SOFC XVI, Kyoto	Claudia Göbel	The Influence of Different Factors on the Dual Atmosphere Effect
8-13/9/2019	Poster presentation at conference	SOFC XVI, Kyoto	Matthieu Tomas	Cu-Based Coatings for IT-SOFC Applications
11/9/2019	Oral presentation at conference	SOFC XVI, Kyoto	Belma Talic	Improved Robustness and Low Area Specific Resistance with Novel Contact Layers for the Solid Oxide Cell Air Electrode

Table 2 Papers published in 2019

Authors	Title	Journal / proceeding name	Year	Volume, Issue, Pages
H.L. Frandsen, I. Ritucci, P. Khajavi, B. Talic, L. Han, R. Kiebach, P.V. Hendriksen	Enhancing the Robustness of Brittle Solid Oxide Cell Stack Components	ECS Transactions	2019	91(1), 2201-2211
C. Goebel, R. Berger, C. Bernuy-Lopez, J. Westlinder, J.E. Svensson, J. Froitzheim	Long-term (4 year) degradation behavior of coated stainless steel 441 used for solid oxide fuel cell interconnect applications	Journal of Power Sources	2020	In press
M. Tomas, C. Goebel, J.E. Svensson, Froitzheim	Cu-Based Coatings for IT-SOFC Applications Interconnect, Contact and Sealing Materials	ECS Transactions	2019	91(1): 2291-2298
C. Goebel, C. Bo, J.E. Svensson, J. Froitzheim	The Influence of Different Factors on the Dual Atmosphere Effect Observed for AISI 441 Interconnects Used in Solid Oxide Fuel Cells Interconnect, Contact and Sealing Materials	ECS Transactions	2019	2261-2266
B. Talic, I. Ritucci, R. Kiebach, P.V. Hendriksen, H.L. Frandsen	Improved Robustness and Low Area Specific Resistance with Novel Contact Layers for the Solid Oxide Cell Air Electrode	ECS Transactions	2019	91(1):2225-2232

3 Dissemination activities planned in 2020

The dissemination activities planned for 2020 are primarily in the form of conference presentations and journal articles. An overview of already scheduled presentations and papers is given in

Table **3** and Table 4, respectively. Most of the project partners are planning to attend the European Fuel Cell Forum (EFCF) in Lucerne in 2020, although not all had the presentation title ready at the point when this report was submitted.

A one-day workshop on the mechanical failures in SOC stacks will be organized in 2020 (see Table 5). The workshop is scheduled to be held in Lucerne the day before the EFCF, such as to attract as many visitors as possible from the SOC industry and scientific community.

Table 3 Presentations planned in 2020

Date(s)	Type of activity	Name and place of event	Presenter	Title of presentation
28/1/2020		ICACC2020	Carlos Bernuy-Lopez	Mass manufacturing of coated steel coils for Solid Oxide Cells: a journey of collaborative research and development.

29/6/2020		European Fuel Cell Forum 2020, Lucerne	Henrik Lund Frandsen	Multi-scale model to describe the local degradation and mechanical failures in an SOC stack
29/6/2020		European Fuel Cell Forum 2020, Lucerne	Carlos Bernuy-Lopez	Conditioning optimization in Sandvik Sanergy® HT 441 after the forming process
New dates (Covid 19)	Presentation of poster at fair	Hannover Messe	Ragnar Kiebach	LOWCOST-IC project

Table 4 Papers planned to be submitted in 2020

Authors	Working title	Journal / proceeding name
H.L. Frandsen, O. B. Rizvandi, X Miao, A K. Padinjarethil, A. Hagen, A. Hauch	Multi-scale model to describe the local degradation and mechanical failures in an SOC stack	Proceedings of the European Fuel Cell Forum 2020, Lucerne
I. Ritucci, B. Talic, R. Kiebach, H.L. Frandsen	High toughness well conducting contact layers for solid oxide stacks by reactive oxidative bonding	To be decided.
B. Talic, Å.H. Persson, I. Ritucci, R. Kiebach, P.V. Hendriksen, H.L. Frandsen	In-situ oxidized Mn-Cu and Mn-Co metal powders as contact layers for the solid oxide cell air side	To be decided

Table 5 Workshop, conferences, events planned in 2020

Date(s)	Title	Name and place of event	Participants	Organizer
29/6/2020	Workshop on SOC stack robustness	In connection with European Fuel Cell Forum 2020, Lucerne	Open workshop for industry and academia	Henrik Lund Frandsen

4 Exploitation plan

The ambition of LOWCOST-IC is to ensure that the created results not only are available to the consortium partners, but that they are also accessible to all stakeholders interested in SOC technology, both in the industry and the scientific community.

4.1 Exploitation strategy

Based on the expected outcome of the LOWCOST-IC project, we have identified several "exploitable items", listed in Table 6. For each of these exploitable items, we have identified the potential markets and suitable methods for exploitation, as detailed below.

Table 6 Identification of exploitable results

Exploitable item	Expected project result
Cost-effective alloy for SOC interconnects	Extensive testing carried out in WP2 will identify the most suitable alloy for SOFC interconnects based on combined consideration of cost and performance. Long-term demonstration in a real-life stack will create the relevant credibility required by potential customers. Techno-economic analysis in WP6 will demonstrate the potential cost-savings using the new interconnect material.
Improved interconnect coatings with proven performance	Corrosion testing and coating development in WP2 will target an improved coating solution. Long-term demonstration in a real-life stack will create the relevant credibility required by potential customers. Techno-economic analysis in WP6 will demonstrate the potential cost-savings using the roll-to-roll PVD process for coating interconnects steel.
Guidelines for IC (+coating) shaping with hydroforming	The possibilities, design limitations and cost of using hydroforming investigated in WP3 and WP6 will be summarized in the final project report. This report will enable SOFC manufacturers and companies interested in starting activities in this field to ensure that their interconnect design can be realized without technical difficulties. The results of the LOWCOST-IC project with prove that the hydroforming technology is compatible with pre-coated materials in order to create functioning interconnects.
A novel contact material based on reactive oxidative bonding.	Testing the novel contact solution in a prototype stack (WP 5) will allow acquisition of novel know-how, and after one year constitute a new product ("contact paste for screen and inkjet printing") to serve clients (SOFC/SOFC stack producers).
DoD printing for SOC components	The process of depositing advanced ceramic pastes onto stainless steel substrates by DoD printing will be demonstrated in the project.

Techno-economic analysis report	The economic benefit of the high-volume processing methods combined in LOWCOST-IC are assessed by AVL, through a thorough cost-benefit analysis of the different production methods available. The SOC stack companies will benefit from the analysis in considerations about further upscaling, and the analysis can serve as guidance for designing the plants. The sub-suppliers will also gain by this direct comparison, as it will highlight the advantages of their production method, and promote the deployment of their respective technologies.
Novel interconnect design	The interconnect designs will be made publicly available (without revealing Sunfire IPR). Even more importantly, the developed approach for optimizing the interconnect design will be made available, so that also other stack manufacturers can benefit from the results.
Improved SOFC modelling software	The know-how created within the project will lead to an improved SOC stack model, which readily can predict failures in SOC stacks. Credibility towards customers will be created by demonstrating the approach (model → implementation).
Academic exploitation items	Scientific questions from the project will form the base for several MSc and PhD theses at Chalmers and DTU. In this way the project contributes to the education of European engineering students in general and with skills in fuel cells in particular.

4.1.1 Exploitation strategies for each exploitable item

Cost-effective alloy

Main beneficiary: Aperam
Potential market: All SOC stack industry

Exploitation strategy. The identified alloy will be advertised on Aperam's web page, and a technical data sheet for download and distribution at conferences and fairs will be made available. The results from the project will be used in technical meetings with potential customers (producers of SOC or CHP systems).

Interconnect coating

Main beneficiary: Sandvik
Potential market: SOC stack industry relying on thin plate IC. Parts of chemical/energy industry requiring corrosion protection of steel

Exploitation strategy. The developed solution will be added to Sandvik's existing portfolio on SOFC coatings. The improved version will be presented at conferences and exhibitions, as well as advertised on Sandvik's web page.

Shaping with hydroforming

Main beneficiary: Borit
Potential market: SOC stack industry relaying on thin plate IC. Automotive industry.

Exploitation strategy. The knowledge gain from LOWCOST-IC will be added to Borit's existing competences. The design guidelines for shaping, in combination with the developed pre-coated materials will be used in marketing and in prototype production projects to ensure proper design for manufacturability. The results from the project indicating the technical performance of the interconnect formed from pre-coated material will show that pre-coated materials combined with hydroforming is a viable way to produce high quality parts on an industrial scale.

Contact solution

Main beneficiary: DTU
Potential market: All SOC stack industry. Suppliers of slurries/inks.

Exploitation strategy. DTU will contact four potential European suppliers (ESL ElectroScience, Schott glass, Fuel Cell Today, Kerafoil) for licensing the product (WP7, D7.3), which also will be presented to relevant customers at the Hannover Fair 2022 and at the EFCF2020 and SOFC XVII conferences.

DoD printing for SOC components

Main beneficiary: Tecno Italia
Potential market: SOC stack industry is the primary market. Other markets could be electronic boards printing, automotive, avionics and other advanced sectors

Exploitation strategy. Targeted countries in EU for commercializing must be defined. In a first stage, the target countries could be: Year 1 Italy and Germany; Year 2 Rest of Europe and Year 3 Global. The commercial distribution and service network of Tecno Italia takes care of the training of final costumers and the service for both the mechanical and electronic parts of the machines. It includes: Polab (Poland), TecnoPrecision (China), Sempa (Turkey), Italab (Thailand), Tecno Italia (Spain), Tecno Italia (Italy), PT Techno Cher. (Indonesia), Italcer (Mexico), Euromec (Brasil), Eurolaser (Argentina).

Tecno Italia will seek initial market entry in Italy and Germany because SOLIDpower and Sunfire, from Italy and Germany respectively, are partners in the project. After successful launch, we will seek global entry starting with the rest of the EU, then North and South America and finally Asia. We will make use of our existing distribution channels and seek to engage new distributers in other regions.

To achieve the commercial and expansion goals, dissemination activities will be carried out. We have planned activities for increasing visibility at international trade fairs of SOCs and SOFCs. We will (1) participate in international fairs, (2) propose technical papers in recognised technological and scientific journals and (3) create videos, posters, presentations of our solution. We will also conduct demo on site experiences of DigiGraphic printer for potential customers and hold training courses on its correct use for newly installed systems and for the installation service teams of our distributors. DigiGraphic printer testing could be running at Sunfire (Germany) and at SOLIDpower (Italy).

Techno-economic analysis report

Main beneficiary: AVL
Potential market: All SOC stack industry.

Exploitation strategy. The SOC stack companies will benefit from the analysis in considerations about further upscaling, and the analysis can serve as guidance for designing the plants.
The sub-suppliers will also gain by this direct comparison, as it will highlight the advantages of their production method, and promote the deployment of their respective technologies.

Interconnect design

Main beneficiary: DTU/FZ Jülich
Potential market: All SOC stack industry

Exploitation strategy. The interconnect designs and the developed approach for optimizing the design will be made publicly available (without revealing Sunfire IPR). The design guidelines will be marketed towards other stack manufacturers that can benefit from the results.

SOFC modelling software

Main beneficiary: DTU
Potential market: All SOC stack industry.

Exploitation strategy. DTU will apply the model in future projects, and will promote consultancy to relevant stakeholders at conferences and fairs.

4.2 Market analysis

SOC technology is on the brink of true commercialization. The global market for solid oxide fuel cells was valued at 230 M€ in 2016 and is expected to grow at a CAGR of 13.88% from 2017 to 2025, reaching a market size of 1,040 M€ by 2025[1]. IEA's global scenario in 2050[2] assumes an installed capacity of 200-300 GW of SOFC is needed to meet the demand for combined heat and power in buildings.

To quantify the impact and market potential already at this low TRL level, the following scenarios and assumptions have been made:

- ***Scenario A***: Near future scenario (2022) with SOFC power of 50 MW/year installed. This scenario requires 400,000 interconnects assuming a conservative stack footprint of 20*20 cm^2 and an average stack current density of 0.33 A/cm^2.
- ***Scenario B***: Global scenario (2050) based on assumptions from the international energy agency (IEA)[3]. In this scenario, SOFCs primarily fueled by natural gas, are expected to respond to the demand for combined heat and power in buildings, reaching 200-300 GW of installed capacity by 2050 (or 5% of global capacity). In this scenario, 200 GW correspond to 1,600,000,000 interconnects.

Based on the above scenarios, the expected long-term impact of this project on innovation and industrial growth of each of the commercial partners is outlined in Table 7.

Table 7 Expected long-term impact on innovation capacity, new markets and growth

Industrial Partner	Expected impact on innovation capacity, new market opportunities and growth*
Aperam	Aperam is already a global player in the stainless steel market, with 2.5 megatons of flat stainless steel capacity in Europe and Brazil. LOWCOST-IC represents an excellent opportunity for Aperam to introduce their steels to a new market. In case of Scenario A ca. 100 tons of stainless steel is needed to produce the interconnect material[4], corresponding to a niche market for Aperam. For an annual production of 200-300 GW SOFC/SOEC (Scenario B), ca. 400,000

[1] Solid Oxide Fuel Cell Market by Type (Planar and Tubular), Application (Power Generation, Combined Heat & Power, and Military), End-Use (Data Centers, Commercial & Retail, and APU), Region (North America, Asia Pacific, and Europe) - Global Forecast to 2025 (link)
[2] IEA Energy Technology Essentials, IEA (2017) (link)
[3] [https://www.iea.org/publications/freepublications/publication/essentials6.pdf]
[4] Assuming an interconnect made from a 0.2 mm thick sheet and disregarding any scraps.

	tons of stainless steel is needed to produce the interconnect material[4]. Scenario B corresponds to a market size of 1,500 M€.
Sandvik	The results from LOWCOST-IC can facilitate broader market share of the Sandvik pre-coated solution for fuel cells by offering several products for the different SOC technologies. Higher performance with long lifetimes will potentially also contribute to faster market expansion. Sandvik has capacity to cover the need for PVD coated interconnects for Scenario A in 2022. The revenue in this time frame is expected to be in the level of 1 M€. For Scenario B, Sandvik is committed to any additional investment in capacity that is justified from the market development scenario. The product and process will require continuous development over time and hence revenue estimations for the 2050 time-frame are still uncertain. However, in the longer time-frame (scenario B) Sandvik expects revenues from the SOFC market well above 100 M€.
Borit	Currently, Borit has the production capacity for interconnect production in the scale of 50 MW/per year (400,000 interconnects). Such a production would increase the revenue around 0.5 M€. A scaling up to meet increased demands in case of larger market penetration towards 2050 (Scenario B) can easily be realized and would further increase the revenue by 1.5 M€ per 10 million produced interconnects.
Tecno Italia	Successful demonstration of DoD printing on SOFC interconnects will open new market opportunities in this segment. Assuming, i) an annual production of 50 MW SOFC/SOEC corresponding to 400,000 interconnects by 2022 and ii) that 25 % of the needed interconnects are coated by DoD, an additional revenue of 1.3 M€, corresponding to 4 new jobs, is expected[5]. Furthermore, novel capabilities developed in this project (printing of metallic particles, printing on pre-shaped 3D structures) can be applied in flexible electronics and the automotive industry.
SOLIDpower	SOLIDpower is currently up-scaling their production capacity to be able to manufacture up to 33,000 1.5 kWe systems per year. This represents an investment in the order of 22 M€, and is expected to employ up to 210 workers and staff. With a successful integration of new steels and novel robust contact layers, 30 % longer life-time is estimated. This will influence

[5] The number of created jobs is calculated from the expected turnover increase (factor 0.2)

	the OPEX of the SOC stack systems, as replacement of stacks is minimized. With a yearly production of 50 MW, this results in an increase of the gross margin of 8 M€, on a yearly basis.
Sunfire	In addition to the expected increased life-time of materials, introduction of cost-effective interconnect steel and cheaper deposition of contact materials will decrease the CAPEX of the SOC stacks by ~20%. With the extended life-time and cheaper production methods, Sunfire estimates an expected gain in revenue by 30-50 M€, under the assumption of a yearly production of 50 MW.

It should be emphasized that this initial analysis was made based on different publicly available sources. An updated and more accurate market analysis will be included in the later versions of the PEDR. The updated market analysis will be made on the basis of the techno-economic analysis, which is made in WP6.

4.3 Exploitation management

4.3.1 IPR management

The industrial partners of the project are already operating with their current technologies on the market. In LOWCOST-IC, the industrial partners will optimize their current technology to increase the life time or decrease the cost of the SOC technology. These modifications are not foreseen to be hindered by any current IPR.

In LOWCOST-IC, the contact layer for the oxygen electrode utilizes the concept of reactive oxidative bonding, resulting in conductive spinel oxides. For work related to the novel contact layer, a preliminary patent search has been performed, with the purpose of identifying existing patents that might eventually hinder commercialization of the project's technological results. This preliminary patent search was done using EPODOC and WPIAP.

Searching for contact materials comprising metals, many patents were found related to the contacting on the *fuel* side[6,7,8,9]. One patent utilized the concept of phase (reduction) change during assembly going from NiO to Ni[9]. In patents describing contacting on the *air* side, the state of the art well-conductive perovskites are suggested in multiple patents[10,11,12]. One patent suggests the use of noble metals [9]. One patent suggests the use of spinels[13] but without introducing the essential step to achieve high toughness; namely the reactive oxidative bonding which occurs when the spinels are formed due to oxidation of a *metallic* contact layer. Thus, no current patents were found that would hinder commercialization of possible technological results with regards to the reactive contact layers.

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