PROJECT FINAL REPORT

Grant Agreement number: 621213

Project acronym: STAGE-SOFC

Project title: Staged SOFC Stack Connection for Efficient Power and Heat Generation

Funding Scheme: FP7 Programme, SP1-JTI-FCH.2013.3.4: Proof of concept and validation of whole fuel cell systems for stationary power and CHP applications at a representative scale

Period covered: from 1.4.2014 to 30.04.2018

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Table of Contents

1. Final publishable summary report

1.1 Executive summary

Solid oxide fuel cells (SOFC) are ideally suited to the conversion of hydrocarbons at high electrical efficiencies. The main application of SOFC systems are small-scale combined heat and power units (CHP) or autarkic power generators, as, compared to gas engine driven power generation, electrical efficiency is essentially independent of system size. Conventional SOFC system layouts are either based on catalytic partial oxidation (CPOx), which are simple and robust but limited to a maximum electrical efficiency of 35%, or on steam reforming, where electrical efficiencies of approx. 50% are achievable but are reliant on error-prone, maintenance-heavy water supplies or costly anode off-gas recirculation. A new concept featuring the serial connection of an exothermal CPOx stage with one or multiple endothermic steam reforming stages was therefore developed. The system combines the benefits of the simple, robust CPOx layout with the high efficiencies achievable using the steam reforming process. air supply facilitates individual stack temperature control and savings in costly heat exchanger area.

Building on successful lab-based proof of feasibility (1st protoype), a proof-of-concept (PoC) system was developed that achieved an electrical efficiency of >45 % at nominal load and >50% in part load. Also the potential of thermal efficiencies of over 80% could be shown. The system was designed for small-scale CHP and off-grid applications and operated in a power range between 1.5 and 5.5 kW.

The second period was dedicated to the testing of the 1st prototype, design and construction of a new hotbox, optimization of components including functional integration and finally construction and testing of the 2nd prototype. As a result, all project targets could be fulfilled with the exception of the 3000 h long-term testing of the system in a simulated CHP environment.

The Consortium consisted of an industrial stack/hotbox developer, a system integrator associated and experienced research institutes charged with addressing specific scientific-technological questions linked to system and component layout: Project highlights were the detailed parametric study of the overall system showing the most economic set of operation parameters, fundamental work on the reforming of anode-off-gas / natural gas mixtures, development of sophisticated power electronics concepts, support of components and module development by CFD simulations, or performing detailed investigations on the control and safety system and investigation Balance of Plant components according to standards in the heating industry.

Besides the technical development work, a larger part of the project was dedicated to the investigation of potential markets, business cases, techno-ecnomic analysis, costs invstigation for different phase of project maturity and finally a LCA to show the advantages of SOFC-based CHP in terms of CO2 emssion reductions. From here, requirements for the system design were derived in terms of costs, power and efficiency targets and operational profiles of the "Proof-of-Concept" (PoC) prototype.

1.2 Project organization

The project organization and work package structure are depicted in Figure 1.

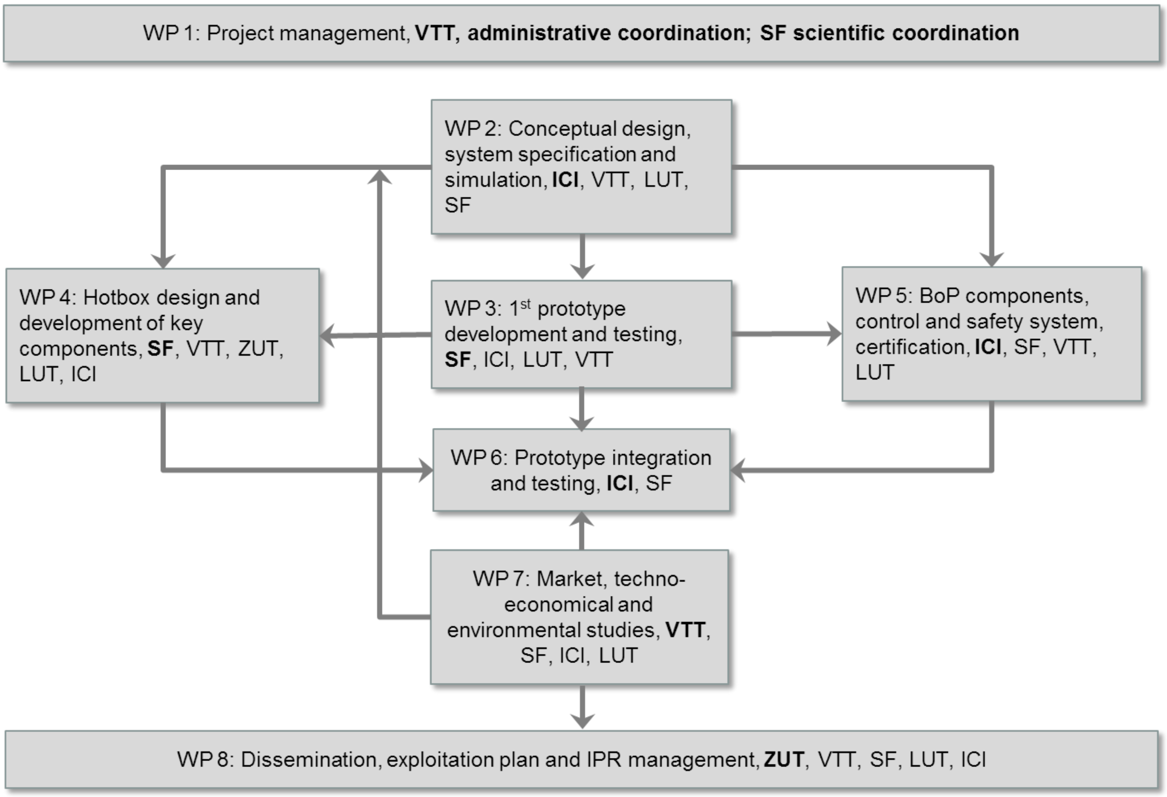


Figure 1. Project organization and word package structure of STAGE-SOFC.

1.3 Contractors involved

There were five contractors participating the Consortium as described in Table 1.

Table 1. List of project participants.

No	Name	Short name	Country	Project entry month	Role[2]	Project exit month
1	Teknologian tutkimuskeskus VTT Oy	VTT	Finland	1	CO	49
2	Sunfire GmbH	SF	Germany	1	SC	49
3	ICI Caldaie SPA	ICI	Italy	1	CR	49
4	Lappeenrannan teknillinen yliopisto	LUT	Finland	1	CR	49
5	Zachodniopomorski Uniwersytet Technologiczny w Szczecinie	ZUT	Poland	1	CR	49

[2] CO=Coordinator, SC=Scientific coordinator, CR=Contractor.

1.4 Main scientific and technological results and foregrounds

1.4.1 WP2–Conceptual design, system specification and simulation

The objectives of WP2 were the assessment of system sizes for the two prototypes and the definition of the system concept and setting of system specifications. This was possible thanks to the development of a system model and a consequent definition of component specifications based on process modelling results. All this information was necessary to be able to carry out correctly the evaluation of end-user integration options and energy management systems.

1.4.1.1 Process simulation

The purpose of the system modelling in WP2 was the development of a system model, execution of optimization simulations and definition of component specifications based on process modelling results.

The detailed system modelling work in this project was divided into two phases. The first phase concentrated on tasks that support the system design and component sizing for the manufacturing. In this phase the feasibility of the original system layout was checked in all relevant operational points (nominal operational point, part load, end of life conditions and using different fuel options from methane rich natural gas to methane lean biogas). Several modifications to the original system layout were required in order to run the system within the complete operational window.

After the first modelling phase the focus of the system modelling work was shifted to optimization of the operational conditions. In this project, the most important parameters to be optimized were the AC efficiency and the total efficiency. To find out optimal operation conditions 5D-multiparametric simulations were carried out by performing a 3^5 full factorial design. Processing of the raw data was done with multilinear regression model for all output quantities.

For the first prototype, the predicted AC to net efficiency with all parasitic effects taken into account was 44%, which is in good agreement with the experimental testing results. The nominal operational point of the second prototype was set to be on more demanding conditions and the predicted AC to net efficiency was about 49% and the predicted total efficiency about 83%.

1.4.1.2 System specification

System specification were elaborated for the 1st and the 2nd protoype. The aim was to fulfil needs of small scale CHP and off-grid applications concerning high electrical efficiency, part load capability and heating circuit integration. This included determination of final system layout, specification of BoP components, stack sizes and power electronics as well as validation of concept and performance targets.

In addition to the MATLAB® simulations described in Section 1.4.1.1, a steady state flowsheet simulation with PRO II® process simulation software was carried out. Results from the simulation part where used to find the optimal configuration in terms of stack size rate between first and second stage, CPOx air ratio, oxgygen-to-carbon ratio of the steam reforming reactor and fuel utilizations. It turned out that power targes of >5 kW_{el} and efficiency targets of $45\%_{el}$ and $85\%_{total}$ can be achieved, if the system is operated close to the carbon formation limit. To fix this limit, a detaild analysis of the anode-off-gas / natural gas mixture was performed in Task 4.2. A good compromise between economics and efficiency turned out at a cell number ratio of 1:3 between CPOx and steam reforming stage. Finally, it was decided to use a 90 cell stack module for stage 1 and a 240 cell module in stage 2 since these modules are already available.

The selection of components was based on a piping and instrumentation diagram (P&ID), which was developed with the help of simulation results. The P&ID was finalized later by means of the HAZOP analysis in order to define the required safety equipment.

A change in the system layout was also defined: It turned out the adiabatic reforming stage will cause some problems with the heat management since the internal reforming rate would be too high. Therefore, it was decided to replace the unit with a heat exchanger integrated reformer.

A system and component specification of both prototype generations was elaborated and filed. The original plan was the design of a sub-scale 1st generation prototype followed by a full-scale 2nd prototype. This plan was changed to two identical system sizes due to stack module availability and avoidance of rescaling of main components.

1.4.1.3 End-customer integration and energy management

The STAGE-SOFC system was designed for small-scale CHP and off-grid applications in the power range of 5 to 50 kW. It operates with natural gas, but also options for operation with biogas and LPG were investigated. The objective of the task is to make a techno-economical study of typical installations in the European countries with varying characteristics in terms of energy requirements. This activity is supported by an evaluation of the SOFC's integration into existing (e.g. boilers installed, etc..) or new structures.

The results of this study can be summarized as follows:

- Stage SOFC system can't competitively supply only one average dwelling even reducing its size, this is valid for all countries considered in the analysis (i.e Austria, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Poland, Portugal, Spain, Sweden, Switzerland, UK).
- It becomes competitive if it can supply several dwelling, also when compared with different systems (as well as when compared with other fuel cell systems).
- System is not competitive in the market if the natural gas and electricity costs are low, but it becomes very suitable if the electricity to natural gas price ratio is highest.
- Around 5 years PBT is however still a long time if the estimated lifetime is 10 years. In order to start large sales volumes, it is necessary to drop below 3 years. This means a reduction in specific price.
- Until production costs cannot be reduced, it is indispensable to make use of government grants.
- Good lifetime and good availability are essential.
- The limiting factor under energy-economic profile is the total heat consumption especially in the countries in which the thermal demand is low.
- The optimum configuration is linked to total consumption of thermal energy. So the system becomes more feasible for the countries which have a larger thermal energy demand.

1.4.2 WP3–First prototype development and testing

The objective of WP3 was the verification of basic layout and operation concepts using an initial integrated prototype. Instead of a lab-type sub-scale system it was decided to develop a full scale prototype based on already existing stack modules which will finally save time in the development of the final PoC prototype. A further objective was the development of a flexible control system that allows the testing of a larger parameter set like O/C rate, air ratio, fuel utilization or reforming temperature.

1.4.2.1 Module design, P&ID, electrical layout, manufacturing of hotbox

A thermally self-sustained, compact system with flexible fuel supply and load connection was established, whereas the system design was based on existing Integrated Stack Modules (ISMs). The electrical and mechanical design of hotbox and coldbox components was performed. In Figure 2 the complete prototype one is shown.

Figure 2. System design of complete prototype one.

The outer dimensions of the system are 1450 x 1300 x 2170 mm^3 (l x w x h) excluding the electrical cabinet. The exhaust gas suction blower and the heat exchanger for waste heat recovery were placed on top of the unit. The lower part represents the coldbox with valves, mass flow meters and sensors. Figure 3 shows the inner layout of the hotbox with the two stack modules and main components of the gas processing unit.

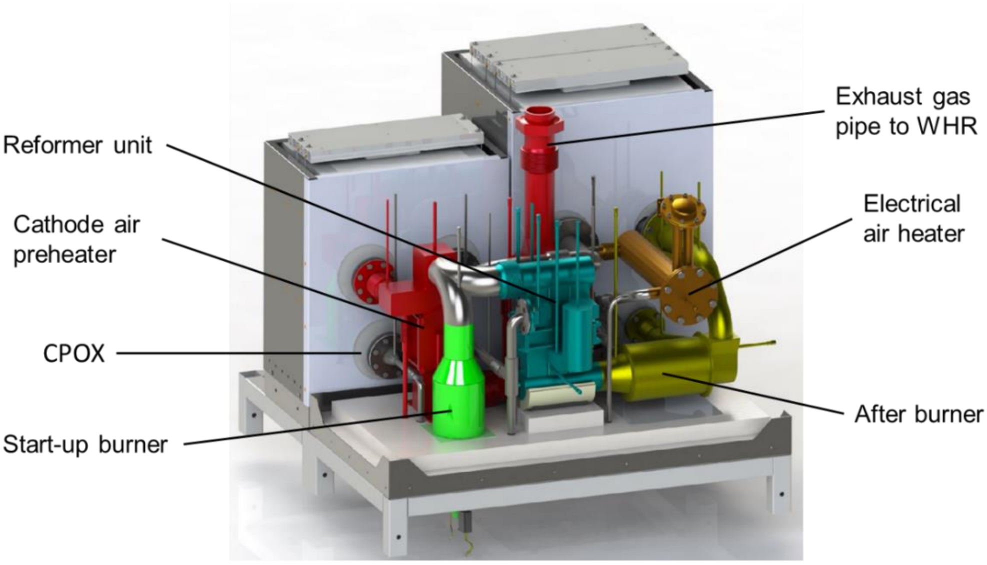


Figure 3. Hotbox design of 1st prototype.

The system was installed in SF's testing lab. Laboratory DC loads were used for the stack operation. Therefore, only the DC power output could be measured, the AC value was calculated using AC/DC converter efficiency targets from the LUT developments.

1.4.2.2 Development of control & safety system

A PLC based control software, graphical user interface and data storage system were developed. Based on input from the HAZOP analysis, the required sensor equipment and safety procedures were defined. Furthermore operation modes (start-up, shut-down, normal operation, safety states) were defined and detailed sequences for all modes were elaborated. A detailed description of these operation modes and an example of a typical control loop is given in chapter 1.4.4 – task 5.2.

The STAGE-SOFC system was equipped with a multistage safety system consisting of three interlock safety levels. Safe system operation is ensured by safety functions like an emergency stop button, temperature and pressure monitoring, hard-wired safety switches for critical parameters, a certified burner safety relay and a test rig gas detector for toxic and explosive gases.

1.4.2.3 System integration and testing

After completed manufacturing, the prototype 1 system was integrated in one of SF's test stands. The system was then in operation for 6 weeks (about 600 hours) to test and optimize the software, PID controllers, operation procedures and different system parameters. Another important issue was to check the design and function of the coldbox and hotbox components. The main results of the testing are the following:

- Stable operation at 30 … 100% system load
- Validation of influences of parameter variation on electrical efficiency
- Record of load-efficiency curve
- Testing of operation procedures and part load behaviour
- Experiences regarding system controllability
- Input for improvement of components and system layout

The result of this work package is a first prototype of the STAGE-SOFC concept that has almost achieved the efficiency targets of 50% at one part load point and 45% at 5 kW_{el} which were defined in the project description as Figure 4 shows. While the DC load was measured directly, the AC efficiency was calculated by using state-of-the-art inverter efficiencies.

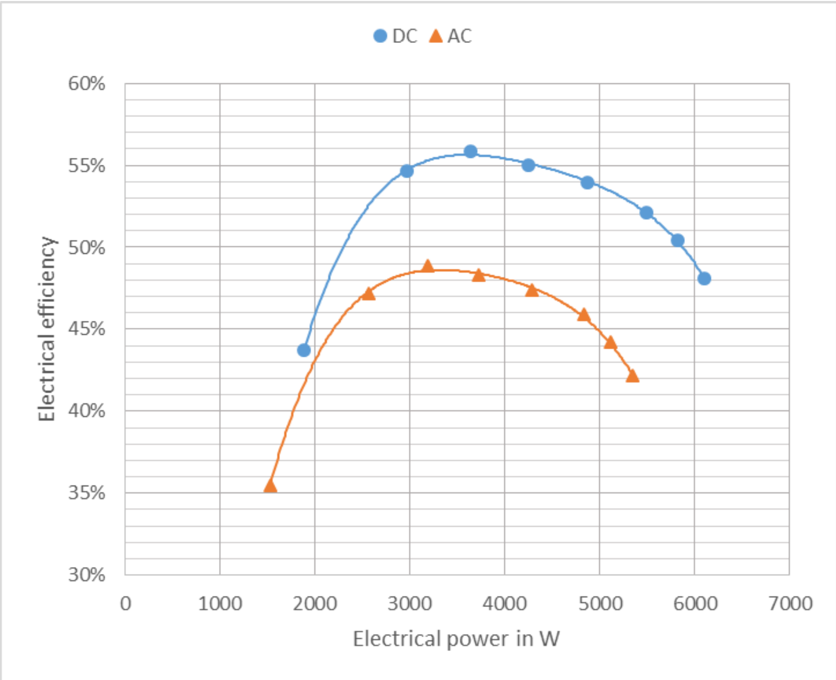


Figure 4. Electrical DC and AC efficiencies under variation of electrical power output.

It was possible to operate and control the system at different loads from 1.5 to 5.3 kW_{AC}. A main part of the work was to study the influence of single parameter variation on the electrical efficiency. Parameters like O/C ratio, CPOx air ratio, and fuel utilization were investigated under constant conditions of other system parameters. It turned out that the O/C ratio has the highest effect on the efficiency. The results were used to support the detailed design of the 2^{nd} prototype.

All in all the testing was very successful which is also due to extended simulations and thorough design of the first prototype. Last but not least the system operation revealed strengths and weaknesses of the current system design which were integrated in the design process of the 2^{nd} prototype. Those are for example a combination of start-up and after burner, an integrated reformer heat exchanger with catalyst coated plates and more efficient heat utilization and distribution.

1.4.3 WP4–Hotbox design and development of key components

The main objective of WP4 was the design of compact stack hotbox and functional integration of parts. Furthermore, key components had to be developed and optimized: adiabatic and heat exchanger integrated steam reforming stage, heat exchangers, and power electronics. The work was supported by modelling efforts and mass-manufacturing investigations.

1.4.3.1 SOFC Hotbox layout and modelling

SOFC Hotbox layout

In WP4, two alternative hotbox concepts were designed that include sophisticated components (e.g. functional integration of start-up burner and afterburner as well as steam reformer). The work was performed in parallel to the WP 3 activities. It has been decided to keep the existing stack modules (90 cells and 240 cells respectively) and to integrate new, cost-effective and function optimized components in a compact hotbox. The component development was supported by CFD analysis. Later on, an optimized hotbox was designed as shown in Figure 7. It reveals the potentials of the STAGE-SOFC concept to gernerate a compact, manufacturing-friendly and cost-effective system.

The detailed system simulations and calculations performed in work package 2 had revealed the need for two important design features in addition to the original STAGE-SOFC concept: 1) an additional cathode air heat exchanger for the fresh air line to the second stage, and 2) a heated steam reformer instead of an adiabatic reformer.

The improved hotbox layout for prototype 2 is shown in Figure 5.

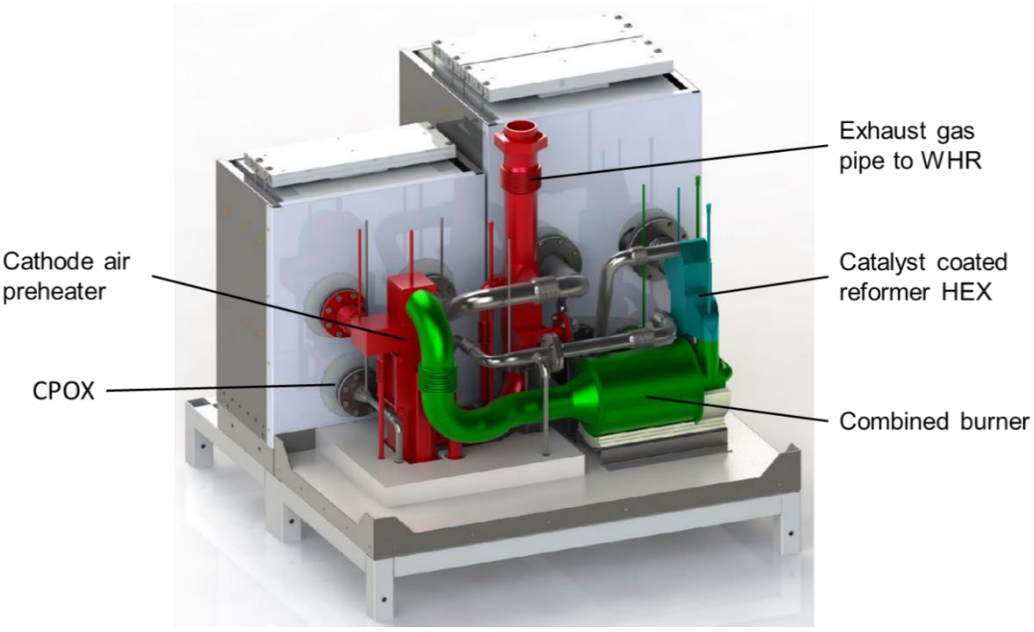


Figure 5. Hotbox design with main components of prototype 2.

Start-up and afterburner were integrated into one compact, combined burner as shown in Figure 6. The combination reduces the hotbox size and the close thermal integration allows an earlier start of load operation due to the higher temperature in the combined burner. The design of the combined burner was checked by CFD simulations. The simulations from ZUT revealed a complete combustion in the burning chamber, but have also shown some temperature peaks in the diffusion zone.

As a result, the 2^{nd} prototype was designed and constructed. Part of the work was dedicated on the elaboration of design features for the off-grid market, where a further simplification of the system will be necessary to improve the overall robustness and availability.

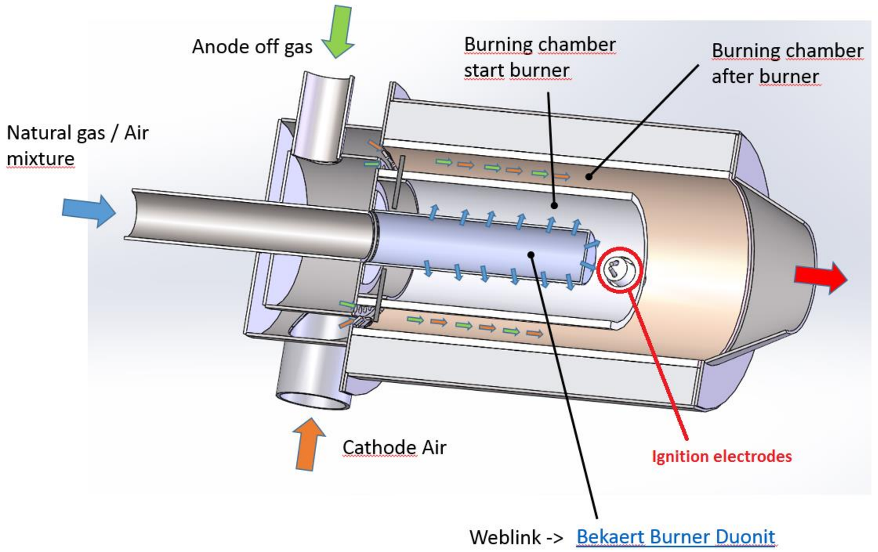


Figure 6. Design of combined burner.

Hotbox modelling

The objectives of the Hotbox modelling work were to support efforts in the field of manufacturing with an optimized design evaluation by numerical simulations of the SOFC hotbox.

CFD simulations of heat exchangers, combined burner, and stack modules were carried out using the commercially available ANSYS Academic Research CFD software with ANSYS Academic Solid Oxide Fuel Cells module. MATLAB Simulink and ASPEN TECH were used for the BoP modelling of the SOFC power generation system. In addition, HSC investigations were performed to calculate the conditions and regions of depositing filamentous carbon deposists in the CPOx, wet and dry reforming reactions.

The main significant project results within this part consisted in the development of the numerical approaches that enable to predict:

- the capabilities of two towers with eight SOFC stacks regarding a cathode off gas flow distribution. Three cases of the towers with SOFC stacks were considered under different designs without and with air distribution sheet as well as different heat transfer conditions.
- detailed intensity of mass and heat transfer processes in the membrane-electrode assembly of the single planar SOFC based on the fully coupled CFD model.
- heat transfer between the cathode off gas and air inside different plate heat exchanger configurations.
- the burner flow behaviour and emission characteristics
- analysis of the transient response of the reformers, fuel cells and the burner was carried out, based on the model implemented in MATLAB Simulink^R environment. The dynamic behaviour of the system during transient conditions was investigated by the load step changing.
- dynamic response of SOFC stacks was tested using ASPEN Dynamic process simulator tool in order to develop a control strategy of the SOFC power generation system.

- carbon deposition analysis using a CPOx reformer was carried out for selected hydrocarbon fuels such as methane and LPG.

The main contribution was the demonstration of the ability of quantitative prediction of two towers with eight SOFC stacks, heat exchanger, SOFC based power energy system behaviour as well as filamentous carbon impact under different decomposition conditions of hydrocarbons.

Investigation of mass-manufacturing requirements

The objective was the design of a hotbox with the principles of production engineering which needs to be compatible with mass-manufacturing methods to minimize fabrication costs. Further a close integration / functional combination of individual components was aimed to reduce the number of interfaces.

A new hotbox has been designed which not only functionally integrates the main components but also the stacks in a very compact hotbox as shown in Figure 7. The number of interfaces is reduced so that the manufacturing becomes less costly.

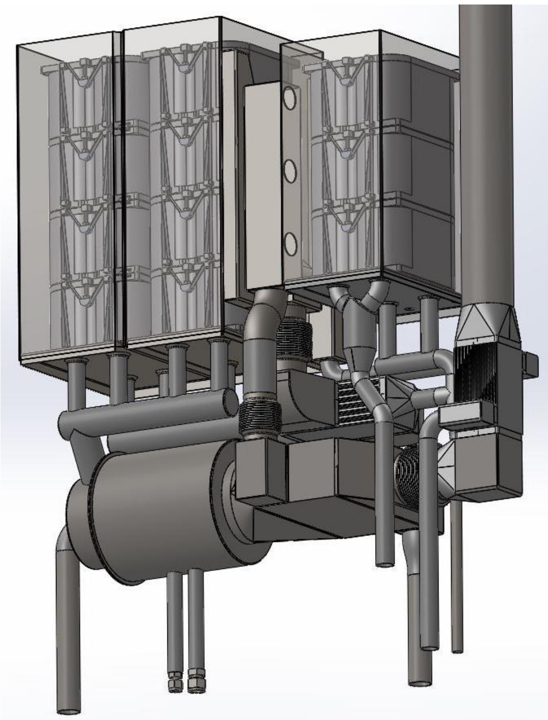


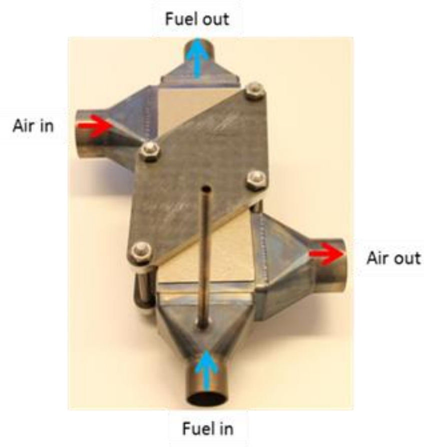
Figure 7. Design study of new compact hotbox.

The functional integration of e.g. start- and afterburner or steam reformer was already done.

1.4.3.2 Adiabatic pre-reforming reactor

A pre-reformer is required before the second stack in STAGE-SOFC system. The anode off-gas is used to reform the fresh natural gas. The work was started by studying the operational window of the reformer, mainly O/C ratio of the gas going to the reformer. The O/C ratio is an important parameter in prediction of carbon formation possibility. The experimental results were compared with thermodynamic calculations on carbon formation and it was observed that the reformer can be operated in thermodynamic carbon formation region without carbon formation in practice.

During the system modelling work in WP2, it was find out that the degree of reforming is not high enough with adiabatic reformer in part load operation. Thus, it was necessary to develop a heated reformer to achieve higher methane conversion. In the first prototype, a solution with two serial connected, adiabatic reformer catalysts with intermediate heating was used. Due to the complex geometry of this heated reformer, a more compact solution was developed for the second prototype using a simple plate-type heat exchanger with a precious metal catalyst coating on the plate surface to reform natural gas with anode-off gas, Figure 8. The heat exchanger reformer was tested in a test bench and the conversion and temperature results were satisfactory. In addition, another heat exchanger reformer was developed and tested as a back-up option. That reformer was tested for 1000 h and the operation was stable. However, that reactor was in dimensions larger than the first one and not suitable for the hotbox integration for that reason.



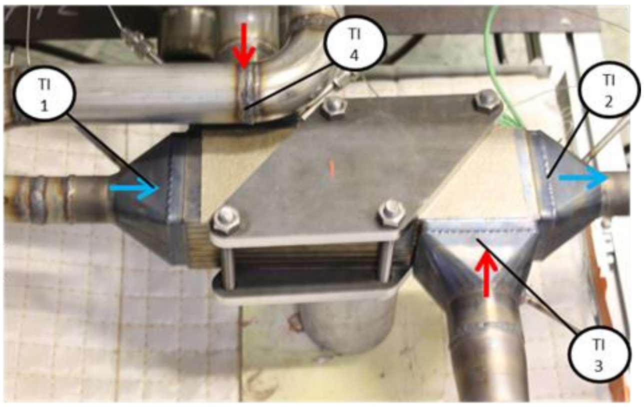


Figure 8. Heat exchanger reformer. Air flow indicated with red arrows and fuel flow with blue arrows. The places of thermocouples are indicated with black lines.

1.4.3.3 Heat exchanger

The target of TASK 4.3 was an improved heat exchanger design and optimization of material use to meet targets in terms of cost, long-term durability and chromium evaporation minimization. SF has investigated promisiong heat exchanger materials that show high mechanical stabilites at temperatures in excess of 900 °C and low chromium evaporation rates. Tests have been performed in a furnace with an oxidizing atmosphere. At the beginning, just 3000 h were planned, but it turned out that 1) differences will be low at these short exposure times and 2) operation times are too low taking into account that a commercial unit needs to be operated for 60,000 h and more. Finally, the test has been performed for 19,000 h and is still ongoing. Additionally, tests were performed with low-cost bulk materials and applied coatings. However, it was observed that the mass gain is higher, making it questionable whether this material will be stable in the long-run.

Heat exchangers were designed for the different system prototype generations. In parallel, different commercial suppliers, mainly from the automotive industry, were contacted for the technical and financial feasibility in case of large production volumes. These cost estimations were integrated into the analysis in TASK 7.2.

1.4.3.1 *Power electronics*

The electrical power produced by the fuel cells must be converted to appropriate frequency and voltage so it can be fed to the grid or be used by standard equipment. The nominal peak voltage of fuel cells is commonly limited by its isolation, and therefore a boost conversion is required. This conversion stage conventionally accounts for the electrical isolation between the grid and the fuel cell. The boosting DC-DC converter is also the converter that is in direct interaction with the fuel cell, and therefore the focus of the power electronics research for the fuel cell systems was in the DC-DC converter. In order to achieve high overall efficiency for the electrical conversion, it is crucial that all conversion stages must have very low losses.

The isolating boost converter used in this project was dual active bridge (DAB) converter. DAB was chosen because it has high efficiency at most loading conditions, which can be achieved by soft-switching of the converter.

The dual active bridge converter has multiple degrees of freedom on the way that the converter is controlled. The soft-switching region can be extended from the conventional control by exploiting new degrees of freedom. During the project a new control method that uses a varying switching frequency for the converter was invented. The method allows the converter to be in soft-switching region through the whole operational range.

The dual active bridge converter topology is known to have a phase drift in the transformer voltages. One of the main reasons for the drift is nonlinear dynamics of the power electronic switches as a function of current and voltage. During the project, a method that is able to compensate the drift was found, allowing the converter control to function more accurately.

The studied fuel cell system has two or three fuel cell units, and each unit has to have its own isolating DC-DC converter. These converters are parallelly connected and they feed the power to a central inverter that feeds the power to the AC grid. The power rating for a single DC-DC converter is 2.5 kW. A prototype converter was built and it is illustrated in Figure 9.

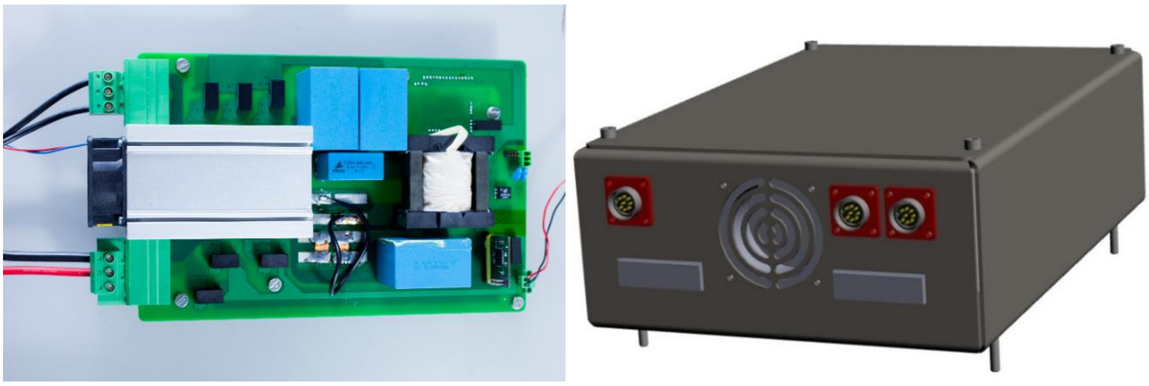


Figure 9. Converter prototype (left) and designed converter closure (right).

The converter testing was executed at 20 A input current and with 50 V input voltage, so the peak power was approximately 1 kW. The secondary voltage was controlled to 400 V during the experimental testing. Some problems were encountered in the testing of the prototype. The prototype converter operational power range was limited due to two factors. The first was insufficient conductor cross-section area of certain vias on the printed circuit board, which resulted in overheating of these vias. The second factor was insufficient common-mode rejection ration of the current measurement circuit, which led to current measurement error that is dependent on the common-mode voltage. Despite extensive efforts, a stable operation could not be achieved and the new design had to be abandoned. Instead, an available power electronics solution that was not optimized nor specifically specified for the Stage-SOFC project was used by SF.

1.4.4 WP5–BoP components, control and safety system, certification

The objectives of WP5 were the specification, selection and cost analysis of BoP components, the development of a hotbox control concept for the staged stack design, the safety analysis and determination of safety measures together with the elaboration of certification requirements and related technical solutions.

1.4.4.1 Balance of Plant components

A list of the BoP components as a result of technical market investigations was elaborated with a focus on reliability and durability. Particular attention was paid to the potential cost of the various components in the instance of large sales volumes. The starting point for the costs analysis was to divide the components in three types of product:

- Market-standard components based on mature technology, the cost of this commodity doesn't change so much with the quantity
- Market-specific components based on mature technology, study-time have been spent by the supplier to reduce significantly the cost when quantity increases.
- Immature component that has required a lot of study time to develop, it is just a prototype phase.

The result of the investigation was a definitive BoP list of components for the prototype, keeping in consideration economical and technical aspects such as durability, reliability and costs in a prospective of a large sales volumes.

1.4.4.2 Hotbox control concept

The target of TASK 5.2 was the development of a simple, robust and failure tolerant control and safety system, using a minimum number of sensors and low-cost components where available. The control system for the first and second prototype was based on an industrial PLC in order to ensure maximum flexibility. The definition of system operation modes with a detailed sequence control was performed. The optimization of start-up and shut-down procedures in combination with load changes was also be addressed. The main control loops to be developed and optimized was the CPOX air ratio control, O/C ratio control of the steam reformer, control of individual stack temperatures, start-up and afterburner temperature and electric load control.

In Figure 10 the operation modes for the STAGE-SOFC system and their dependencies are summarized. Six different operation modes were controlled automatically by a script with defined operation sequences.

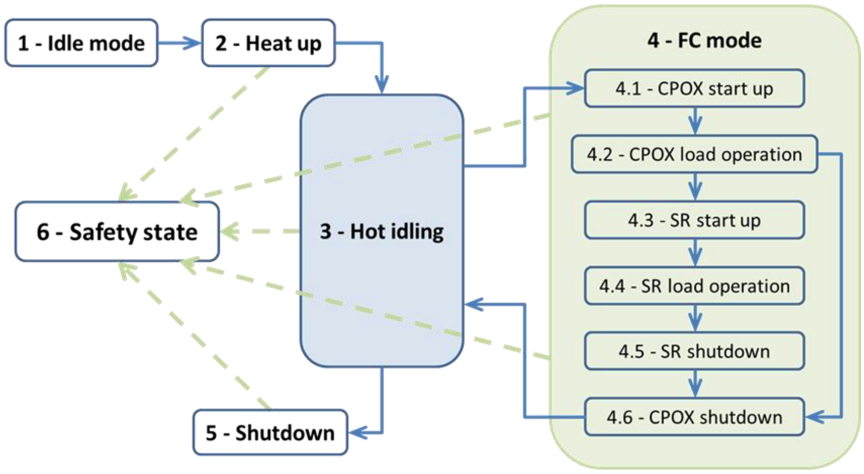


Figure 10. Overview and relation of operation modes.

A failure analysis was performed for the 'calculated' parameters CPOx air ratio , fuel utilizations and O/C as they are the most critical parameters for system operation. They are calculated from potentially deviating (sensor drift, natural gas composition) flow measurements, which are known to be inaccurate.

All in all the control concept and single functions were adapted very well to the STAGE-SOFC system allowing simple and automatic control of load and performance, which is a requirement for CHP or off-grid applications.

1.4.4.3 Safety system

The objective of the STAGE-SOFC prototype safety studies was to identify and analyse hazards related to the prototypes and to their operation. The main focus was on the hazards which can cause harm to people but also operational problems and equipment failures were considered.

HAZOP technique was selected as the analysis method for the STAGE-SOFC prototype safety studies because it is a widely used method and HAZOP studies have proved to be useful in the development and design phases of new systems. By identifying potential hazards and operability problems in a structured and systematic manner, many improvements and remedial measures were suggested to the prototypes.

1.4.4.4 Certification requirements

For the certification requirements, a list of the applicable directives and normatives have been individuated. The development of the prototype has taken this list as a reference point to be followed during the setup. The detailed list is available in D5.3.

1.4.5 WP6–Prototype integration and testing

The objectives of WP6 are the proof-of-concepts for system development and testing, the assessment of testing results against application derived criteria, the durability testing conducted over several hours and the valuation of results and derivation of measures for next generation prototypes.

1.4.5.1 PoC system design

The 2nd prototype (PoC) system design was based on the results on the SOFC hotbox design, the safety analysis, controly system optimization and the operational results in the 1st prototype. One main safety measure was to keep the system in underpressure mode in order to avoid external leakage by using an exhaust gas blower. This will avoid the necessity of gas sensors in future system installation.

The coldbox was based on a combinaton of dedicated components for the SOFC systems and standard part from the heating industry as recommended by ICI. Power electronics was planned to be delivererd from LUT, however, as described below, a change in the planning was necessary which required an update of project schedule. The final system layout is shown in Figure 11.

Figure 11. STAGE-SOFC prototype 2 system.

1.4.5.2 System assembly and commissioning

The manufacturing of the 2nd prototype was performed by SF. However, it turned out that the power electronics prototype, built by project partner LUT, was unsuitable to be used with a fuel cell due to problems with current measurement and overheating of the circuit board. Therefore, SF decided to built the power electronics based on existing components instead of developing a new solution adapted to the STAGE-SOFC system, with the consequence of lower DC/AC conversion efficiencies. During operation of the 2nd prototype, a defect of the current control occurred. Furthermore the pressure loss over the reformer heat exchanger was too high to reach loads higher than 3 kW. Therefore, a new reformer heat exchanger from an external supplier was integrated in the final system.

Unfortunately, due to a leakage in a natural gas solenoid valve, natural gas was flowing to the anode of the second stage stack module during system heat-up and has caused carbon formation. In the end the stack module was irreversibly damaged. After integration of a new stack module and replacing the reformer heat exchanger, the reworked prototype was ready for commissioning. The software and control procedures of the system were optimized for the final validation phase. Finally the second STAGE-SOFC prototype was operated for 16 days in SF's SOFC lab under various loads from 3 to 5 kW(AC). All components have shown a good performance and interaction with each other, so the system could be operated in its intended power range.

1.4.5.3 TASK 6.3 PoC system validation

The STAGE-SOFC system was installed into ICI's testing environment. The system heat-up and transfer to load operation was performed with an automatic sequence control. As shown in Figure 12, the system was in load operation for four days and the load was varied from 4.1 to 4.7 kW(AC).

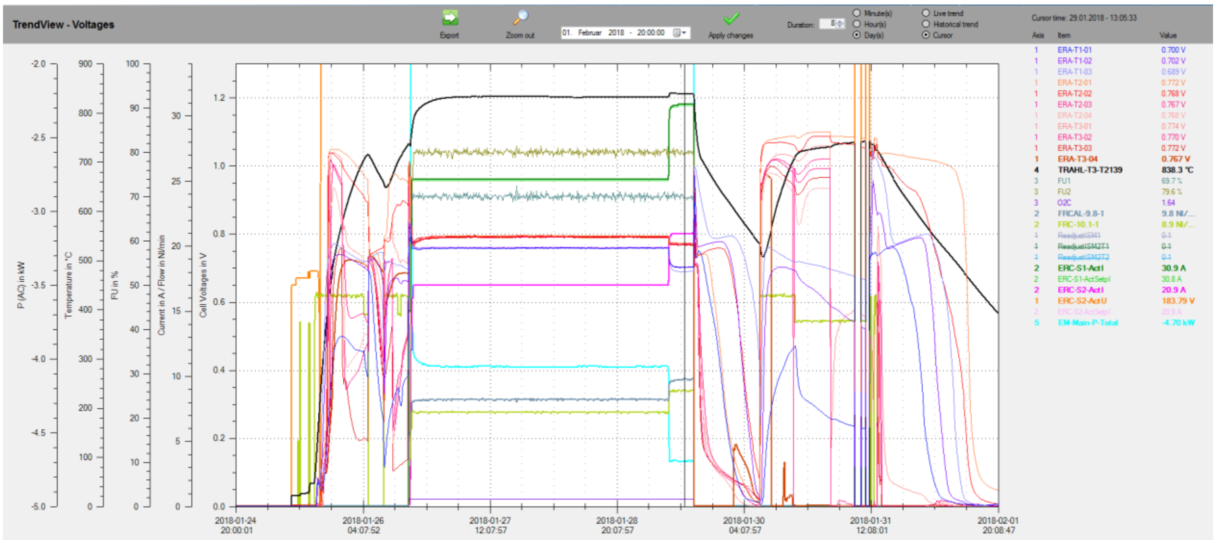


Figure 12. Whole test run of second STAGE-SOFC prototype at ICI.

However, an emergency shut-down was initiated by its safety system due to a sudden decrease of one stack voltage of the second stage stack module. A short circuit in the stack module was detected. Additionally, it was found that during the next heat-up the natural gas solenoid valve became untight again, similar to the situation during commissioning of the prototype.

A post mortem analysis of the complete stack module revealed that the underpressure in the stack module housing has caused a contact of the metal sheet of the housing with the stacks, resulting in a short circuit.

The short circuit as well as the carbon formation due to the leaking natural gas valve caused an irreversible damage of the system, which couldn't be repaired by the end of the project. The performance of the system could be evaluated, but STAGE-SOFC failed to perform the long-term test.

1.4.5.4 PoC system validation and evaluation of results

The system was installed into ICI laboratories which is an integral part of ICI production site. Here, a specific area was modified in order to provide all the gas and fluid required by the system, together with heat removal system, suction hood and gas sensors. The installation site is show in Figure 13.

Figure 13. Second STAGE-SOFC prototype installed into ICI laboratories.

A smooth development and integration of STAGE-SOFC system has been done. The system worked automatically long enough to prove that the technology come to TRL 5/6.

With an optimized and adapted power electronics solution an electrical AC net efficiency of 45 to 50% (depending on the system load) were possible. Furthermore, the combined burner and the reformer heat exchanger showed excellent characteristics.

Altogether the results have shown that the STAGE-SOFC system is working and reaching its efficiency targets and can support the reduction of green house gas emissions in the field of micro-CHP. A rigorous product development and field test of a next STAGE-SOFC generation is now necessary to ensure that customer as well as legislative needs are satisfied.

The performance parameters of the second STAGE-SOFC prototype were determined during the commissioning in December 2017. The results at four different loads are shown in Table 2 and Figure 14. The performance tests were carried out under optimal operating conditions, which were already investigated earlier within work packages 2 and 3. The DC/AC power electronics solution used for the second prototype has shown a poor efficiency (around 87%). For this reason the AC net efficiency of the system was only in the range of 41.7% to 45.3%. Therefore, a theoretical performance with an optimized power electronics efficiency of 94% was calculated. This value is based on power electronics efficiencies that already have been achieved in other SF systems.

Finally, an assessment of the development of key components was performed. A main improvement of the air heat exchangers in prototype 2 was the standardization of the plate sizes of first and second stage heat exchangers. Thus, a mechanical coupling of both was possible. Furthermore, the parallel connection of the heat exchangers on the exhaust gas side has reduced the pressure loss. For reforming of fresh natural gas with anode-off gas a reformer heat exchanger with catalyst coated plates was used. The performance couldn't be measured, however, the operability of the overall system was improved. The new combined burner design, which integrates a start-up burner and afterburner functionality into one device has shown significant advantages in comparison to the separate arrangement in the first prototype like excellent reliability, reduced heat-up time and safe combustion of anode-off gas in all operation modes.

Table 2. Operating and performance parameters at different loads.

Load	-	**3 kW**	**4 kW**	**4,8 kW**	**5 kW**
I1	A	17.90	25.10	31.60	33.10
U1(cell)	V	0.80	0.75	0.69	0.67
P1	kW(DC)	1.30	1.69	1.96	2.00
FU1	-	70.0%	70.0%	70.0%	70.0%
λ(CPOX)	-	0.32	0.31	0.30	0.29
I2	A	12.20	17.00	21.50	22.50
U2(cell)	V	0.82	0.79	0.77	0.76
P2	kW(DC)	2.39	3.22	3.94	4.10
FU2	-	80.0%	80.0%	80.0%	80.0%
O/C	-	1.69	1.67	1.65	1.63
Actual performance with inefficient power electronics					
η(el,DC)	-	55.7%	53.4%	51.1%	51.0%
η(el,PE)	-	86.6%	88.0%	87.1%	87.2%
η(el,AC)	-	45.3%	43.8%	41.6%	41.7%
P(el,AC)	kW(AC)	3.00	4.03	4.80	5.00
Theoretical performance with optimized power electronics					
η(el,PE)	-	94.0%	94.0%	94.0%	94.0%
η(el,AC)	-	49.4%	47.0%	45.1%	45.2%
P(el,AC)	kW(AC)	3.27	4.32	5.21	5.40

As already described, the power electronics solution used for the second STAGE-SOFC prototype was not adapted to the special needs of the system. Unfortunately, the LUT solution turned out to be not mature enough to be integrated in a prototype system.

The exhaust gas suction blower used in the STAGE system belongs to the cold BoP components with potential for improvement. The current suction blower is noisy and the blower efficiency is with maximum 25% on a very low level. Also the temperature resistance of the blower is with 50 °C too low for operation with a connected heating circuit.

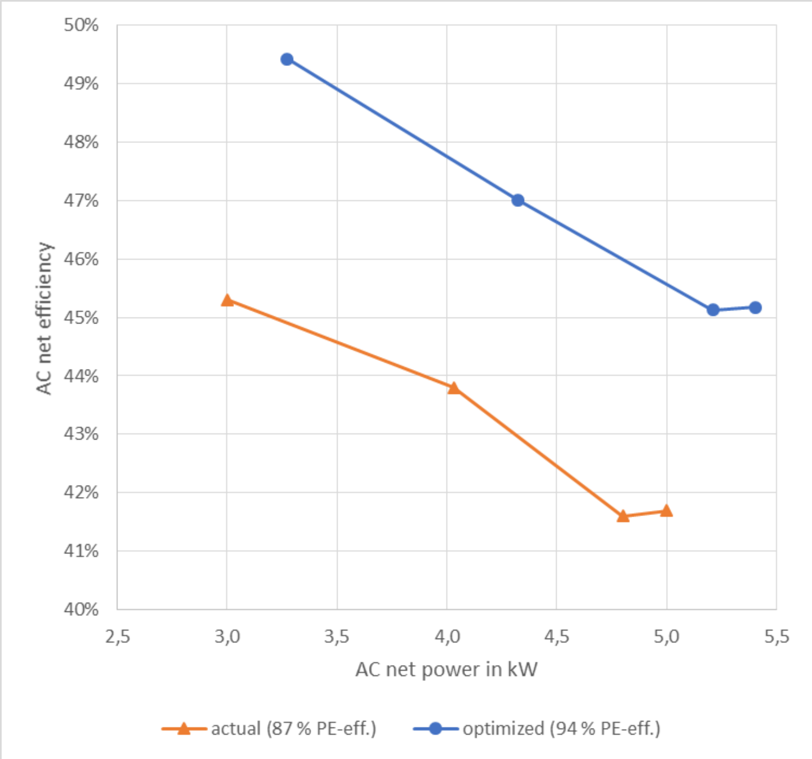


Figure 14. Efficiency-power-curve for second STAGE-SOFC prototype.

1.4.6 WP7–Market, techno-economic and environmental studies

The objectives included the evaluation of business cases for European markets, cost analysis of the state-of-the-art system and production in larger quantities, definition of operation requirements based on the most-promising business case and evaluation of CO_2 emission mitigation.

1.4.6.1 Business cases

In task 7.1 the market segments for integrated, heat-driven fuel cell CHP solutions in specific local markets for certain application areas were investigated.

The chosen local markets were countries with characteristics most suitable for STAGE-SOFC:

1. Germany is Europe´s biggest economy and has the highest consumption of energy. Because of the very high spark spread (difference between natural gas and electricity price) it is attractive for every kind of CHP solutions.
2. United Kingdom has a very high share of gas based heating systems. The energy consumption and the spark spread are also very high.
3. Italy was chosen as a represent southern Europe country, were not all buildings need a heating system. The spark spread is close to the European average.
4. Poland was chosen as an Eastern Europe country. The spark spread and the energy consumption are close to the European average and the income is lower. Because a higher share of old technologies, Poland has a CO_2 intensive Power mix.

The analysis was focused on the commercial market scale (5-400 kW_{el}) which was separated into segments. Apartment, agricultural and storage buildings were chosen for the 5 kW_{el} Segment. The

25 kW_{el} segment included retail and office buildings. For the 100 kW_{el} market some special industrial consumers were chosen e.g. data centres, wastewater treatment facilities or heat intensive industrial manufacturing.

The assumptions were divided into two phases, the market entry phase and the phase for a fully developed market. The market entry phase would most likely be a three year period (i.e. from 2017 – 2020) with the numbers of units sold would in average sum up to the data shown in Table 3. The annual sales in market entry phase were estimated to be altogether about 30 M€.

Table 3. Share of market (SAM) in Germany, UK and Italy during the market entry phase.

Size kW_{el}	**Germany**		**United Kingdom**		**Italy**	
	Market Share	Units/a	Market Share	Units/a	Market Share	Units/a
5	1%	59	1%	50	1%	21
25	1%	39	1%	74	1%	36

The **developed market phase** assumes that the market entry has successfully been achieved and a market penetration around 5% of the QAM could be reached. The prices for the systems were set to 6000 €/kW_{el} for the 5 kW_{el} system and 4000 €/kW_{el} for the 25 kW_{el} system, bringing the systems close to grid parity. After a three to five years market entry phase the market would be well developed with a significantly higher market penetration at lower prices. The numbers of units sold at the developed market phase are shown in Table 4.

Table 4. Share of market (SAM) in Germany, UK and Italy during the developed market phase.

Size kW_{el}	**Germany**		**United Kingdom**		**Italy**	
	Market Share	units/a	Market Share	units/a	Market Share	units/a
5	10%	591	3%	151	5%	104
25	5%	195	5%	370	5%	181

Based on the market analysis the estimates for the market potential range from 40 M€/a in the market entry phase to 100 M€/a in a fully developed market for 5 kW_{el} and 25 kW_{el} units of the STAGE-SOFC system. Knowing the assumptions are very generic the following numbers should be used with care and an awareness of the uncertainty that lies behind the figures. However the big picture of the market potential is shown and shows the attractiveness for the STAGE-SOFC system at least in niche markets with potential to higher volumes if the benefits of the system should resonate in the market.

1.4.6.2 *Cost analysis*

The primary focus of the STAGE-SOFC concept was the stationary market, where it will generate considerable customer value as a result of reduced operating costs (higher efficiency) and reduced capital costs (low system complexity). The key USP of SOFC systems is their high electrical efficiency. Relevant market segments for stationary SOFC products are determined on the basis of the benefit derived by the end customer. The cost analysis focused on these three market segments:

- microCHP – power range 1-10 kW,
- off-grid – independent power supply in remote locations,
- small CHP – power range 10 to several 100 kW operated with natural gas or biogas.

Starting from the unit structure and actual manufacturing costs of the second STAGE-SOFC prototype, the cost analysis and cost projection for production of larger quantities was carried out.

SF has a very clear cost reduction pathway at stack level, since not all measures that result in cost reduction will finally be successful, two scenarios were considered: a conservative scenario (base case) and a more ambitious case. The cost projection at system level is more uncertain, since there are still many options to optimize the system in terms of functioning, complexity and costs. Here, the cost analysis and projection was started from the actual manufacturing costs of prototype 2 referred to as recent costs. The total system costs were normalized to a power output of 5 kW, providing enough degradation reserve for keeping the power output constant over the first 10,000 operation hours.

The cost degression on system level at larger production quantities can be realized with two different features. The first feature is a decrease of specific material costs by quantity, taking into account the discount for standard components as well as for customized components when buying large quantities. The second feature is a reduction of production costs, that means hours for assembly of a subunit or a complete unit, by a more simple design of the unit or by improvement of the manufacturing process. Furthermore material cost reductions by research and development can be considered with a fixed cost degression rate. The production volume and specific costs by year for the 5 kW STAGE-SOFC system are summarized in Figure 15.

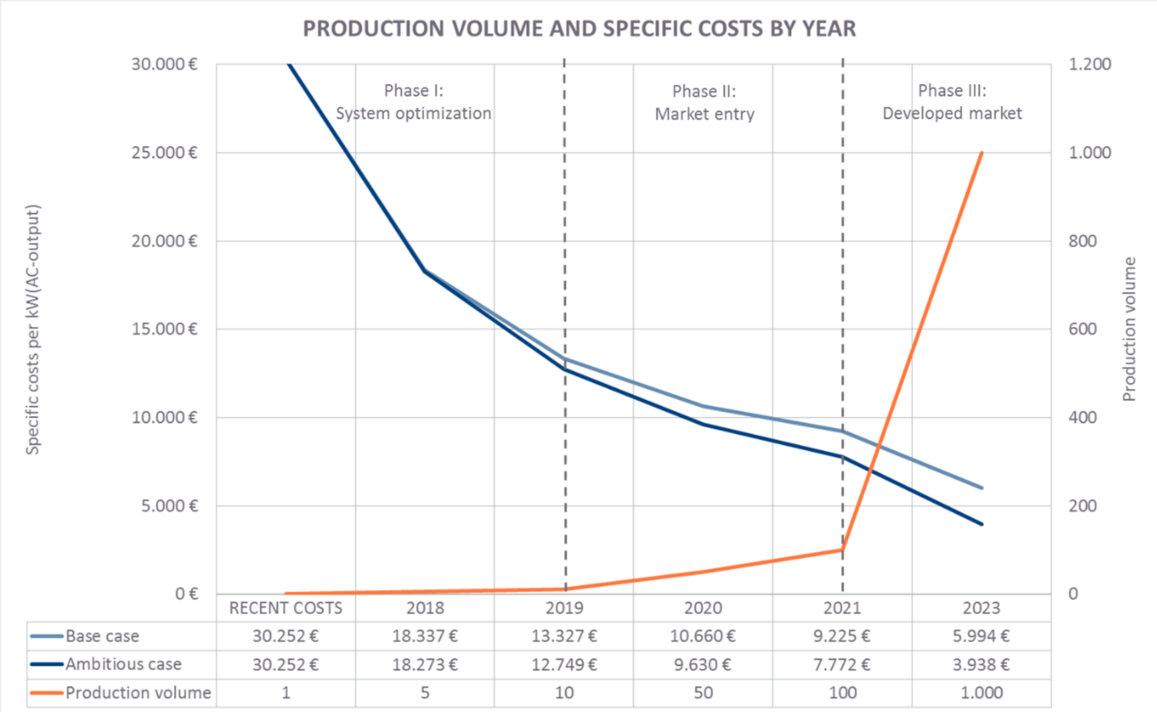


Figure 15. Predicted production volume and specific costs of 5 kW STAGE-SOFC system.

The resulting curve for the predicted production volume and specific costs was devided into three phases. The first phase (2017 - 2019) is comprising a fundamental optimization of the current prototype system towards a marketable product. The manufacturing costs are still very high in phase I, which means that only niche markets with a high cost tolerance like off-grid applications can be served. In phase II (2019 - 2021) the manufacturing costs decrease considerably with increasing production volume, reaching the level of 9,000 €/kW, which was identified as the target price for the market entry in the 5 kW_{el} CHP sector. In phase III starting from 2021, the manufacturing costs fall below the level of 6,000 €/kW with the possibility to enter the mass market with a production volume of more than 1,000 units per year.

The analysis of the cost distribution reveals that the “Stack Unit” is by far the most expensive system part and also remains in this position in the future. That means that the stack costs are of great importance and determine if the complete system can be economically successful. A clear path to the market for the STAGE-SOFC system was defined and strategies and measures to achieve the ambitious cost targets for a market entry were indicated.

1.4.6.3 Techno-economic studies

The techno-economic feasibility of three chosen applications for the STAGE-SOFC system was assessed in this task. These applications were:

1. a 5 kWe combined heat and power (CHP) system for a several apartments house with natural gas as fuel.
2. a 50 kW_{el} combined heat and power (CHP) system for a small farm that is fuelled with biogas from anaerobic digestion plant utilising animal manure and other agricultural bio waste.
3. a 5 kWe system off-grid application again with natural gas as fuel.

Case studies were carried out for applications 1 and 2 and the considered countries were United Kingdom, Germany, Italy and Poland. The application 3 was not considered country-specific. In the application 1 and the application 2, the design of the system was aimed to fulfil the average electricity demand, and the additional peak electricity demand would be fulfilled by purchasing electricity from the grid. The revenues in the calculation of feasibility (net present value, NPV) were the savings when electricity and heat were not purchased from the grid or local producer. Thus instead of real income the revenues in the calculation were “saved” costs. The retail electricity price for consumers used as revenue in this study included taxes, levies, network costs and profit for the electricity producer. Heat price estimate was calculated based on the natural gas price.

The owners purchasing the 5 kW_{el} CHP STAGE-SOFC system fuelled with natural gas were assumed to be consumers (a group of households in an apartment house). Different combinations of full load hours, degradation rate, system cost and country-specific prices and subsidies were assessed.

Three parameters (worst, baseline, best) were used for system related costs (investment and stack replacement costs, and degradation of the fuel cell stacks). Germany turned out to be the most potential country, in which the case with baseline parameters and 6000-7000 full load hours was profitable (Figure 16). In Italy the system with baseline parameters was nearly feasible, and minor changes may change the baseline system feasibility. In UK and Poland the baseline system was not feasible. A more detailed sensitivity analysis was carried out for Germany. It showed that to attain the baseline degradation rate is an important target, apparently even more important than the decrease of the investment, stack replacement and annual maintenance cost. It also showed that if assuming that the stack replacement cost decreased 5% every year, the baseline case with 4000 h at full load was feasible even with the highest stack replacement cost. This assumption had such a significant impact to the feasibility that it could probably make the baseline Italian and UK cases feasible too.

The 50 kWe CHP STAGE-SOFC application was targeted to a small farm. The fuel was biogas derived from an anaerobic digester which feedstock was manure and agricultural waste from farm. Biogas cost was assumed to be 20-41 €/MWh. In case of UK, Italy and Germany, the profitability of the farm application was reached with baseline system cost and baseline degradation at 6000-7000 full load hours. The German case was the most feasible. Main challenges for the farm application are the high investment cost of the combined digestion plant and the STAGE-SOFC system for a small farm. However, the outstanding power to heat ratio of the STAGE-SOFC system compared to the competitors would be a benefit. The important task would be to identify the types of farms, which heat and power demand profile would suit to the power to heat ratio of the STAGE-SOFC system best.

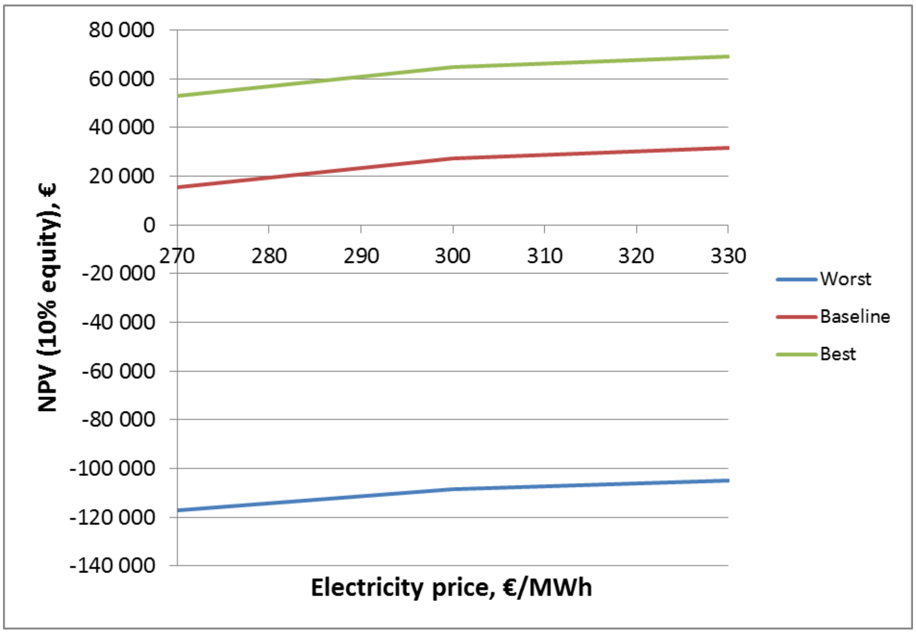


Figure 16. 5 kWe CHP in Germany: Sensitivity of NPV to the electricity price and natural gas price (worst: high degradation, high system cost, low full load hours, best: low degradation, low system cost, high full load hours).

Off-grid power generation is a niche market but a valuable business case that supports growth in other markets as the CAPEX reduction take place. The most important parameters were in addition to electricity cost a high reliability and a long maintenance interval. The results showed that the off-grid STAGE-SOFC application could be competitive at the niche market of off-grid generation in cases where the characteristics of the STAGE-SOFC system are required (Figure 17).

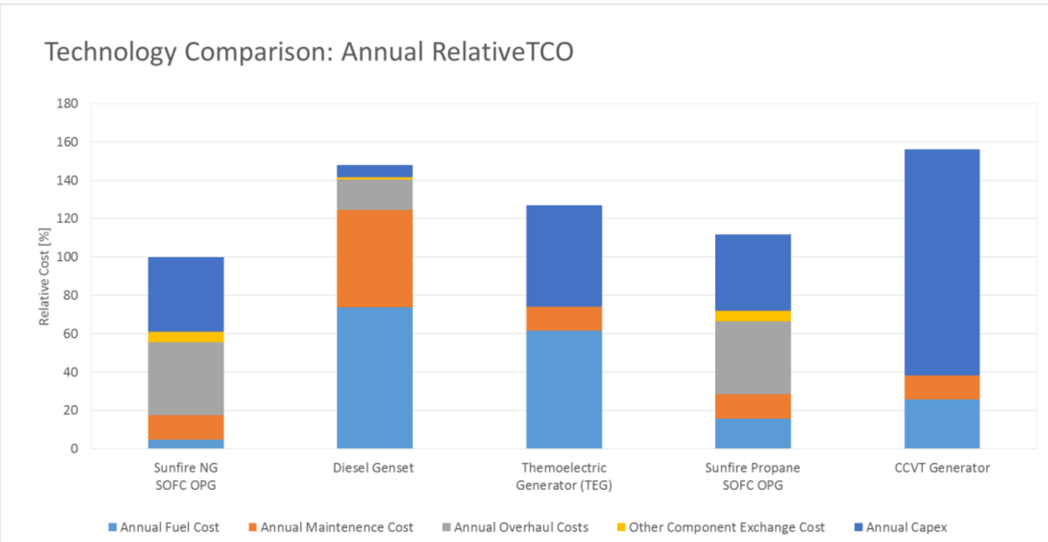


Figure 17. Comparison of TCO of different off-grid generation technologies at 2.5 kWe l level, calculated for Western Canada.

As a conclusion of the feasibility assessment, the off-grid application is clearly the most potential market entry phase product. Based on the results of CHP applications, the most promising countries are Germany and Italy, followed by UK. In addition, the profitability of the CHP cases with 4000 full load hours requires both low system cost and low degradation to be feasible. The important targets would be to obtain the baseline system cost and the baseline level degradation in order to reach the feasibility for CHP applications. The annual decrease (5%) in stack replacement cost would significantly improve the feasibility of the system. Positive sign for the future of small scale distributed energy production is the planned netmetering, option to sell or purchase electricity from/to grid depending on the production and demand at relatively low cost.

1.4.6.4 Potential mitigation of CO_2 emissions

The impact of the STAGE-SOFC system on Global Warming Potential (GWP) was screened by carrying out a streamlined LCA analysis of CO_2-eq emissions. Streamlined analysis takes into account the main sources of emissions but ignores insignificant emissions sources. Based on the literature study, the operation of a SOFC system causes the highest emissions, whereas the disposal phase is negligible and the manufacturing phase insignificant. Two fuels were included into analysis, natural gas and biogas produced from manure. The two scenarios were compared to reference scenarios of separate power and heat production; electricity production in large scale by either coal combustion (electrical efficiency 39% LHV) or natural gas -fuelled gas turbine combined cycle (electrical efficiency 55% LHV), and heat production by residential boiler fuelled by either coal or natural gas (thermal efficiency 85%). Median electrical efficiencies of the power plants were chosen for the reference scenarios.

The result of the natural gas-fuelled STAGE-SOFC CHP system showed that 21% of CO_2-eq. emissions would be avoided if the STAGE-SOFC system were used instead of a GTCC and NG -fired residential boiler. 52% of CO_2-eq. emissions would be avoided, if the STAGE-SOFC system replaced a coal power plant and NG-fired residential boiler, and 55% of CO_2-eq. emissions would be avoided, if the STAGE-SOFC system was replaced by a coal power plant and coal -fired residential boiler. The CO_2-eq emissions of biogas-fuelled STAGE-SOFC system consisted only of the STAGE-SOFC system manufacturing and biogas production process, because biogas derived from manure is considered biogenic fuel, and GWP impact includes only CO_2-eq emissions from fossil origin. CO_2-eq emission estimate of biogas production was based on literature. The biogas –fuelled STAGE-SOFC CHP system had lower CO_2-eq emissions than NG –fuelled. When comparing to reference systems, 70% of CO_2-eq. emissions would be avoided if the biogas fuelled STAGE-SOFC system were used instead of a GTCC and NG-fired residential boiler. 82% of CO_2-eq. emissions would be avoided, if the biogas fuelled STAGE-SOFC system were replaced by a coal power plant and NG-fired residential boiler, and 84% of CO_2-eq. emissions would be avoided, if the STAGE-SOFC system replaced a coal power plant and coal -fired residential boiler.

1.4.7 Project in relation to the set targets

The following table summarises the status of the project in relation to the set targets.

Table 5. Project in relation to set targets.

Target Source	Parameter	Unit	Target for project	Achieved in project	Target status	Description	Identifier
MAIP 2008-2013	Electrical efficiency (AC, LHV) at system level	%	45	45	Achieved	Verified theoretically (system simulations) and experimentally in PT1 and PT2	D2.1 (Fig. 42/43) D3.1 (Fig. 13) D6.1
MAIP 2008-2013	Total efficiency (LHV) at system level	%	80	80	Achieved	Verified theoretically (system simulation)	D2.1 (Fig. 42/43)
MAIP 2008-2013	Stack lifetime	h	40000	20000	(Not achieved)	Long-term stack investigations in parallel to the project, 20,000 h confirmed by Vaillant in system. 25,000 h achieved in off-grid power system.	
MAIP 2008-2013	Cost per unit @ 5 kW class	€/kW	4000		Achieved	Cost analysis shows that number is achieveable by mass-production	
DoW	Prototype running time	h	3000		Not achieved	Long-term testing couldn't be performed due to system failure.	
DoW	Prototype electrical power	kW	5	5.35	Achieved	Power target achieved in PT1 and repeated in PT2	D3.1 (Tab. 2) D6.1

1.5 Potential impact of the project

1.5.1 Impact

Strategic focus of the Annual Implementation Plan

- Decarbonisation and reductions in CO_2 emissions

The reduction of CO_2 emissions of at least 20% by 2020 is a primary EU target. It has been shown via LCA analysis that the SOFC-based CHP system is able to reduce CO_2 emissions by minimum 20% compared to central power generation using natural gas and residential boilers. Even higher reductions can be achieved compared to coal-based power reduction. An operation with biogas or sewage gas as alternative fuel reduces CO_2 emissions by 70% and more. The STAGE-SOFC concept system layout makes it possible to achieve high electrical efficiencies (> $45\%_{LHV}$ at nominal operation (> $50\%_{LHV}$, without the need of an external water supply.

- Implementation of a closed carbon cycle

SF's business mission is to close the carbon cycle. It therefore develops the SOEC technology required in order to generate synthetic natural gas (SNG) using CO_2 and fluctuating renewable electricity. The proposed technology solution also achieves higher overall efficiency during the conversion of electricity to SNG. The reconversion of methane to electricity is most efficient when carried out using a SOFC system that reaches an electrical efficiency of up to 50%. SF has build a reversible SOC system within the project GrInHy, where results of the STAGE-SOFC project are included.

- Improvement of air quality

Besides CO2 emission reductions, fuel cell systems doesn't emit NOx or SO_2. Stronger emission regulations would help to support the introduction of clean energy generation systems. Here, politics is asked to support technologies with a suitable legal framework.

- Energy security

Energy source security and the availability of affordable electricity and heat are two social and political factors focused on in EU energy policy. Successful introduction of CHP systems can contribute to reductions in energy costs if they are able to achieve competitive system prices. Using renewable fuels or SNG decreases the dependency from energy imports.

- International competitiveness

The majority of fuel cell systems are currently developed in Japan and the USA. Highly-innovative concepts are required in order to remedy existing fuel cell system disadvantages and in turn keep pace with competition in the sector. One advantage that Europe enjoys is its strong, innovative foundation for research. Cooperation with leading research institutions in relevant fields contributes to rapid, high-quality development which can subsequently be used by industrial partners.

Market penetration with fuel cell system is difficult due to high initial system costs. It requires public funding or niche markets to increase production volumes. The European market is strong enough to get fuel cell systems into operation if legal hurdles are banned (e.g. freedom to feed electricity into the grid at fair compensations).

- Employment

FC-based CHP systems will require investment and create new jobs across a wide range of industries such as suppliers of components and services, system integrators, installers and service providers. Precise quantification of potential employment is difficult at the current stage of the project, as production planning has not yet occurred and it has not been decided which components are to be manufactured in-house and which are to be sourced from suppliers.

MAIP area 3.3.3: Stationary Power Generation & Combined Heat and Power (CHP)

The Annual Implementation Plan (AIP) and Multi-Annual Implementation Plan (MAIP) defines in area Stationary Power Generation & Combined Heat and Power (CHP) following targets:

- 45% electrical efficiency (power-only systems)
- 80% overall power efficiency
- Lower emissions than incumbent technologies
- Lifetime requirement of 40,000 hours for cells and stacks
- Cost targets for small-scale CHP units: 4000 €/kW (100+ units); 2000 €/kW (50,000 units)

Within performance tests of prototype 1 and 2 system efficiencies of $47\%_{LHV,AC}$ at nominal load and $50\%_{LHV,AC}$ in part load were achieved. Mature SOFC systems have proven that total efficiencies of $95\%_{LHV}$ can be achieved. Within STAGE-SOFC, overall efficiencies of up to 75% could be shown, higher efficiencies will be possible with an improved thermal integration of the hotbox. The PoC system wasn't optimized in a way which ensures complete thermal integration and minimization of heat losses. However, simulations have shown that the targets are possibl.

Emissions are inherently lower in FC systems than in gas motors, gas turbines or similar CHP modules, especially concerning NOx, SO_2 and particulates.

CHP applications require a lifetime of at least 40,000 h. This couldn't be proven with the STAGE-SOFC prototypes. However, it was shown that SF stacks achieve >20,000 h in µCHP systems (Vaillant) and >25,000 h in an off-grid power generator. SF has set out a clear path towards the doubling of the system lifetime with the aid of various measures at cell and stack level. The STAGE-SOFC project contributed to the increase of knowledge concerning operation strategies and critical operation modes where stacks might be damaged (thermo-mechanical stresses, carbon formation).

European approach and complementary national and international research activities

The project partners possed complementary expertise and formed a very strong European Consortium that is capable of commercializing the project results. The project's partners linked it to numerous past and ongoing EU projects. The techno-economic evaluation task included in the proposed project was linked to the SOFCOM project, which studies and evaluates small-scale biogas and SOFC-based CHP systems. VTT was responsible for this activity within the framework of both projects, and therefore ensured the smooth transfer of information.

SF and VTT are partners in the project GrInhy, where results of the natural gas processing investigation within STAGE-SOFC were used to develop a reversible SOC system based on natural gas for the reconversion of gas to electricity.

ICI is a partner in the ReforCELL project (FCH-JU-2010-1). Its active role consists in the integration of a new FP system based on LT-PEMFC and the evaluation of cost, industrialization and impact on the market.

1.5.2 Dissemination activities and exploitation of results

Dissemination activities

The dissemination of the achieved results, the transfer of knowledge and technology related to the fuel cells as well as the creation of awareness about the applications of the SOFC based power generation systems are the key factors in the project and represent an integral part of the work of the project within the WP8. Therefore, all partners were encouraged to get involved in the dissemination activities. In this context, the following list of tasks was implemented to execute dissemination actions:

- promotion of the project to targeted audiences through the website,
- presentation of the project results at conferences, workshops and other fuel cell events,
- preparation of papers and scientific publications for journals,
- organisation of thematic symposium,
- development of relations to other European research projects,
- involvement in the users communities.

Dissemination activities, which have been carried out during the project are detailed presented in detail in the following sections.

The main target of our dissemination activities were industrial players: suppliers and system integrators that transfer technology as well as industrial entrepreneurs that adopt a new technology into the market. It is of critical importance to ensure that implementation of the new technology into the market will be based on knowledge. In order to do so, the project partnerts attract the public community by promoting the benefits of the SOFC based system. Through the participation in the fuel cell trade fairs and events the consortium tried to convince the sceptical players and end users about the benefits of the fuel cell technology. This practice was aimed at influencing on the political decision makers as well.

The next target group was the academic players: students, young scientists and engineers, who were advised on the methods in the field of fuel cell and outcomes related to the project. Academic institutions were represented within the project by two project partners: LUT and ZUT. Three PhD and one Master students have been involved in the project.

In order to reach the different target audiences identified in the Deliverable D8.2. Plan for dissemination activities, the following communication material was produced.

- Logo, poster and presentation templates

Project logo, poster and presentation templates have been prepared and used for publicizing the project during the workshops, conferences and meetings. The communication materials made available for partners on the web platform SharePoint protected by passwords (private part for the project partners only).

- STAGE-SOFC website

The STAGE-SOFC website http://www.stage-sofc-project.eu/ is the reference point for the public and scientific community and for the dissemination. It is intended to external communication providing public access to the project's information.

- Internal project portal

The web platform SharePoint is the central feature for collecting information that revolves around the project. It is intented to internal communication and exchange of information, documents between the project partners. The project portal is accessible only to the project partners.

- Publication of scientific papers

The privileged way to reach the academic community is scientific publications in journals and conference proceedings targeting the field of fuel cell and related technologies such as mechanical, electrical or chemical engineerings. Sixteen scientific papers were published in the project. An updated list of publications related to the STAGE-SOFC project is given later in Chapter 2.

- Communication events: conferences and seminars

To improve visibility and support the dissemination effort, the STAGE-SOFC consortium has organized and participated in a number of events such as conferences, symposium, seminars, meetings, worskhops, trade fairs related to the fuel cell topics.

The STAGE-SOFC consortium has organized the Symposium "Fuel cells – energy and transportation – design, prototyping, implementation, which took place in Szczecin, Poland in the Regional Centre for Innovation and Technology Transfer on 22nd of April 2015. More than 90 participants attended the one-day event. The Symposium consisted of a series of presentations referred to fuel cell technology.

Two keynote speakers highlighted important developments in the field of fuel cells. Dr Erich Erdle, from efceco, Germany, presented the lecture on "Fuel cells – their history, their presence and their future role". Dr Ulf Bossel, ALMUS AG, Switzerland, discussed selected approaches for generation, compression, transportation, storage and conversion hydrogen to electricity.

The STAGE-SOFC project partners participated in conferences and other major events related to the main topics of the project in order to give rise to deeper discussion on its results and benefit from possible feedback from other experts in the fuel cell research area.

The STAGE-SOFC project was presented at the EUROPACAT conference in Italy as well as ESCRE – European Symposium on Chemical Reaction Engineering in Germany or International Symposium on Solid Oxide Fuel Cells in USA.

An updated list of presentations and posters in conferences is given later in Chapter 2.

- Trade fairs and exhibitions

The STAGE-SOFC industrial project partners attended several technical fairs and exhibitions. They gave technical talked to the fuel cell community during the Group Exhibit Hydrogen + Feull Cell in Hannover or F-cell Stuttgart. Trade fairs stimulated the discussion and innovation concerning fuel cells based power energy systems. The industrial partners have participated in the following fairs and exhibitions:

- SF:
  - Group Exhibit Hydrogen + Fuel Cell, Hannover Fair, 08/04/2014, Hannover, Germany.
  - F-cell Stuttgart, 07/10/2014, Stuttgart, Germany.
  - Enertec Leipzig, 29/01/2015, Leipzig, Germany.
  - E-world Energy + Water, 10/02/2015, Essen, Germany.
  - FC EXPO, Tokyo, 25/02/2015, Tokyo, Japan.
  - Distributed Energy & NG Energy Expo China, 01/04/2015, Beijing, China.
  - Group Exhibit Hydrogen + Fuel Cell, Hannover Fair, 13/04/2015, Hannover, Germany.

- LUT:
  - Progress in Fuel Cell Systems, 9th Workshop, 31 May – 1 June 2016, Bruges
  - Progress in Fuel Cell Systems, 8th Workshop, 1 – 2 June 2016, Bruges

- Education seminars

In order to attract young scientists and engineers attentions, lectures and demonstrations in numerical labs using Ansys Fluent and Aspen Tech tools were organized. Participants, mainly students had got an unique opportunity for a complete update on all aspects of numerical simulations of the fuel cell based systems. The aim of these lectures that were carried out during the courses: "CFD in Chemical Engineering" or "Hybrid sources of energy" was to present to the participants basic information in the core topics that constitute the multidisciplinary area of chemistry, mass and heat transfer, electrochemical phenomena and mathematical modelling.

- Development of a wide community of researchers

Through the Erasmus+ researcher exchange program, a representative from ZUT delivered guest lectures at the University of Ostrava, Czech Republic. The visit was focused on demonstrating the achievements of the project and on promoting the numerical results.

- Links and exploitation of liaison with other EU Projects and the Commission

The STAGE-SOFC consortium put an effort in maintaining the cooperation established during the previous years with a number of EU projects and initiatives including SUAV, SAPIENS, SAFARI and projects as well as different research networking programme. At VTT the techno-economic evaluation (T7.3) and potential mitigation of CO2 emissions (T7.4) were linked to the SOFCOM project (FCH-JU-2010-1 GA 278798), which also studied and evaluated small-scale biogas and SOFC-based CHP systems. ZUT was part of the FP7 SOFC projects SUAV: "*Microtubular Solid Oxide Fuel Cell power system development and integration into a Mini-UAV*", SAPIENS: "*SAPIENS – SOFC Auxiliary Power In Emissions/Noise Solutions*" that were completed on 30/11/2015 and 31/10/2015, respectively. In addition, ZUT was also involved in the 7th Framework Programme under the FCH JU in the project with an acronym SAFARI: "*SOFC Apu For Auxiliary Road-Truck Installations*". The SAFARI project was finished on 31/12/2017.

- Project meetings

Several project meetings were organized to ensure good internal communication and cooperation between the project partners. The list of the project meetings is given herein:

- project kick off meeting, 2-3/04/2014, Dresden
- 6 month progress meeting, 8-9/10/2014, Helsinki
- 12 month progress meeting, 23/05/2015, Szczecin
- 18 month progress meeting, 7-8/10/2015, Dresden
- 24 month progress meeting, 12-14/04/2016, Lappenranta
- 30 month progress meeting, 18-19/10/2016, Verona
- 42 month progress meeting, 25-26/09/2017, Verona.

The current monitoring of the dissemination activities helps to track the project evolution and to identify the innovative points of the project that have been shared and communicated. The project success in the dissemination activities carried out by all the project partners, generated interest at the industrial partners, stakeholders, academic institutions as well as policy makers. One of the main aim of the dissemination activities was to spread the project's message under the tagline: "innovative SOFC system – the only one source of energy and heat – that you need" and to attract the public and industrial communities by promoting the capacities of the SOFC based power generation system. The best evidence for the consortium's active involvement in the dissemination field is the following summary:

- 16 scientifics papers in journals,
- 7 oral presentations at international conferences,
- 1 organized fuel cells symposium,
- 8 posters at international conferences,
- 11 participations in the trade fairs,
- 5 participations in exhibitions,
- 3 PhD theses,
- 1 Master thesis,

2. Use and dissemination of foreground

Section A (public)

A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS									
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Year of publication	Relevant pages	Permanent identifiers[3] (if available)	Is/Will open access[4] provided to this publication?
1	Core and air gap influence on the accuracy of inductor AC winding resistance calculation methods	V. Väisänen, J. Hiltunen, P. Silventoinen	EPE'14-ECCE Europe	26-28 Aug. 2014	EPE	2014	7770-7782	doi: 10.1109/EPE. 2014.6910916	No
2	Input filter damping without external passive components	J. Hiltunen, V. Väisänen, P. Silventoinen	EPE'14-ECCE Europe	26-28 Aug. 2014	EPE	2014	1 - 7	DOI:10.1109/EPE.2014.6911025	No
3	Variable-Frequency Phase Shift Modulation of a Dual Active Bridge Converter	J. Hiltunen, V. Väisänen, R. Juntunen, P. Silventoinen	Transactions on Power Electronics	Volume 30, Issue 12, Dec. 2015	IEEE	2015	7138 - 7148	doi: 10.1109/TPEL. 2015.2390913	No

[3] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).
[4] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

4	Phase drift phenomenon in dual active bridge converter – analysis and compensation	V. Väisänen, J. Hiltunen, R. Juntunen, P. Silventoinen	International Review of Electrical Engineering	Volume 10, Issue 1, 1 Feb. 2015	Praise Worthy Prize	2015	1-11		No
5	Maximum Efficiency Point Tracking Algorithm for Dual Active Bridge Converters	V. Väisänen, J. Hiltunen	IEEE Energy Conversion Congress And Exposition	20-24 Sept. 2015	IEEE	2015		doi: 10.1109/ECCE. 2015.7309747	No
6	Carbon formation in catalytic steam reforming of natural gas with SOFC anode off-gas	Kihlman, J.	International Journal of Hydrogen Energy	Vol 40, January 2015	Elsevier Ltd	2015	1548-1558	doi:10.1016/j.ijhydene.2014.11.074	No
7	Carbon formation in catalytic steam reforming of natural gas with SOFC anode off-gas	J. Kihlman, J. Sucipto, N. Kaisalo, P. Simell, J.Lehtonen,	Intern. J. of Hydrogen Energy	40		2015	1548-1558	doi:10.1016/j.ijhydene.2014.11.074	No
8	Model development of integrated CPOx reformer and SOFC stack system	P. Pianko-Oprych, M. Hosseini, Z. Jaworski	Polish Journal of Chemical Technology	18, 4		2016	41-46	doi: 10.1515/pjct-2016-0069	yes
9	3D CFD fluid flow and thermal analyses of a new design of plate heat exchanger	P. Pianko-Oprych, Z. Jaworski	Polish Journal of Chemical Technology	19, 1		2017	17-26	doi: 10.1515/pjct-2017-0003	yes
10	Numerical investigation of a novel burner to combust anode exhaust gases of SOFC stacks	P. Pianko-Oprych, Z. Jaworski	Polish Journal of Chemical Technology	19, 2		2017	20-26	doi: 10.1515/pjct-2017-0043	yes
11	Analiza numeryczna wpływu konstrukcji wymiennika ciepła na efektywność wymiany ciepła (in Polish)	T. Zinko, P. Pianko-Oprych	Postępy w technologii i inżynierii chemicznej	I		2017	190-192	-	No
12	Development and testing of innovative SOFC system prototype with staged stack	] J. Bachmann, O. Posdziech, P. Pianko-Oprych,	ECS Transactions	Vol 78, May 2017	Electrochemical Society	2017	133-144	doi: 10.1149/07801.0133ecst	No

	connection for efficient stationary power and heat generation	N. Kaisalo, J. Pennanen							
13	On nanotube carbon deposition at equilibrium in catalytic partial oxidation of selected hydrocarbon fuels	Z. Jaworski, P. Pianko-Oprych	International Journal of Hydrogen Energy	42, 27		2017	16920-16931	doi: 10.1016/j.ijhydene.2017.05.191	yes
14	On thermodynamic equilibrium of carbon deposition from gaseous C-H-O mixtures. Updating for nanotubes.	Z. Jaworski, B. Zakrzewska, P. Pianko-Oprych	Reviews in Chemical Engineering	33, 3		2017	217-235	doi: 10.1515/revce-2016-0022	yes
15	Simulation of SOFCs based power generation using Aspen	P. Pianko-Oprych, M. Palus	Polish Journal of Chemical Technology	19, 4		2017	8-15	doi:10.15P1o5l/.p jJc. t-C2h0e1m7-.0 0T6ec	yes
16	Dynamic analysis of load operations of two-stage SOFC stacks power generation system	P. Pianko-Oprych, M. Hosseini	Energies	10, 12		2017	2103-21024	doi: 10.3390/en10122103	yes

A2: LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities[5]	Main leader	Title	Date/Period	Place	Type of audience[6]	Size of audience	Countries addressed
1	Conference, presentation	SF	11th European SOFC & SOE Forum 2014	1–4 July 2014	Lucerne	Scientific Community		International
2	Conference, poster	SF	ESCRE 2015 – European Symposium on Chemical Reaction Engineering,	27-30 October 2015	Munich	Scientific Community, industry		International
3	Conference, presentation	SF	SOFC XIV	26-31 July 2015	Glasgow	Scientific Community		International
4	Symposium, presentations	ZUT	Fuel cells – energy and transportation – design, prototyping, implementation	22 April 2015	Szczecin	Scientific Community	100	Germany, Italy, Finland, Switzerland
5	Workshop, presentation	VTT, LUT	Progress in Fuel Cell Systems, 8th Workshop	2-3 June 2015	Brugge	Scientific Community	20	Germany, Italy, Finland, Belgium, UK
6	Conference, poster	VTT	2nd International Conference on Renewable Energy	7-8 May 2015	Barcelona	Scientific Community, industry		International

[5] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[6] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

			Gas Technology REGATEC 2015					
7	Workshop, presentation	LUT	Progress in Fuel Cell Systems, 9th Workshop	31 May -12 June 2016	Brugge	Scientific Community, industry	20	Germany, Italy, Finland, Belgium, UK
8	Conference, presentation	VTT	1st Finnish Young Scientist Forum	9 April 2016	Tampere	Scientific Community	70	*Finland*
9	Conference, poster	SF	SOFC XV	23-28 July 2017	Hollywood	Scientific Community		International
10	Conference, Poster	VTT	13th European Congress on Catalysis (EUROPACAT 2017)	27-31 August 2017	Florence	Scientific Community	10	European

Section B (Confidential[7] or public: confidential information to be marked clearly)
Part B1

No patent applications, trademarks, registered designs etc. were filed during the project.

[7] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

Part B2

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary (s) involved
Commercial exploitation of R&D results	*New SOFC-concept*	*No*	*Application of the STAGE-SOFC concept for CHP*	*Energy service companies*	*2018-*	-	*ICI*
Commercial exploitation of R&D results	New compact and cost-effective Hotbox	No	Enhanced off-grid power, CHP & Datacentre cooling	System integrators	2018-	-	SUNFIRE
Commercial exploitation of R&D results	Improved BoP for SOFC systems	No	Enhanced off-grid power, CHP & Datacentre cooling	System integrators	2018-	-	SUNFIRE
General advancement of knowledge	Improved DC/DC and DC/AC converters	No	High-efficiency DC/DC and DC/AC converter solutions for fuel cells or other power sources	System integrators	2018-	-	LUT
General advancement of knowledge/ Commercial exploitation of R&D results	Reforming incl. carbon deposition know-how for the development of fuel processing units for SOFC applications and process integration designs	No	Improved Power generation based on fuel cells	System integrators	2018-	-	VTT
General advancement of knowledge/Commercial exploitation of R&D results	Durable catalyst coatings on metal surfaces	No	Intensified reactors in chemical industry or CHP production.	Heat exchanger manufacturers, System Integrators	2019-	-	VTT

7 A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.
9 A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary (s) involved
General advancement of knowledge	New type of reformer	No	Heat-exchanger-type small scale reformers in CHP (SOFC, gasification) or synthesis applications	Heat exchanger companies, system integrators	2019-	-	VTT
General advancement of knowledge	CFD modelling of planar SOFC	No	Numerical predictions of process efficiency, validated simulations of characteristics of equipment units and dynamic responses	Developers of fuel cell CHP components and systems	2018-	-	ZUT
General advancement of knowledge	Improved control systems	No	Optimised control and operation of the STAGE-SOFC system	System integrators ,Off-grid power CHP Datacentres (cooling)			Sunfire
Exploitation of R&D results via standards	Development of SOFC applicable standards and certification process	No		System integrators, Off-grid power CHP Datacentres (cooling)			Sunfire

The deliverable reports: D8.1. Launch of public website, D8.2. Plan for dissemination activities, D8.3. Summary of dissemination of project results as well as D8.4. Summary of exploitation roadmap, gave an overview of all dissemination activities and evaluation of the STAGE-SOFC project results. For a successful communication of fairly complex SOFC based power generation system technology we have identified few key target groups, who were approached through different communication strategies. The most important target groups were:

- potential stakeholders – industrial entrepreneurs, suppliers, system integrators, experts in fuel cell field, fuel cell community, who deal with problems that were solved within the STAGE-SOFC project. The aim of dissemination activities was getting critical feedback to the activities of the project, but also raising the awareness of the SOFC system solutions among the practitioners' communities. This group had an impact on the policy makers, who can influence on the international and national laws in which the SOFC based power generated system would be implemented in the future to the market;
- academic institutions – in different disciplines starting from the chemical engineering, electrical engineering, mechanical engineering through material science as well as computer scientists. It was an opportunity to enhance interdisciplinary research in the areas of fuel cells development. Dissemination activities were connected with publishing papers, attending conferences and sharing the knowledge generated in the project during educational seminars and practical workshops with students in the numerical labs.
- end users – general public. The aim of the dissemination activities to the third main target group was to raise general awareness of the potential of fuel cells.

During the first year, the project targeted groups were mainly informed by the STAGE-SOFC project website and direct contacts. During the second to fourth year of the project implementation the STAGE-SOFC partners participated actively in several international conferences and trade fairs. Previous types of activities such as direct contacts and updates of the website were continued as well. The feedback from the stakeholders was used to improve the project. Moreover, to target the academic players scientific papers were published in journals as additional medium of communication. 16 papers were prepared by the project partners during the project. Within the WP8 four deliverables were written.

An exploitation road-map was presented in the WT7.1 "Business cases", WT7.2 "Cost analysis" and WT7.3 "Techno-economic studies". The exploitation road map was elaborated by industrial partners SF and ICI. SF checked system integrators interested in licensing or using the entire hotbox, ICI discussed these issues with end-users.

The rules for IPR, exploitation rights, confidentiality procedures, cooperation after the end of the project and negotiation with third parties were defined in the Consortium Agreement. No declarations of invention have been made. VTT with its legal affairs department and patent officer monitored the situation within the consortium.

3. Report on societal implications

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	6212123
Title of Project:	Staged SOFC Stack Connection for Efficient Power and Heat
Name and Title of Coordinator:	Matti Reinikainen, Dr. Sci., Principal Investigator

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	
RESEARCH ON HUMANS	
• Did the project involve children?	***No***
• Did the project involve patients?	***No***
• Did the project involve persons not able to give consent?	***No***
• Did the project involve adult healthy volunteers?	***No***
• Did the project involve Human genetic material?	***No***
• Did the project involve Human biological samples?	***No***
• Did the project involve Human data collection?	***No***
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	***No***
• Did the project involve Human Foetal Tissue / Cells?	***No***
• Did the project involve Human Embryonic Stem Cells (hESCs)?	***No***
• Did the project on human Embryonic Stem Cells involve cells in culture?	***No***
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	***No***
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	***No***
• Did the project involve tracking the location or observation of people?	***No***
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	***No***
• Were those animals transgenic small laboratory animals?	***No***
• Were those animals transgenic farm animals?	***No***
• Were those animals cloned farm animals?	***No***
• Were those animals non-human primates?	***No***
RESEARCH INVOLVING DEVELOPING COUNTRIES	

• Did the project involve the use of local resources (genetic, animal, plant etc)?	***No***
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	***No***
DUAL USE	
• Research having direct military use	***No***
• Research having the potential for terrorist abuse	***No***

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	1
Work package leaders	2	6
Experienced researchers (i.e. PhD holders)	3	5
PhD Students	3	3
Other	3	10

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	4
Of which, indicate the number of men:	2

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?	X ○	Yes No

6. Which of the following actions did you carry out and how effective were they?

		Not effective at all → Very effective
X	Design and implement an equal opportunity policy	○ ○ ○ X ○
❑	Set targets to achieve a gender balance in the workforce	○ ○ ○ ○ ○
❑	Organise conferences and workshops on gender	○ ○ ○ ○ ○
X	Actions to improve work-life balance	○ ○ ○ X ○
○	Other:	

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

X No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

X Yes- please specify: Summer schools, hands-on software demonstrations

○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

X No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

○ Main discipline[10]:

○ Associated discipline[10]: ○ Associated discipline[10]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	○ X	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No

	○ Yes- in determining what research should be performed ○ Yes - in implementing the research ○ Yes, in communicating /disseminating / using the results of the project		
11c	**In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?**	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

[10] Insert number from list below (Frascati Manual).

13c If Yes, at which level? ○ Local / regional levels ○ National level ○ European level ○ International level	
H Use and dissemination	
14. How many Articles were published/accepted for publication in peer-reviewed journals?	**16**
To how many of these is open access[11] provided?	**7**
How many of these are published in open access journals?	
How many of these are published in open repositories?	
To how many of these is open access not provided?	**9**
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available X no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[12]: ……………	
15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**0**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**

17. How many spin-off companies were created / are planned as a direct result of the project?	**0**
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

X	Increase in employment, or	X	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

[11] Open Access is defined as free of charge access for anyone via Internet.

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	X

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes X No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes X No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

X	Press Release	X	Coverage in specialist press
❑	Media briefing	X	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
X	Brochures /posters / flyers	X	Website for the general public / internet
❑	DVD /Film /Multimedia	❑	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	X	English
❑	Other language(s)		

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

[12] For instance: classification for security project.

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]