SUPPLEMENTAL POWER GENERATION

Energy Efficiency

EUDP 2013-I

Project identification 64014-0135

Ser energy® The Power of Simplicity

eUDP Energiteknologisk udvikling og demonstration

AALBORG UNIVERSITY

Abbreviations and acronyms

- MEA — Membrane Electrode Assembly
- CO — Carbon Monoxide
- Pt — Platinum
- PBI — Poly Benz Imidazole
- HT PEM — High Temperature Polymer Electrolyte Membrane
- RMFC — Reformed Methanol Fuel Cell
- BOP — Balance of Plant
- TRL — Technology Readiness Level
- RMFC — Reformed Methanol Fuel Cell
- LPG — Liquefied Petroleum Gas
- LT PEM — Low Temperature Polymer Electrolyte Membrane
- SOFC — Solid Oxide Fuel Cell
- USD — United States Dollar
- DC — Direct Current
- CAPEX — Capital Expenditure
- OPEX — Operational Expenditure
- TCO — Total Cost of Ownership
- kW — Kilo Watt
- kWh — Kilo Watt Hour
- APU — Auxiliary Power Unit
- OEM — Original Equipment Manufacturer

Content

1.1. Project details

Project title	Supplemental Power Generation
Project identification (program abbrev. and file)	2013-I, Project ID 64014-0135
Name of the Program which has funded the project	EUDP
Project managing company/institution (name and address)	Serenergy A/S Lyngvej 8 DK 9000-Aalborg Denmark
Project partners	Serenergy A/S AAU – Aalborg University
CVR (central business register)	DK29616647
Date for submission	31-05-2017

1.2. Short description of project objective and results

In English

The Introduction of a new supplemental power generation product based on fuel cells and methanol. The current diesel generators set will be replaced in telecommunications application in regions with poor or no grid connection. The solution will reduce CO2 emissions and optimize the total operations economy with a higher efficiency and cheaper fuel.

In Danish

Med en Introduktion af en strøm generator produkt baseret på brændselsceller og methanol søges det at erstatte Diesel generatorer til telekommunikations marked i regioner med ingen eller ringe strømforsyning. Løsningen vil reducere CO2 udledning samt effektivisere total økonomien med bedre konverterings effektivitet og billigere brændstof

1.3. Executive summary

English

With the introduction of a supplemental power generation product Serenergy will leverage on years of technological development towards significant and scalable commercial success.

Currently several major operators are requesting specific products specs and trials of a Methanol fuel RMFC product to replace Diesel generators powering telecommunication equipment.

The HT PEM based RMFC product has clear advantages over diesel generators and other methanol based fuel cell technology in terms of electrical efficiency, temperature compliance and ease of implementation/installation.

The supplemental power generation product will give following benefits:

- Low fuel costs
- Low fuel consumption
- No preventive maintenance
- Significantly lower CO2 emission
- No emission of health damaging particles
- Compliance with legislation
- Low noise
- Ability to be completely integrated with current solution

The CO2 emission of a diesel generator will be reduced comparatively by up to 70% using the RMFC solution in a hybrid configuration. In addition to this no particle or sound emissions will be directed to the surrounding installation area.

With low volume pricing, the RMFC solution will have a lower lifecycle cost compared to diesel generators this will enable a good portion of the market including regulatory demands set forward in e.g. India for green decentralized power provision.

The Supplemental Power generation product will be commercially launched in 2017 after a development and trial period to several regions where grid power is not present or unstable.

The project will entail close collaboration in the development and trial phase with end customers and operators currently engaged in a dialogue for the feasibility of the final commercial product.

Danish

Med Introduktionen af et Supplerende Strøm Generator produkt vil Serenergy bruge flere års teknologisk udvikling til at skabe en skalerbar kommerciel Susses.

En række større operatører efterspørger specifikke produkt specifikation og felt test af en Methanol brændselscelle løsning til at erstatte diesel generatorer der forsyner telekommunikationsudstyr.

Et HT PEM baserede brændselscelle produkt har klare fordele over en diesel generator og andre Methanol baserede brændselscelle løsninger i for af elektrisk effektivitet, temperatur grænser og implementerings venlighed.

En Supplerende Strøm Generator produkt vil give følgende fordele:

- Lave brændstofs omkostninger
- Lavt brændstofs forbrug
- Lave vedligeholds omkostninger
- Signifikant reduceret CO2 emission
- Ingen emission af partikler
- Opfyldelse af lovgivning.
- Lav støj
- Evnen til at blive integreret direkte i Telecom løsninger

CO2 emission fra en diesel generator vil blive reduceret med op til 70% sammenligneligt ved at anvende et RMFC produkt i en hybrid konfiguration. Yderligere vil der ikke blive udledt partikler i de ofte bymæssige omgivelser.

Ved lav volumen pris vil RMFC produktet have en lavere livscyklus omkostning sammenlignet med diesel generatorer, dette vil sikre en god markeds penetration inklusiv regulative krav stillet i f.eks. Indien for grøn decentral strøm produktion.

Den Supplerende Strøm Generator vill blive lanceret kommercielt I 2017 efter en udviklings og felt testperiode i flere forskellige regioner hvor der er ustabil eller ingen fast strømforbindelse.

Projektet vil omfatte tæt samarbejde i udvikling og flet test fasen med slutbrugere og operatører der for nuværende er i dialog omkring bæredygtigheden af det endelige kommercielle produkt.

1.4. Project objectives

PROJECT OVERVIEW

The project was initiated in September 2014 with an expected duration of 30 months, pointing out the final completion of the project in March 2017. Small progress delays occurred mainly due to the specificities of the R&D, in particular, some much needed calculations to support the results and validate the data. None of these constraints affected the development of the project, just requiring additional meetings to keep track over progress and adjust the timetables to keep the overall project on track. The project consortium consisted of Serenergy A/S and Aalborg University (AAU).

The four (4) project milestones are listed in individual charts, with the information relating to Lead, timeframe, description of the objectives/goals and deliverables. This same framework was applied to the commercial milestones (2), since the technology development has multiple market applications.

The technical component of the project was divided in twelve (12) specific Work Packages (WP), having the respective leaders/organisations compiled the sections on each individual WP according with the project structure.

Contributions to the project:

Serenergy A/S

SerEnergy will contribute with the development, test and production of the fuel cell product and the process of field trials directly with the operators/infrastructure providers.

AAU

Aalborg University, Department of Energy Technology has an inter-disciplinary fuel cell system research program with 5 faculty members, 2 postdocs and 6 PhD students. The program is centered on fundamental and applied research in fuel cell components, subsystems and complete systems and involves experimental as well as modeling activities. Aalborg University will contribute with know-how in fuel cell system modeling and control as well as assist the development of the fuel cell stack and the reformer. AAU will additionally contribute with test and validation, in order to support the internal Serenergy test activities with focus on climatic and third-party validation.

Operators and infrastructure providers

The end customers or trial participants are not an integrated part of the project but will act as the unbiased customer. At the present stage, three has been selected among several for direct trials.

Main objective

In terms of the Supplemental power generation product, it is building on a HT PEM RMFC platform where the core components are developed though a number of years with technology development projects.

Objective

The main objectives of the project are as follows:

- Developing a Supplemental power generation product to replace diesel generator sets in regions with poor or no grid power.
- Trial with minimum 3 operators or infrastructure providers
- Trial minimum 10 units with the before mentioned customers
- Trial systems in varying configurations, operations patters and environments.
- Conduction studies and optimization of dynamic operation as well as general longevity studies.
- Formulating and executing commercial compliance with operators/infrastructure providers.
- Publishing results and findings in close cooperation with integrators and end-users.

Prospects

The focus is supplemental power over backup power. This means the focus is on Kwh price more than kW price although this always has an impact on TCO.

The platform will replace combustion engine generators and large battery packs as a maintenance free and highly reliable solution. Fuel distribution costs and storage density enables a low operational cost and a small footprint saving siting and rental fees for the operator.

This project will also lay the ground foundations for further commercial applications for the technology in relevant areas such as E-mobility and combine other ongoing initiatives such as Green Methanol Initiative, into a unified platform with a clear commercial purpose.

Milestones

M1 - Product specification
M2 - Product development complete
M3 - Internal product validation
M4 - Trial Completed

Commercial milestones

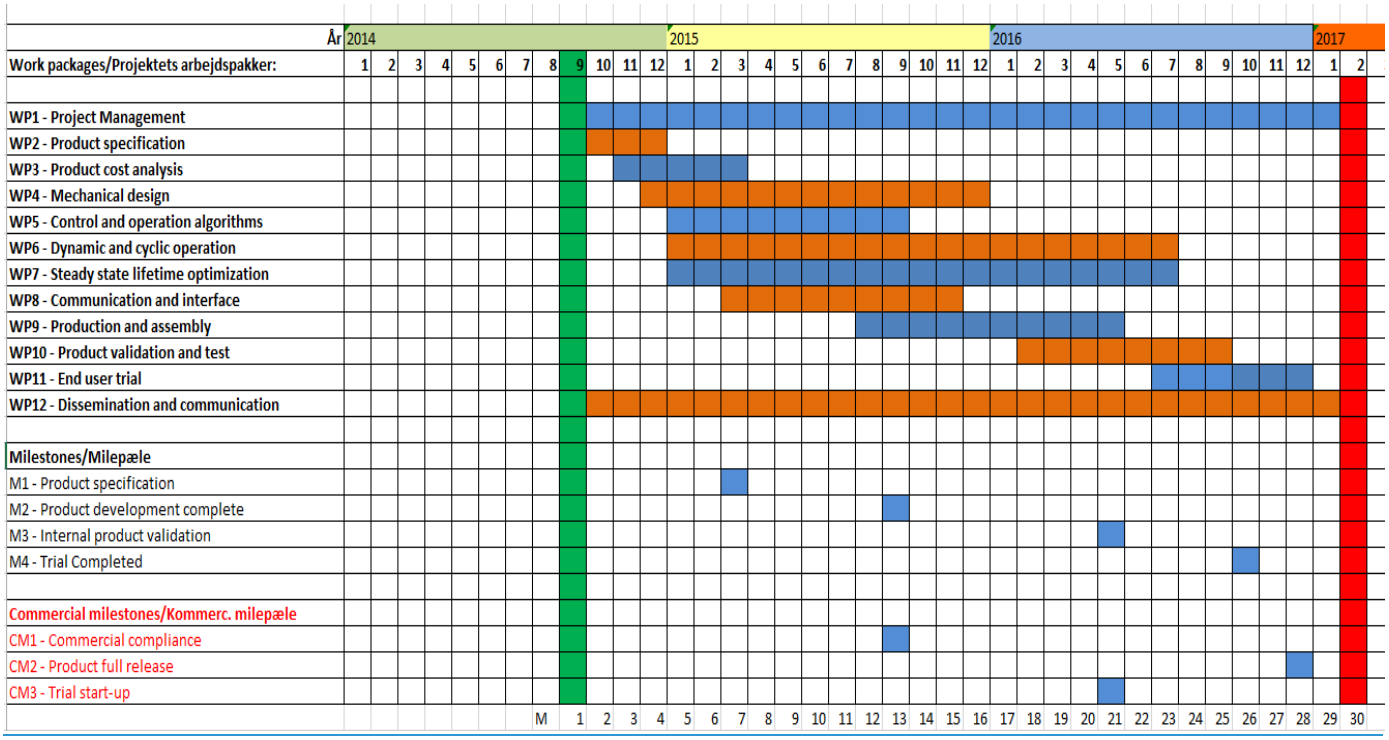
CM1 - Commercial compliance
CM2 - Product full release

Work packages

WP1 - Project Management
WP2 - Product specification
WP3 - Product cost analysis
WP4 - Mechanical design
WP5 - Control and operation algorithms
WP6 - Dynamic and cyclic operation

WP7 - Steady state lifetime optimization
WP8 - Communication and interface
WP9 - Production and assembly
WP10 - Product validation and test
WP11 - End user trial
WP12 - Dissemination and communication

Gantt Timeplan



1.5. Project results and dissemination of results

Project results

Milestones

Milestone 1 – Design Specification	
Lead: SERENERGY	
Timing	M7
Description	The milestone represents the finalization of the complete design and specification of a dedicated product for telco solutions primarily focused on supplemental power generation for off or low availability grid. The milestone also included a CAD mockup and introduction to the concept that enables a full insight into the coming final product offering. This is to be used in external validation and marketing.
Link	WP2 – WP3 – WP4
Deliverables	• Design specification • Specification sheet • Technical design guide

The completion of this Milestone delivers the standard specifications for Design, Technical Design guide of the final product and a Specification sheet, marketable for different Telco clients as a final product on the form of brochure, flyer, newsletter, among others.

Outdoor cabinet: The Outdoor cabinet offers a complete power supply solution incorporation the H3-series of Reformed Methanol Fuel Cell systems and auxiliaries such as; Fuel tank, battery pack, power distribution and wireless communication for remote monitoring. The cabinet can be packed to reduce shipping size and simplify the installation process. Methanol hybrid systems.

The Reformed Methanol Fuel Cell system works in parallel with an onsite external battery pack existing on site or installed with the system. The embedded charge controller enables regulated DC power for all applications and battery types.

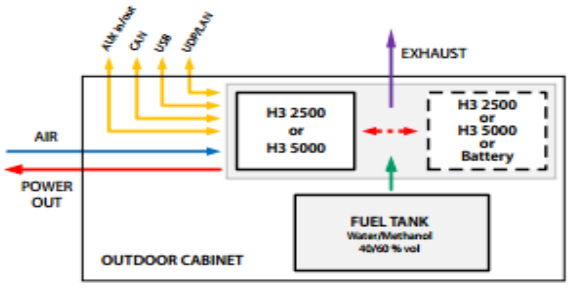
The RMFC features catalytic startup enabling fast startup and minimum power consumption in standby and during the startup process.

Methanol fueled. High temperature PEM with an integrated methanol reformer for onsite hydrogen generation enables high power density and high fuel energy density. The fuel is a methanol mix fuel readily available through several global suppliers. The integration of fuel cell and reformer enables a highly energy efficient system due to reuse of fuel cell waste heat for the reformation process.

Multiple applications. The Methanol power system has multiple applications both off- or on-grid including application in critical backup power, temporary power or continuous power.

Performance characteristics

Parameter	Config 1	Config 2	Config 3	Config 4	Config 5	Config 6	Config 7
Modules	H3 2500 Battery pack	H3 5000 Battery pack	H3 2500	H3 5000	H3 2500 H3 5000	H3 2500 H3 2500	H3 5000 H3 5000
Power output, electrical [kW]	2,5	5	2,5	5	7,5	5	10
Runtime (100% load)	4 days	2 days	4 days	2 days	1,5 days	2 days	1 days



System diagram

Milestone 2 – Product development complete	
Lead: SERENERGY	
Timing	M13
Description	The milestone marks the completion basic product development process of the telco product. Work will continue however as optimization and bug fixing towards a full release product. Based on this milestone internal product validation and certification can be initialized
Link	WP4 – WP5
Deliverables	• Product documentation • Prototype • Beta manual

The completion of Milestone 2 marks the completion of basic product development process of the Supplemental Power Generation, telco product.

The telco product, the H3 Outdoor Cabinet offers a complete power supply solution incorporating the H3-series of Reformed Methanol Fuel Cell systems and auxiliaries such as; Fuel tank, battery pack, power distribution and wireless communication for remote monitoring.

The project proceeded according to plan. Through testing of the Outdoor Cabinet in field trial with several telco operators in South Africa and India we have reached the second milestone and the product development is complete. Testing has resulted in a development of the product, which has undergone three phases to reach the point of completion, thus complying with the feedback from the telco operators.

Development of the cabinet

The Three Phases

Phase I: Testing of the H3 5000 Outdoor Cabinet in controlled premises at Serenergy. We have recently reached 3000 hours of runtime on the module. We however continue to work to optimize and bug fix the product towards a full release.

Phase II: Mark I: The Mark I has been through testing with several telco operators in South Africa, India, Indonesia and the Philippines. After having retrieved data from the sites, we have been able to develop the H3 Outdoor Cabinet.

Phase III: Mark I, V2: The Mark I V2 is the latest edition, building on the data retrieved from the testing of the Cabinet in phase II. Currently we have a field trial of Mark I V2 in China.

Development of the cabinet

Phase I:

H3 Outdoor Cabinet I, Testing

Phase II:

H3 Outdoor Cabinet, Mark I

Phase III:

H3 Outdoor Cabinet, Mark I, V2

Milestone 3 – Internal Product validation	
Lead: AAU	
Timing	M21: 05-2016
Description	The milestone accounts for the completion of the product validation based on internal testing and external certification of basic product safety. The product validation will correlate results from test with design spec and specific customer requirements.
Link	WP6 – WP7 – WP8
Deliverables	• Test report • Technical dossier

See WP6, WP7 and WP 8 for full description of the results. The relevant technical documentation was compiled in a technical dossier for use by the field technicians and Commercial Department

Milestone 4 – Trial completed	
Lead: SERENERGY	
Timing	M26
Description	The milestone marks the Completion of the external trials with Supplemental power generators in the field with operators or infrastructure providers. Trials will be executed with 3 operators with up to 3 units per operator running in various configurations and operations patterns.
Link	WP9 – WP10 – WP11
Deliverables	• Trial with 3 operators with up to 10 units • Field reports – data analysis

The field trials scope was wide and had a global range to test, develop and prove the technology on the field and, through Data analysis, identify and improve key components towards reliability and overall efficiency, to ensure that the final commercial application of the technology will present high levels of operation, regardless of the deployment environment.

Partnerships were made with:

- OEM of Telecom equipment, to try joint systems integration on the field and better understand next to them, the full potential and future applications of the technology in other projects.
- Telecom companies to deploy the equipment and run the tests, proof of reliability and overall stability of the system as a whole.

Trials:

- In the Philippines, 3 sites are running 5kw FC generators. Another site has 2 modules of 5kw each running simultaneously (10Kw total supplied power).
- In Norway, a 2,5kw FC generator running off-grid and on high altitude was deployed, to access the reliability of the system in mountain conditions.
- In India, a 2,5 kw off-grid site, running in combination with solar panels and batteries to test a 24/7 solution, extending the needed refueling process. A second site with 5kW module was added on another location.
- In South Africa, a 2 x 5kw FC testing site in altitude has been deployed.
- In China, there is currently deployed a 2,5kW and 5kW FC site in a special cabinet to try new potential configurations and electronic components.
- In Finland, the site has a 5kw FC module running under permanent negative temperatures.

The current deployed units have hardware and software updates that have uniformized the operations standards and extended the overall lifetime of the fuel cell. These updates now allow a greater predictability on the models offered to the customers, for performance and reliability of operations.

1.5.1. Commercial Milestones

Milestone 1 – Commercial compliance	
Lead: SERENERGY	
Timing	M13
Description	The milestone marks the completion of a deeper commercial compliance with the individual operators. The commercial milestone will include deeper negotiations on a commercial level including warranty and performance metrics related to the trial.
Link	WP2 – WP3- WP11
Object	• Commercial compliance sheet on each operator • Business case/proposition per operator

Milestone 2 – Full product release	
Lead: SERENERGY	
Timing	M29
Description	The milestone marks the completion of the entire process and the starting point to a full commercial ramp up. The commercial milestone will mark the product launch and activities that will lead to a scalable business platform based on successful trials.
Link	WP11
Object	• Product launch • Marketing events • Dissemination of limited trial results

Milestone 3 – Trial start-up	
Lead: SERENERGY	
Timing	M21
Description	The milestone marks the start of the trial activities at the trial partners. The milestone is met when equipment/solutions are on the ground, connected and commissioned. Furthermore, the data retrieval system is up and running insuring good data to internal project participants. The Milestone is met when initial trials are started up with additional trials are planned.
Link	WP11
Object	• Trial Contracting • Solution commissioning • Data recovery start-up

1.5.2. Work packages

WP1 – Project Management	
Lead: SERENERGY	
Start **End**	M1 M30
Description	Project management including coordination of steering committee meetings and summaries and the half yearly reporting to ENS the technical project management and administration. Furthermore, the project management section entails running coordination of all deliverables and cooperation.
Link	All WP
Objects	• Quarterly statements • Progress report • Final report

All quarterly reports were send to the project partners within the given timeframe. The Gantt Schedule was followed with more or less accuracy given some time and research constrains related with the complexity of some tasks and the improvements introduced while carrying over work.

This report is the final public version of the report with the major key findings and results obtained at the end of the project.

WP2 - Product specification	
Lead: SERENERGY	
Start **End**	M2 M4
Description	The WP will deliver a full technical specification enabling a design and build of a final product. The WP will outline the product in all relevant metrics such as operation features, specifications in terms of size weight etc.
Link	WP3
Objects	• Product specification • Technical design guide

The main draft for the design and specifications of the system was elaborated with direct input from the key selected partners and attending the specific field trials requirements.

Parallel to this process, the whole regulatory harmonization process for installation of Methanol equipment was started in order to accommodate local, regional/federal and national regulamentation for testing and deployment of equipment for the field trials and future final solution installation of the commercial product.

After several intentations and external reviews, a flexible solution was developed to install a range of HT PEM from 2,5kw up to 10kw with an internal 200 lts methanol tank, with the possibility of installing an additional external tank to address multiple requirements and needs from different clients.

WP3 - Product cost analysis	
Lead: SERENERGY	
Start **End**	M3 M6
Description	The WP accounts for an in-depth analysis of the final product costs from cradle to grave to be used in calculating the lifecycle cost per kWh at the customer site. Service and maintenance perspectives as well as the core product will be in focus.
Link	WP2 – WP4
Objects	• Economic analysis • Bill of Materials BOM

A cost analysis performance was conducted for the cabinet, as initially produced by an external supplier which compasses the total end cost of the "kits". Additionally, the same analysis was performed over the electrical internal installation in the solution with fuses, cooling and external communication equipment. At the present, the standardization of all internal electrical installation and communications will add value to the overall product due to simplification of installation and deployment, reduced supply chain management and substantial economies of scale over deployment of units. From the Telco perspective, this will reduce the associated learning curb over product deployment and use and partial staff salaries reduction. Other cost reduction initiatives can encompass the local manufacturing of the cabinet, reducing partially the freight costs.

WP4 - Mechanical design	
Lead: SERENERGY	
Start **End**	M4 M13
Description	The WP entails the conception of the full mechanical hardware side of the product from core components to external packaging. The WP will include several prototype stages and tests of design with focus on functionality, cost and scalability in terms of assembly.
Link	WP2 – WP3
Objects	• Hardware design • Specialty component design • Prototype unit • External packaging of module

Having the Design guide as a starting point, three prototype designs were built to access the optimal systems integration and operation for the H3 series outdoor cabinet.
The Design process was conducted in cooperation with several local cabinet manufacturers, being those also responsible for the production of the cabinet.
For the system assembly and fitting, a special emphasis was devoted to a number of key components in order to simplify the overall layout and servicing of the system, as well as improve the ergonomics. The key components are:

- air filter
- chemical air filter
- fuel filter
- universal wireless solution

WP5 - Control and operation algorithms	
Lead: SERENERGY	
Start **End**	M5 M13
Description	The WP is covering the full development of a software and control package to operate the fuel cell system on an embedded control platform. Furthermore, the WP will cover safety aspects in case of malfunctions or failures. The WP will contain and integrated bug solving process before SW release.
Link	WP6 – WP7
Objects	• Control and SW package • Embedded control platform (printed circuit board)

As a result of the analysis of the data gathered over the field trials with the selected partners, the fuel cell embedded control platform has been updated with a number of key features that were considered relevant for the test cases.
These features include an HTML 5 based interface that can be executed directly in any web browser over multi platforms, from operations systems, to PC's or tablets without the need of use additional software.
The printed circuit board (PCB) received a special attention towards ruggedization in order to increase the performance under extreme environments such as high temperatures, improving the stability and reliability of the system.

WP6 – Dynamic and cyclic operation	
Lead: AAU	
Start **End**	M5 M23
Description	The WP will test and optimize the product with focus on dynamic operation and start/stop of the module to minimize startup time, energy used in the startup process and to minimize degradation during the process.
Link	WP5 – WP7
Objects	• System analysis • System Simulation • Test report

The system tested in this work package consisted of an Outdoor Cabinet (Figure 1) with a H3 5000 Methanol reformer system rated at 5kW electric output power. The cabinet consists of a fuel tank, filter, cabinet electronics, fuel cell system and battery.

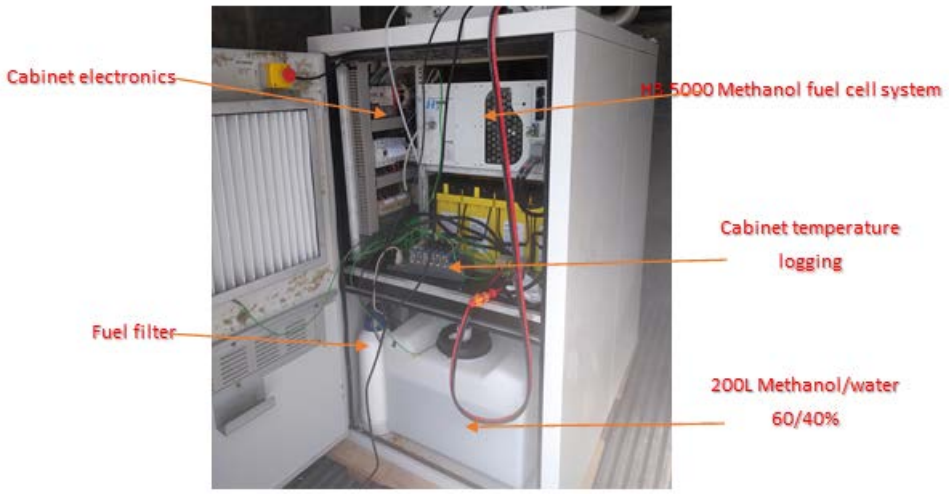


Figure 1 - Methanol system in cabinet

The cabinet was installed with heating elements to keep the cabinet at a minimum temperature and these was disabled before testing. Figure 2 show the cooling container used to test the fuel cell system. The cooling container can cool the system to -30 oC.

Figure 2 - Cooling container

To test the startup time for the system to reach a limited operation a series of experiments was performed. Before the start of the system the temperature of several components in the system and cabinet was observed to ensure the system is cooled to the specific setpoint temperature. This would normally a minimum of about 1 day before the temperature in the system had reached ambient. A series of temperature startup tests was performed and can be seen in Figure 3. These tests indicated that at -10 degrees it was difficult to get the oil pump to start because of the viscosity of the cooling oil. If enough time passed the adjacent components would heat up the oil enough for the pump to run, however, it would take significantly more time to start.

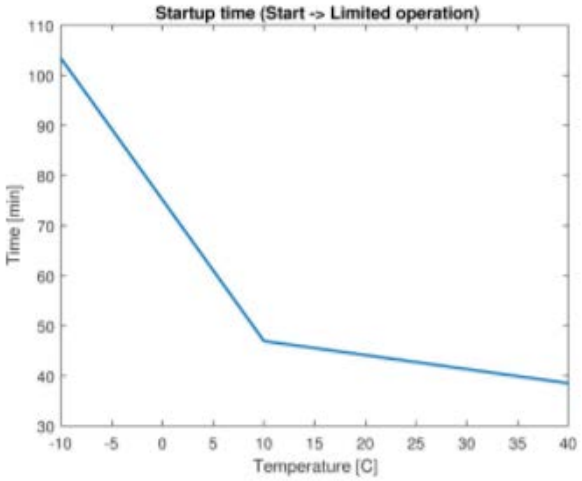


Figure 3 - Startup time vs ambient temperature

At this low temperature, the timeout for the system to reach a certain temperature would be enabled and the system would go into shutdown. The system was put into the same startup procedure immediately after and continue the startup procedure.

It was concluded that the viscosity of the oil is the critical part to get the system operational and a startup strategy was performed as can be seen in Figure 4 (below).

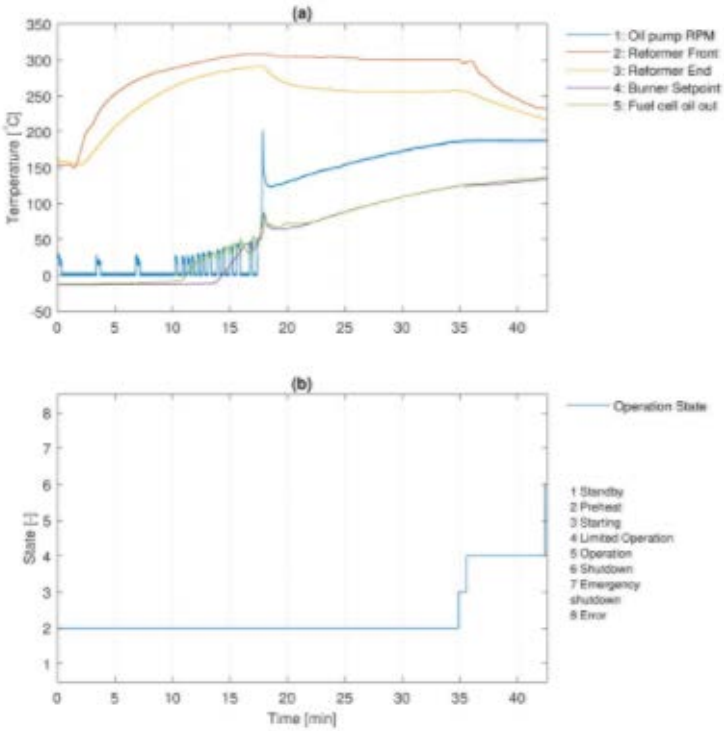


Figure 4 – Oil viscosity (a) & Statup time (b)

WP7 – Steady state lifetime optimization	
Lead: AAU	
Start **End**	M5 M23
Description	The WP will test and optimize the product with focus on steady state operation for extended lifetime. The main goal is to ensure lifetime targets in boundary conditions such as elevated ambient temperatures and high load operation.
Link	WP5 – WP6
Objects	• Test specification/matrix • Climate test • Test report

To optimize the system regarding lifetime optimization the system was tested at elevated temperatures in an isolated 20-foot container (white container in Figure 5). The container was fitted with several electric heaters and it was possible to reach stable temperatures up to about 60oC. Furthermore, it was possible to increase the relative humidity of the container up to 70-80%. The container was used to test the reformer system for several days without any significant issues, however, a focus was changed to the electronics as these were the critical part in high temperature operation. 4 additional systems were tested outside to test lifetime at ambient temperatures. The tests were divided up into 2 types of tests which are durability and start-stop. Continuous tests were done at a constant current for several days. The start-stop tests were done with up to 5-6 start and stops for each day and another type of degradation was detected compared to the constant current test. The target for these tests were 5000 hours continuous operation and 500 start-stops.

Figure 5 - Test facility for high temperature test.

The unit was also tested in a sub-zero condition in a cooling container, however, any further degradation was not detected after the system was started. Additional tests were made where the system was cooled

to -15oC, without running, for up to a week to test if the cold would affect the startup procedure. The results of these tests showed that there was no significant difference in startup procedures.

WP8 - Communication and interface	
Lead: SERENERGY	
Start **End**	M7 M15
Description	The WP covers the external integration of the modules in Solutions e.g. cabinets and/or shelters with special focus on remote communication and internal communication protocols enabling simple integration into overall telco control systems.
Link	WP2
Objects	• External Communication protocol • Integrators manual • Graphical User Interface (GUI)

The Graphical Use Interface (GUI) was one of the key focal points of this work package. It comprehends a multi-level, customizable graphical interface on which, each customer can make minor configurations "on-site" to get information over several parameters like performance, condition, runtime, load demand and other relevant outputs.
An additional external sensor input can also be connected to extend power measurement for a battery bank and external tank sensor.
This added functionality will add a multitude of options, configurations and functionalities that will increase the specter of usage by individual customers since the flexibility factor is already in-build, adding value to the overall proposition.
An SNMP external communication interface was also designed. This will provide a wide range of Telcos to run a unifying protocol that enables them to control and monitor simultaneously numerous equipment's across the whole network.

WP9 - Production and assembly	
Lead: SERENERGY	
Start **End**	M12 M21
Description	The WP will ensure full documentation related to production and homologation with ERP system in Serenergy including Bill of materials and spare parts list etc. The WP will also cover the initial build of the first batch(s) of fuel cell units for the trial
Link	WP4 – WP10
Objects	• Product documentation and Assembly manuals • ERP homologation • Build of min. 10 fuel cell units

The selected ERP system to be used and integrated on Serenergy daily operations, was used to detail and develop the product documentation and assembly Manuals for workers, in the first stage, and integrators for global deployment of units.

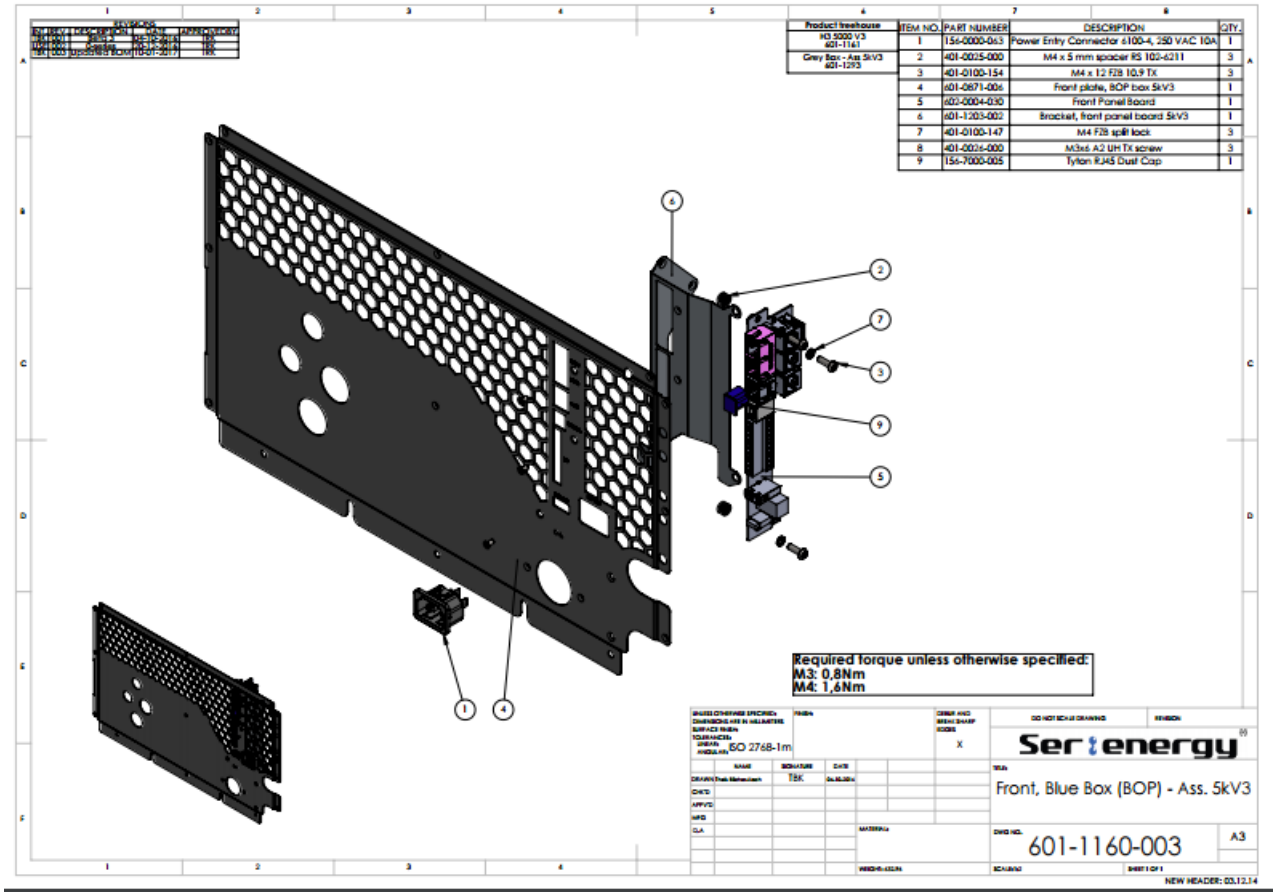


Fig. 6 – technical document for Blue Box assembly and components integration for ERP system

Once all parts were introduced into the ERP system and all agreements with the relevant suppliers were reached, the first 10 units were commissioned to review the whole integration process according with ISO 9001:2015 requirements. All adjustments were done after the first batch manufacturing and it is now a standard practice on the company, including routing of tasks directly to management, operators and commercial team to comply with the different timings and projects on course, including Non-conformities and corrective measures, Stock Status and hardware/firmware updates for all units.

WP10 - Product validation and test	
Lead: AAU	
Start **End**	M18 M24
Description	The WP covers final product validation and testing of the module including certification and internal homologation to specific telco needs both general and from individual operators. All test metrics to be tested and validated that can be handled in house before a trial is done to ensure as smooth an external process as possible.
Link	WP2 – WP4 – WP11
Objects	• Product test/validation • Test report • Certification

To verify the system validation and system components a series of tests are performed before and after assembly.

The system used in this application is under the ROHS and EMC directive, however, does not qualify for the low voltage directive as the system operates under 75V.

A critical part of the system is the fuel cell which will go through a series of tests. The fuel cell stack is pressure tested, after it is assembled, in both the cooling, cathode and anode channel. After pressure test the fuel cell is tested on both pure hydrogen and a reformate gas mix.

The test is performed in accordance to the IEC62282-2 standard for fuel cells. All cells in the stack is monitored during this test and if a cell voltage reaches a limit below a certain threshold (350mV) the cell is replaced and is tested again. An image of the stack test station from Serenergy can be seen in Figure 7. Fuel cell stack Control System Electronic Load Leak detector

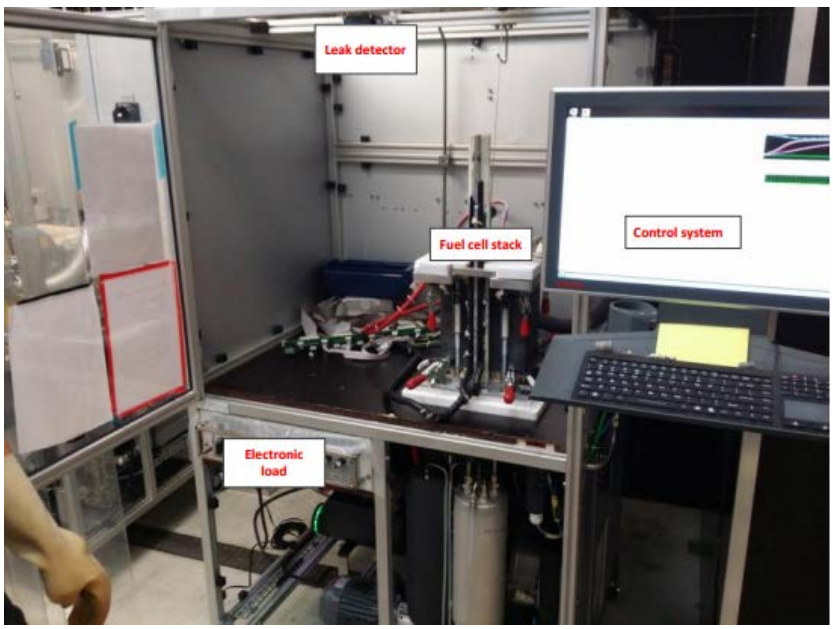


Figure 7 - Serenergy HT-PEM Fuel cell stack test station

During the initial start-up of the system a series of restarts was performed and the resulting temperature in the cabinet can be observed from Figure 8.

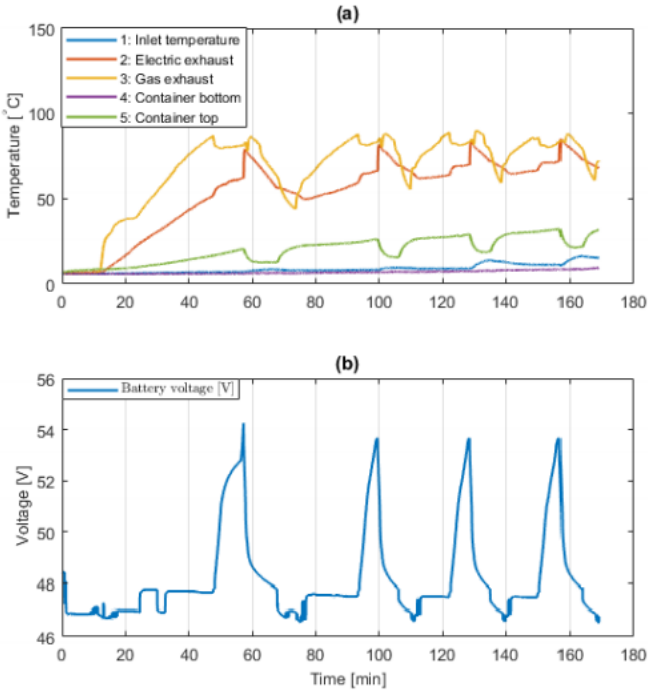


Figure 8 – Unit temperature and battery voltage

WP11 - End user trial	
Lead: SERENERGY	
Start **End**	M23 M28
Description	The WP will cover the field trials with several telco operators including the actual operation and integration process of the fuel cell unit into a site and infrastructure including service/refueling and communication.
Link	WP9 – WP10
Objects	• Trial with min. 3 operators • Trial of min. 10 units (varying operation patterns/configurations and size) • Data analysis

The field trials scope was wide and had a global range to test, develop and prove the technology on the field and, through Data analysis, identify and improve key components towards reliability and overall efficiency, to ensure that the final commercial application of the technology will present high levels of operation, regardless of the deployment environment.

COUNTRY	HT PEM MODULES (KW)	UNITS	WEATHER/LOCATION	RUNNING MODE
Philippines	5	5	Tropical - Hot	PRIME POWER
India	2.5 + 5		Sub-Tropical & Altitude - Cold	PRIME POWER + BACKUP
China	2.5 + 5	2	Altitude - Cold	PRIME POWER + BACKUP
Finland	5	1	Very Cold	PRIME POWER
Norway	2.5	1	Altitude - Cold	PRIME POWER
South Africa	5	2	Altitude - Hot	PRIME POWER + BACKUP

Prime power applications run in a setup 24/7/365(6), providing power to the telecom towers in off-grid locations. Different sites, different loads running over the HT-PEM generators, to access multiple parameters and prove reliability and scalability of both equipment and generators setup to match the demand of clients.

Backup power configurations on the field vary according to client and Serenergy request to access different parameters, namely, start-stop operation and number of supported cycles, peak power generated, total system integration and testing of different fuel tanks and configurations to improve OPEX due to off-grid location.

- Configuration 1 - System setup with Solar Photovoltaic panels and batteries. HT-PEM provides backup for the batteries if needed, working overnight in summer time and between 6 to 10 hrs. in the winter to compensate the lack of sun.
- Configuration 2 - System setup to provide both backup or prime power in areas where, although the system is connected to the grid, the latter one is highly unreliable and dependent of weather factors and quality of the connection itself.

Stationary tests results:

- hot/cold environment start-up & components performance – test conducted in cold environment in Denmark. Hot testing in KIWA, Netherlands at 50C and 95% humidity for preliminary benchmarking, to compare with future tests and data gathered from the current field tests.
- Refueling operation – the pre-mixed fuel is 60% methanol + 40% de-ionized water (V/V). 200 liters' tank as a standard. No major issues to report over the process, although some occurred due to contamination of the fuel during transportation (residues on the transport tanks) that distorted

some results. Action measures were taken in collaboration with the suppliers to eliminate this issue in the future.

- Components integration – test of all components in hot and cold environment. Some improvements were performed over the electronics to optimize their stability and performance on both conditions.
- Total off-grid operation – the system proves to be reliable and due to the high output of the system (5Kw), additional Telco equipment instalment didn't affect the performance of the fuel cell.
- Integration with batteries power banks – initial issues due to different batteries models used by different operators. During pre-start of the module, some high in-rush current occurred, but quickly solved with some setup configurations.
- Transport & Integration issues – Some transport companies consider the fuel cell as a "dangerous good", although others just require some preliminary safety procedures. Substantial efforts have been dedicated to solve this matter to streamline shipping of fuel cells in the near future when mass production starts. Serenergy staff was dispatched on the initial field trials to provide guidance and training to the field operations telco customers, including issue tracking and components replacement (cables, connectors, etc.) on site.

Figure 9 – Philippines field test site

- On-site safety homologation testing – depending on location and local/regional/national fire regulations concerning noise & vibrations, methanol spill and potential effects. Local partners collaborate to expedite the process before the installation of the module.

The data analysis conducted during the tests, allowed to pinpoint some components inconsistencies, as well as some start-stop differences in timing due to the multitude of climates and latitudes, loads of equipment and required up-running time.

The current deployed units have hardware and software updates that have uniformized the operations standards and extended the overall lifetime of the fuel cell. These updates now allow a greater predictability on the models offered to the customers, for performance and reliability of operations.

The data gathered across all mentioned sites has been invaluable to the current R&D efforts. The disparities between environments and configurations, presented on itself a considerable number of challenges. From the Philippines and Norway, Serenergy has already received commercial orders for sale and deployment of the HT PEM in the near future.

WP12 - Dissemination and communication	
Lead: SERENERGY	
Start **End**	M1 M30
Description	As a part of the project statement, dissemination and external communication process is needed to ensure good interaction with stakeholders. Furthermore, this is a platform to account of the progress and the benefits of the EUDP program.
Link	All WP
Objects	• Seminar on project • Organizing 1-2 press conferences /seminars/stakeholder events • Organizing events for potential users

The results will be disseminated at international conferences, symposiums and expositions such as e.g. Fuel cell seminar & Exhibition (USA) and Hannover Messe (DE):

- http://www.h2fc-fair.com/hm17/exhibitors/serenergy.html
- The link above contains as well the videos regarding both Public and Technical Forums on which the whole Serenergy approach and strategy was outlined and the technology was showcased, encompassing the three key areas of operation: Stationary, Mobility and Maritime.

Conference "Green Mobility: The Future of Transportation in Denmark and in the EU", promoted and organized by the Nordic Folkcenter for Renewable Energy (Hurup Thy, DK). Nordic Folkcenter is an NGO which, since 1983, is active in the promotion of the renewable energy technologies on a national and international scale. It was held in Nordic Folkcenter in the period 28-30 April 2017. The event is meant to be of international relevance, with speakers coming from different countries, with focus on a different technology every day: Biofuels (28 April), **Hydrogen and Fuel cells (29**) and Electric and Hybrids (30).

Serenergy was invited as a keynote speaker on the 29th, and Mikkel Præstholm Ehmsen was the representative of the company in the event.

Fig. 10 - Conference "Green Mobility: The Future of Transportation in Denmark and in the EU"

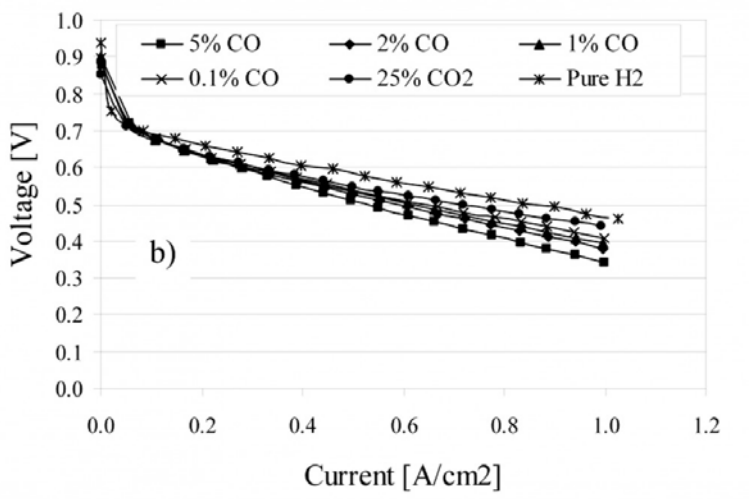
Similar activities were developed by AAU-E on which it promoted and raised awareness internally, next to the students and fellow universities.

The purpose is to attract more students and researchers to this field and create a sustainable academic environment to further develop and conduct research to establish AAU as a leading University in the Fuel Cell domain in Europe.

HT PEM Technology

The HTPEM (High Temperature Polymer Electrolyte Membrane) fuel cell system developed by Serenergy operates at 150-180 degrees C. This gives some key benefits and advantages over other types of fuel cell systems. Mainly CO tolerance (High fuel flexibility), ease of cooling and no need for humidification.

HTPEM fuel cells are highly tolerant to CO. CO is a known fuel cell poison and is a result of using reformed liquid fuels. The high CO content in gases from fuel reformers most often necessitates fuel clean up, which in turn then gives larger more complex and more costly systems.



Due to the elevated operation temperature of the HTPEM fuel cell, hydrogen with a higher CO concentration can be used without the same negative impact on performance, and without the same need for gas cleanup. This makes it possible to use hydrogen reformate originating from cheap, and easy to handle energy-carriers such as methanol, ethanol, diesel etc.

The HTPEM fuel cell can tolerate up to 3% (30,000ppm) CO and up to 20ppm of Sulphur without permanent degradation. In comparison, LTPEM fuel cell normally can tolerate less than 30ppm CO and less than 1 ppm of Sulphur. This is a factor of 1,000 difference in CO tolerance. Because of the high operating temperature, a PrOx reactor after the reformer is normally not necessary. PrOx reactors are expensive, bulky and significantly lower the system efficiency. The result is that very simple, lightweight and inexpensive reformers can be used to produce hydrogen from a broad range of energy-carriers including the choices listed above.

As a result of not needing the humidifiers, air compressor and oversized radiator as in the LTPEM systems, the HTPEM system architecture seems very simple. The Serenergy fuel cell system uses less than 4% of fuel cell power output for balance of plant components -making this the system type with one of the lowest parasitic power consumption. Partly due to the low parasitic losses, the fuel cell system reached efficiencies of up to 57%. Most other fuel cell systems have an energy waste of approximately 10-20% of the fuel cell output, just to achieve operational status.

Current development stage

Currently Serenergy is a leading company in the HT PEM development area and an upcoming player in the fuel cell systems market for vehicles and backup power. Serenergy has so far deployed more than 100 RMFC systems in relevant target applications for trials and demonstration at partners or end-users. The systems are almost exclusively small power air cooled systems.

In addition to the System level Serenergy has to date shipped more than 600 Stacks and integration modules for various customers all over the world. Currently Serenergy has a backlog of more than 200 kW of stacks/integration modules and a pipeline of another 200 kW. On system level, the pipeline includes 100 air cooled systems for backup power and vehicle integration.

The core technology is proven to work and perform to core metrics however this is in the low power range with air cooled architecture. The concepts and proof of concept has been verified in both the smaller systems and in previous COBRA I project. In spite of the progress, the maturity is lower than generic LT PEM fuel cell technology.

1.5.3. Development stage of the different sub-systems

MEA

The MEA is currently at a technological stage where it can perform to the targets needed for the target applications in terms of lifetime and performance. The lifetime is 8000h and the unit cells power is up to 0,4W/cm2 at 1,0 A/cm2. However, work is needed to ensure quality and volume production leading to cost reductions. In addition to this a focus on improving the performance metrics is needed to reduce number of cells to produce the same power also a significant contributor to cost reductions.

Through the development of current products Serenergy has created a unique market position with an operational structure that is optimized for developing new solutions, positioning Serenergy in the forefront within the Fuel Cell Technology field.

Dissemination of results

The project progress will be presented at the frequent meetings in "The stationary/ PEM Strategy Group" within the Danish Partnership for Hydrogen and Fuel Cells.

Scientific results from the project will be published in peer review journals and presented at international conferences, alongside with relevant Danish technical magazines, such as Ingeniøren, Electronic Supply and so will Fuel Cell Bulletin, Fuel Cell Today, Electric and Hybrid and Hzwei.

Participation in the Fuel cell seminar & Exhibition (USA), Hannover Messe (DE) and H2 Fair (Japan).

In supplement to the above events will be held targeting the supplemental telco community such as on the Intelec fair and seeking greater cooperation with TowerXchange group and other market key players.

The final Supplemental Power Generation results will be published in a technical report at the end of the project period and delivered to EUDP, advisory board and other relevant stakeholders. The dissemination will be done in close collaboration with the EUDP secretariat.

1.6. Utilization of project results

1.6.1. Market Applications

There are around 5 million telecom installations with a demand below 5 kW worldwide and with a 300.000 base station additions each year corresponding to 2 billion USD for DC backup, the market is substantial.

The current addressable market for fuel cells is 25.000 units per year. The ambition is to have 2-5% of this market in 2018.

The competitive advantage of a methanol system is where the stabile market needs high energy density/runtime onsite with limited space available. In unstable markets, it is where the yearly runtime is higher than 300 hours and fuel/refuel/service cost is a total cost driver.

Benefits:

- Low fuel costs
- Low maintenance
- Improved working environment
- Compliance with legislation
- Low CO^2 emission
- Extended working hours
- Silent operation
- Low fuel consumption
- Low maintenance
- Low heat signature
- Simple heat dissipation

The market potential for Diesel Generator (DG) replacement is enormous and in the double digit billion USD depending on which analyst and which markets are included in the studies.

In the project and in general, the focus is on the Telecommunication market, as the power range is good when in competition with diesel generators. The power range is from 1 to 2,5 kW as this is the load for 3 and 4G telco equipment and a range where the standard 7,5 kW Diesel genset has low efficiency.

The competition is mainly diesel generators which are widely spread and low cost – in addition to this other methanol fuel cell solutions are in competition. Hydrogen based systems are not in the scope for supplemental power due to fuel cost and logistics

Diesel Generators

There are two main competing technologies and that is on the one side long lasting small diesel generators and on the other side batteries for poor/unreliable grids only.

When it comes to diesel generators, the HTPEM technology has advantages when it comes to noise, emissions, efficiency, CO2/kWh, vibrations, heat-utilization, pack-ability etc. In order to compete against long lasting small diesel generators, the end customer has to appreciate and be willing to pay a premium price for one or more of the advantages associated with HTPEM.

Another possibility are markets where customers are forced to make changes by regulation (E.g. India where telecommunications authorities demand green energy systems as a part of the infrastructure)

Competing Fuel cell technologies

<u>DMFC</u>
+ Reliable for low power applications
+ Has already been implemented on the camping market by SFC energy
- Cannot be scaled for high power demands
- Low efficiency - up to 25%
- Low max. temperature

<u>LT PEM + Reforming</u>
+ on the market, more mature
+ references and trials in the market
- Cost is still high
- Current system limited lifetime (due to cost constraints)
- Low electrical efficiency
- High standby power consumption
- Low max temperature

<u>HT PEM with Methanol reforming – RMFC (Used in the project)</u>
+ Scalable
+ High energy efficiency – up to 45%
+ Compatible to extreme temperatures
+ High power density
+ low standby power consumption
- Relative young technology track
- maturity and references in the field

Direct competitors:

In the trial partnerships currently investigated, there are two actual fuel cell competitors with the product and scope of supply to engage in comparative trials; Ballard power systems (CA) and First Element Energy (US)

1.6.2. Business Plan & Marketing

A detailed business plan was elaborated as part of the technical documentation, submitted alongside the deliverables and objects to ensure full compliance.

The platform will replace combustion engine generators and large battery packs as a maintenance free and highly reliable solution. Fuel distribution costs and storage density enables a low operational cost and a small footprint saving siting and rental fees for the operator.

The marketing plan is to a large extend based on known principles from the industry where niche and special applications is used to leverage and mature the technology.

The supplemental power market is large but there is a clear focus on telco customers already with some experience and knowledge within the area. This shortens the adoption process and ensures commitment behind collaboration.

The products are going to be introduced to OEM's and professional operators - either through partners or directly when the end customer has an integrator role of equipment e.g. telecom operators. Channel partners are kept out of the scope when possible, both to ensure a good cost structure but also to ensure feedback to Serenergy for further development.

The technology will be introduced concurrently with the development process in order to breach the gap between technology and product. This required close OEM collaboration integrated into the project. Actual commercial launch will be done from 2017 – however with a relatively slow deployment rate to ensure test and compliance with market demands are assured.

Serenergy will handle the commercial launch of Methanol fuel cell systems and will focus on creating references that can be shared with industry and ensure feasibility of product offerings and business models.

1.6.3. Economic analysis

The economic analysis will outline some typical user cases within specific applications:

Backup-supplemental power generators

The backup power case in focus on a medium usage supplemental power system – this will often be located in a decentralized location or in a difficult to reach central location e.g. a rooftop site. What is demonstrated is that the advantages of a small footprint/weight, cheap fuel and no preventive maintenance makes up for a premium price based on the 2016 price predictions. It is demonstrated the ROI is 1,5 years within the scope of decision makers in the telecom sector.

	Methanol		Combustion		Hydrogen
CAPEX					
Target application kW	5		5		5
Cost per kW	€ 1.400,00		€ 1.000,00		€ 1.000,00
Installation cost [System]	€ 500,00		€ 1.000,00		€ 1.000,00
Fuel Infrastructure cost [fuel storage/refilling]	€ 100,00		€ 100,00		€ 600,00
CAPEX per unit	€ 7.600,00		€ 6.100,00		€ 6.600,00
OPEX					
Service	€ -		€ 200,00		€ -
Depreciation [yearly]	€ 2.533,33		€ 2.033,33		€ 2.200,00
Site cost - rental [yearly]	€ -		€ 200,00		€ 400,00
operation hours [yearly]	3000		3000		3000
Fuel effeciency [%]	40		15		40
Fuel cost [per kwh]	€ 0,50		€ 0,83		€ 1,50
Fuel delivery cost [per kWh]	€ 0,50		€ 0,50		€ 1,00
OPEX per kWh [yearly]	€ 1,00		€ 1,36		€ 2,53
TCO per kWh [yearly basis]	**€ 1,17**		**€ 1,49**		**€ 2,67**
TCO [yearly]	**€ 3.506,67**		**€ 4.476,67**		**€ 8.020,00**
ROI	**1,55**				

Economic case analysis – Supplemental power

1.6.4. Commercial Roadmap

The below commercial roadmap incorporates sales prices derived from the technical roadmap and the corresponding sales volumes including a pre-commercial deployment for accumulated test systems

SPG COMMERCIAL ROADMAP			2012	2013	2014	2015	2016	2017	2018	2019	2020
SALES PRICE	EUR/KW		€ 4,000.00	€ 3,650.00	€ 3,300.00	€ 3,200.00	€ 3,000.00	€ 2,500.00	€ 2,100.00	€ 1,800.00	€ 1,400.00
BACKUP - SUPPLEMENTAL POWER	UNITS	STATIONARY		10	20	100	150	300	1500	4000	5000
	KW			50	100	500	750	1500	7500	20000	25000
TOTAL	UNITS			10	20	100	150	300	1500	4000	5000
TOTAL	KW			50	100	500	750	1500	7500	20000	25000
TURNOVER				€ 182,500.00 DKK 1,368,750.00	€ 330,000.00 DKK 2,475,000.00	€ 1,600,000.00 DKK 12,000,000.00	€ 2,250,000.00 DKK 16,875,000.00	€ 3,750,000.00 DKK 28,125,000.00	€ 15,750,000.00 DKK 118,125,000.00	€ 36,000,000.00 DKK 270,000,000.00	€ 35,000,000.00 DKK 262,500,000.00

1.6.5. Project Partnership and Research

The project is based on collaboration between a private company and a university and is a market driven application project. The collaboration between external companies is key to ensure commercialization and focus towards the market.

The focus is to integrate the academic specialized knowledge on specific areas with high impact and high potential e.g. lifetime and longevity. Furthermore, it has in the past proven very useful to have candidates from AAU working with systems to later be employed with Serenergy thereby increasing relevance and value to industry when graduated

Patents

For the SPG project, no patents where taken since this is an application project which does not cover the core technology development. This project is being carried out alongside other relevant initiatives and on those, some patent applications are expected.

Results transfer to other institutions

The results of the research conducted are used solely by the parties involved on the project and shared between them. In Serenergy, those results are translated into further research and development towards optimization of components and achieving greater economies of scale to enable greater commercial success across the different stated markets.

For AAU, the work conducted on this area, reinforce the leading position of the institution on the area of Fuel Cell research. The renewed commitment s by both parties over continuous projects (COBRA III application) is fulcral to carry on works and keep attracting the best and brightest minds to this field.

Ph.D. s participation

For this project, no Ph. D students were involved on the work developed, although the outcome of the project can be used by future PhD students to pursue deeper knowledge levels over the core technology and new materials applications.

1.6.6. Danish Energy Policy

The project partners represent a strong and dedicated effort in bringing Danish research, development and demonstration within the area of fuel cell technology, as well as integrating solutions and technologies in a working environment.

The project supports the strategy for liquid biofuels especially the main focus on:

- Ensuring a cost effective long term energy supply
- Ensuring growth potential for Danish companies
- Ensuring the fulfillment of Danish goals in sustainable fuel development
- Maintaining and develop the Danish research platform

Furthermore, the project to some extent support the effort within wind and gasification and the related strategies – this is due to the potential production methods for methanol via biomass gasification and hydrogen/carbon synthesis.

Energinet.dk – the entity in charge of the Danish gas and electricity grid has outlined in their new strategy that Methanol and DME is central in the "power to gas to fuel" chain enabling an interaction between power and gas infrastructure.

The project is aligned with pt. 7.3 of the Danish fuel cell and hydrogen strategy related to strategy and goals for the PEM area. Where support is given to production of cells, stacks and systems and enabling the deployment of said systems. The project is related to and supporting the updated 2012 Danish RD&D

strategy and Road Map for HTPEM Fuel Cells and Transport under the Partnership for Hydrogen & Fuel Cells.

1.7. Project conclusion and perspective

The Supplemental Power generation project has been created based on demands from the operators and infrastructure providers. However, the last step towards implementation and adoption into commercial industrial solutions is challenging and requires some incentives to increase extent and speed. The demand is present now and without support, Serenergy and the novel/superior solution will be set back.

Without the focus of the project, this unique concept may lose pace, total scope and fall behind at a critical stage where the industry is trying to move away from combustion generators.

Serenergy A/S (SE)

The project is vital to ensure the backup/supplemental power track as the first priority and with the most apparent opportunity to leverage from the RMFC platform development. With the customers in hand it would be critical to stop the process due lack of speed and resources. The project will increase focus and speed significantly and enabling to actually leverage goals and targets set forward in roadmaps with the HT PEM area.

Aalborg University (AAU)

For AAU, it is imperative to increase focus on the system aspects of fuel cell systems to maintain a high level of research and a close collaboration with industry. Furthermore, the demand from industry will require new candidates with knowledge in the HT PEM; system area on a continues basis and collaboration projects are critical to maintain the synergy between the academic community and industry.

After the Project period, the basis a commercial solution offering will be ready with some potential corrections and product maturing. An integrated part of the project is the development of an overall strategy and commercial clarification for the employment of the product into mass markets. The trial period integrated into the project will ensure a perfect starting point to be accepted to volume orders.

The Installations and hardware developed and demonstrated in the period will as a rule belong to the partner responsible for the activity. The Solutions in trial will if satisfactory remain in service and/or possibly be replaced by an upgraded version.

Serenergy will build on a common platform to provide Supplemental power generation worldwide through distributors and integrators.

Further attention and work will also be devoted to the support components of the different sub-systems, to increase the overall on-time running conditions, performance and reliability. This focus has, as a purpose, to improve the system benchmark reports, develop a more stable platform for further research and future product release, plus, internally build a continues focused Customer Relationship & Satisfaction Management.

Perspectives

The key applications of the technology follow the EUDP directives for independence of fossil fuels, development of technology with added value for the Danish industry, as well as growth and employment projections to reflect the economic effects generated within the given 1 to 5-year period end in terms of sales, exports and jobs creation.

A major restructure over the corporate structure of the company occurred during 2017, to meet the demand of the market and enable a greater level of growth over the three key segments target by the company for commercial applications of the HT-PEM fuel cell technology: Stationary, Mobility and Maritime.

This will enable the company to reach the desired goal of 75.000 DKK per unit (fuel cell), with an estimated production and delivery of 5000 units, totaling 375.000.000 DKK within the 5-year timeframe stipulated on the project application.

By other hand, this move had a significant impact over the development and production departments, allowing a greater focus on LEAN and AGILE methodologies, to adapt the production to the growing demand and orders placement as the company transits from field testing to delivery of the first units on the Telecom segment and expanding the cooperation and joint projects in the mobility and maritime segments of the market.