WP3 - Genset System Engineering & Proof of Concept

This work package involves the system engineering of the hybrid solid oxide fuel cell (SOFC)-Battery genset, the optimization of the sizing of the SOFC and the battery unit, as well as design validation of the SOFC-Battery hybrid genset in an experimental proof-of-concept (PoC). Finally, the aim of this work package is the development of virtual genset simulator and an engineering proposal for a multi-MW genset whose integration is realised under WP4 – Ship Integration.

3.1 WP Leader

- Deutsches Zentrum für Luft- und Raumfahrt/German Aerospace Center (DLR)

3.2 Tasks and Outputs

Genset process system engineering and validation

- The overall objective of this subtask is to engineer a 5 to 60 MWe SOFC-Battery hybrid genset concept based on key performance indicators (KPI's) defined in WP2 - Requirement Analysis. The task focuses on the development of second Process Flow Diagrams (PFD) by Rijksuniversiteit Groningen (RUG), by including the SOFC performance characteristics obtained from experimental characterization of the large stack module (LSM) from SolydEra SA (SE_SA), as well as the study of the anode off-gas and cathode off-gas recirculation.
- An optimization of the heat exchanger network and the development of a piping and instrumentation diagram (P&ID) was performed by Ecole Polytechnique Fédérale de Lausanne (EPFL). This development process was done iteratively based on the input of the experimental results and analysis of the PoC. At this stage of the project the first PFD, optimization and P&ID development were refined after the results of testing experiments. In addition, first transient models were developed and validated during the experimental campaign by Deutsches Zentrum für Luft – und Raumfahrt (DLR) alongside the application and parameterisation of an energy management system by Rheinisch-Westfälische Technische Hochschule Aachen (RWTH). The final outcome of this task will be a complete P&ID and engineering design of the hybrid genset capable to satisfy the requirements defined in WP2 - Requirement Analysis and safety related requirements.
- Concept design reviews to identify applicable regulations and IMO safety codes with respect to integration requirements for different cruise ship designs was performed by Lloyd's Register EMEA (LR).
- **Deliverable D3.1 – Report on safety and regulatory requirements for large-scale integration of scalable modular gensets on-board cruise ships – completed**

Hybrid genset sizing and design

- In this task the scale advantages for high-power SOFC systems are identified. Current commercial systems are compared with the concept a scalable high-power SOFC unit. The design constraints of a marine SOFC unit are defined in consultation with shipbuilders Chantiers de l'Atlantique (CdA) and Meyer Werft (MW), and marine regulators Lloyd's Register EMEA (LR). The positive effect of cathode

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off-gas recirculation to the decrease of needed airflow to the system is also evaluated and included into consideration.

- The design constrains were met by a concept design by Technische Universiteit Delft (TUD) of a 135 kWe SOFC unit containing six 22.5 kWe stacks. Stack in this unit can be replaced after the degradation of the SOFCs. The visualisation of the unit is in Figure 1.

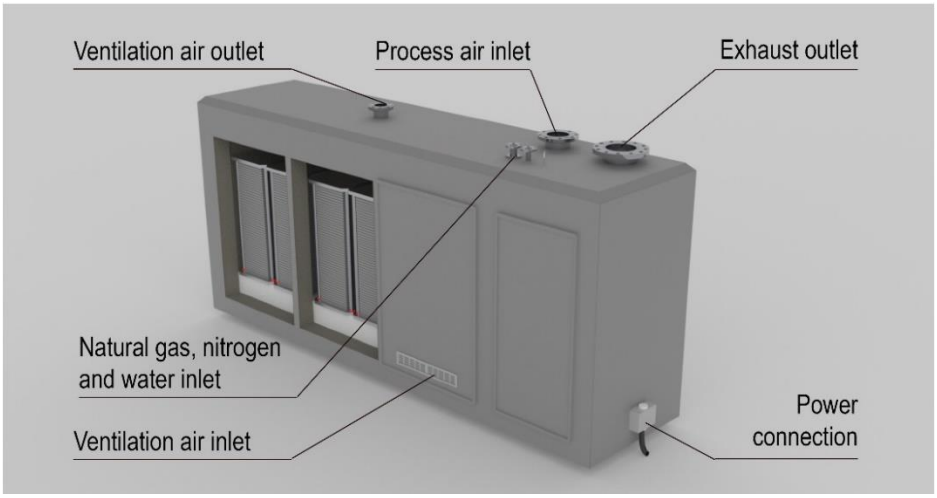

Figure 1 Concept design of a 135 kW SOFC unit

- Deliverable D3.2 – Steady state and dynamic operation of the hybrid genset system with unitized control algorithm – pending.

Fuel cell module assembling and operation

- Within this task a 30 kWe LSM has been assembled, delivered and characterised experimentally. The LSM in Figure 2 was operated in close collaboration between SolydEra SA (SE_SA) and tests at Deutsches Zentrum für Luft – und Raumfahrt (DLR).
- Deliverable D3.3 – Report on sizing of modular genset and scalability to multi-MW scale – pending.

Hybrid fuel cell + battery PoC build-up and operation

- The main objective of this task is to build up and operate the PoC, consisting of the LSM (Figure 2) and the battery (Figure 3) together with the adaptation of the control in the energy management unit (EMU) in Figure 4 c). The test rig was setup including power delivery from the LSM and battery DLR.
- PoC of SOFC-Battery hybrid in Figure 4 was successfully tested at DLR and the first emission measurements were carried out by Lunds Universitet (ULUND) at SolydEra SA (SE_SA) premises, see Figure 5.

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Figure 2 GALACTICA test rig with 30 kWe LSM from SolydEra

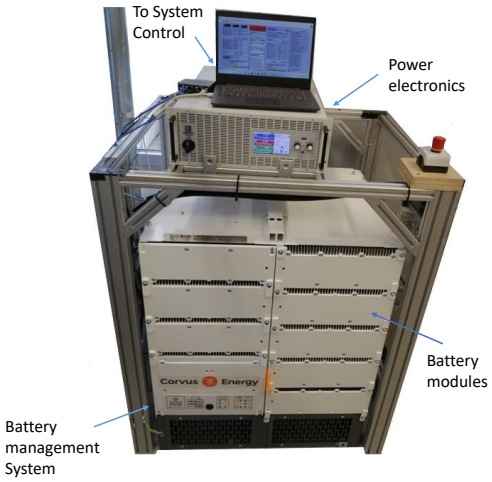

Figure 3 Setup of the Li-ion battery at DLR

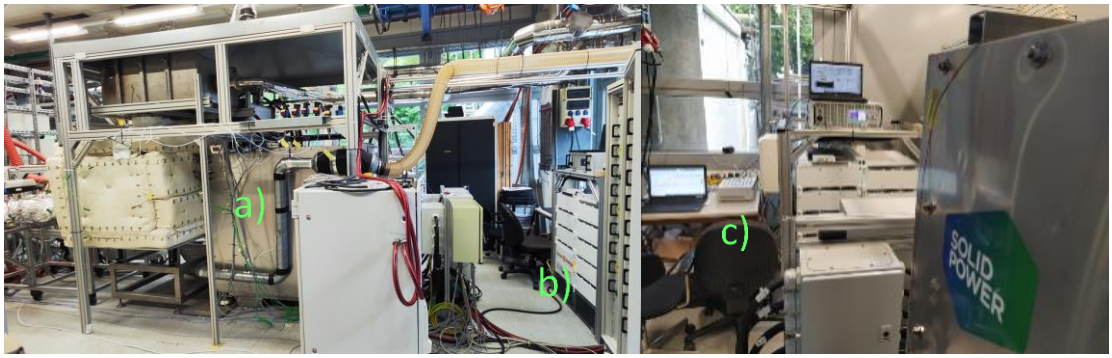

Figure 4 Proof of concept at DLR with a) LSM, b) Li-ion Battery, c) EMU

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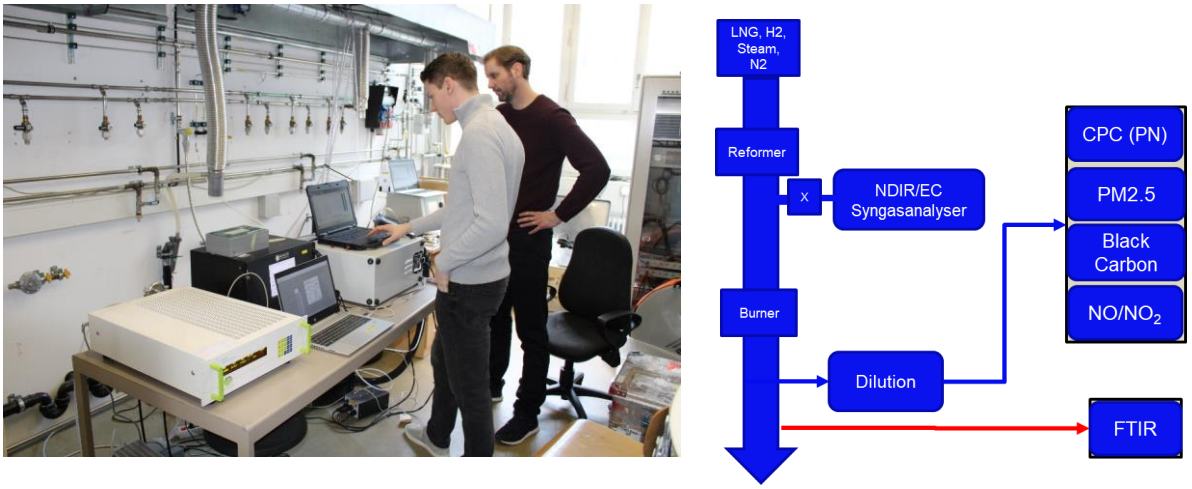

Figure 5 Experimental Set-Up: Emission Measurements by ULUND at SolydEra

- Deliverable D3.4 – Report of the 30 kWe PoC operation for different energy profiles– pending.

Virtual genset simulator

- The purpose of this subtask is to compile the results of work done in several different tasks to build a so-called Virtual Genset Simulator (VGS) that can be integrated to ship energy system simulators used by Chantiers de l'Atlantique (CdA) and Meyer Werft (MW). The production of the Virtual Genset Simulator (VGS) by Teknologian Tutkimuskeskus (VTT) is as a software development project, for which the technical and functional requirements have already been defined as well as technical requirements and specification for the Functional Mock-up Unit (FMU) that comprises the interface between the software packages.
- Deliverable D3.5 – Virtual genset simulator tool – pending

3.3 Duration and Status

- Months 1 – 54
- Status – in progress.
- **MS2: P&ID definition and PoC validated hybrid genset - completed**
- **MS3: Control algorithm in real time PC - completed**
- **MS4: PoC operated – completed**

3.4 WP3 Highlights

- Proof-of-Concept (PoC) of Solid oxide fuel cell (SOFC) + battery hybrid is successfully tested
- Conceptual design of a 135 kWe SOFC unit to be numbered up within the engine room limitations within a ship is finalized
- Development of dynamic model for the SOFC and first validation via experiments, Battery model development and validation
- System process flow design based on ASR-expressions from experiments & its optimisation is achieved
- Safety and regulatory requirements for integration of genset in ship is gathered
- Technical functionality of virtual genset including SOFC stack and balance of plant (BoP) is tested

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3.5 Next Steps

- Conclusion of the experimental campaign on the PoC
- Finalizing of Digital System Design with optimisation of electric and thermal energy
- Further validation of the dynamic models through the analysis of the transient experiments
- Completion of the virtual genset simulator and its integration in ship energy model as digital twin

3.6 NAUTILUS Follows Ups

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