

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate):
 - has fully achieved its objectives and technical goals for the period;
 - has achieved most of its objectives and technical goals for the period with relatively minor deviations¹;
 - has failed to achieve critical objectives and/or is not at all on schedule².
- The public website is up to date, if applicable.
- To the best of my knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 6) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 5 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator:

Date://

Signature of scientific representative of the Coordinator:

¹ If either of these boxes is ticked, the report should reflect these and any remedial actions taken.

² If either of these boxes is ticked, the report should reflect these and any remedial actions taken.

FCGEN – FUEL CELL BASED POWER GENERATION

PUBLISHABLE SUMMARY

Periodic Report 3

Project context and main objectives

For mobile applications the increasing demand for electrical power when the vehicle or boat stands still has led to an increasing need for an on-board electric power generator which operates with high efficiency and very low emissions. Exactly these parameters are the main drivers behind fuel-cell (FC) systems that can be used as auxiliary power units (APUs). However, proton exchange membrane of the FC operates efficiently with hydrogen rather than with the ubiquitous hydrocarbon fuels such as diesel found at gas stations.

Therefore a fuel cell based auxiliary power unit (APU), with a diesel fuel processor is regarded as one of the most interesting options since it combines high efficiency, low emissions and the use of the same fuel as the main engine. The FCGEN project is the first of its kind that seeks to integrate PEM FC-based diesel fuel powered on-board APU systems.

The overall objective of the FCGEN project is to develop and demonstrate a proof-of-concept autonomous diesel-powered PEM fuel-cell based auxiliary unit (FC-APU) in the laboratory environment. (initial goal: real application and on-board a truck). Another objective is to further develop the APU key components and subsystems that are expensive and/or still behind the required level of maturity and stability.

The APU system consisting of a low-temperature PEM fuel cell, a diesel fuel processor and necessary balance of plant components is designed to meet automotive requirements regarding e.g. size, mechanical tolerances, durability etc. High targets are set for energy efficiency and therefore this will lead to significant emissions reductions and greener transport solutions in line with EU targets.

A key goal in the project is the development of a fuel processing system that can handle logistic fuels. Such fuel processor consists of autothermal reformer, desulphurization unit, water-gas-shift reactor, reactor for the preferential oxidation of CO. The fuel processor needs to be tested on standard available low sulphur diesel fuel. Another key point is the development of an efficient and reliable control system for the APU, integrated with the truck systems, including both hardware and software modules. In the final demonstration, the fuel cell based APU has to be operated autonomously in laboratory.

The work in the FCGEN project is carried out by four industrial partners (Volvo, Powercell, JM and Modelon) and three research organisations (Jülich, JSI and IMM). The work in this project is split into five work packages (WP) covering research and technology development, APU demonstration and project management.



Description of the work performed since the beginning of the project

The FCGEN objective of developing and demonstrating a novel, fully operating power unit, required intensive efforts from all partners during the design, building and testing phases. Despite the encountered delays, the truck demonstrating partner (CRF) leaving project and related project goal change, the consortium has undertaken substantial efforts and achieved main project goals with **one of the first demonstrations of autonomous operation of PEM FC based APU and electricity production using commercially available diesel fuel**. The main work achievements are listed below.

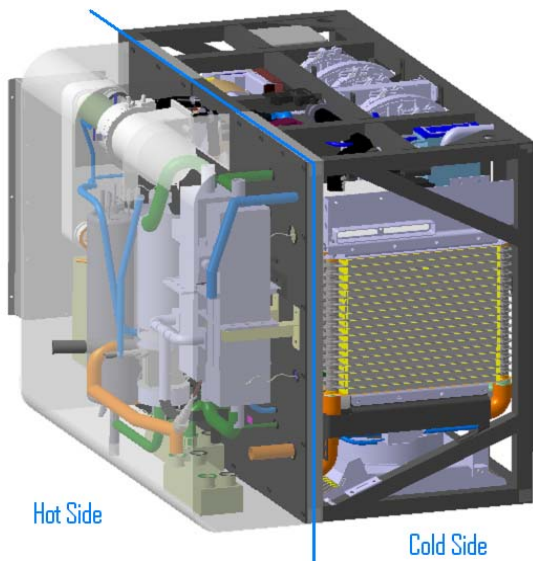
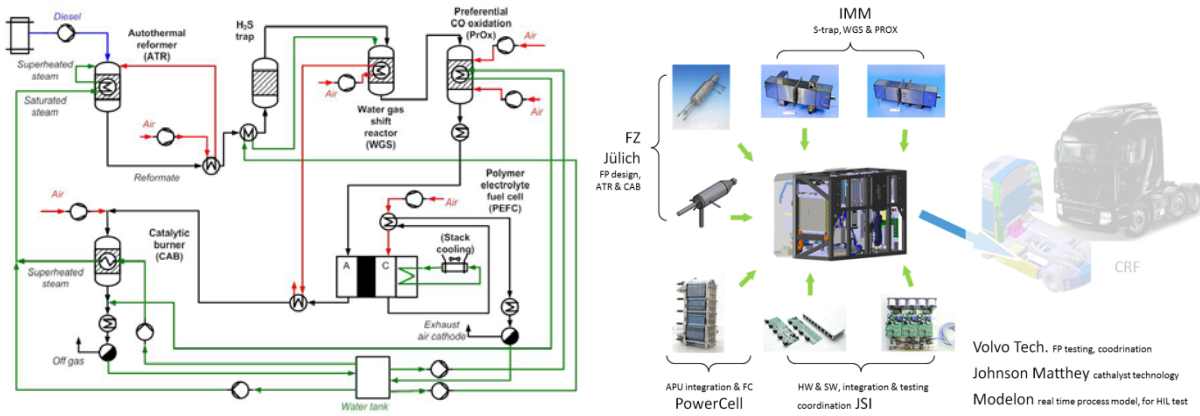


Figure: development phases of the FCGEN APU and brief sketch of partner roles in the project

Main results achieved

The technical development work in the project has been carried out jointly and with the involvement of all participating partners. The development challenges have been discussed in team meetings and valuable inputs to these issues and possible solutions were collected. This way the following results have been achieved:

“Vehicle integration and specification”

- **Vehicle specifications unit were defined** necessary for the development of the APU, and mechanical, electrical and communication interfaces necessary for APU installation and operation were created.
- **Analysis is performed to define the profit of electrifying the most conventional auxiliaries** in terms of fuel saving during travelling and stop phases and to select the electric auxiliaries necessary to the driver when the truck is parked.

- **A study was performed to simulate the fuel consumption** in different vehicle missions at travel and stop phases **to evaluate the best business case for the APU market introduction**. It showed that an anti-idling application of FC APU allows fast return of the investment.
- **A study on safety specification was performed**, including organization of workshop on hazard and safety; additionally risk analysis has been carried out focusing on project, system, and safety risks.

“APU system development”

- A **system model** was developed to **investigate steady state and dynamic behaviour of the APU system** under various conditions. The real-time capable system model was used also to **test control procedures via hardware in loop (HIL) verification**. From time and cost saving point of view, this tool can be used advantageously for system optimization to predict most favourable system and control design.
- Several **Balance of Plant (BoP) components with none or limited availability on the market have been developed and optimized together with selected suppliers**. Aspects such as component cost, durability and material compatibility have been the major drivers in the selection of the on-shelf and developed BoP components. All **BoP components were obtained and tested in component and sub-system tests**.
- A **system design was defined** based on several important aspects among others **start-up requirements, optimized system efficiency by proper heat and water recovery and decoupling of system parts to enable better controllability and optimized response**. The latter is achieved by replacing one main compressor with several small pumps and blowers.
- A number of alternative **packaging layouts have been evaluated** and the most proper model with respect of APU functionality and system volume is selected.
- **New generations of reactors were developed**: reformer (ATR), desulfurization (DS), water gas shift (WGS), preferential oxidation (PROX) and catalytic afterburner (CAB) reactor **based on design guidelines related to system functionality, durability and cost affectivity**. Catalysts in these units have been optimized to improve thermal stability and poisoning sensitivity. The **costs of the catalysts have been reduced by 50-60%** through precious metal thrifting compared to earlier generations, however, **with maintained activities**. A new structured material with **high mechanical stability is developed for the DS unit** to replace the conventional pellets material which does not exhibit the mechanical stability needed for mobile applications
- A **control system (CS) for autonomous efficient on-line control of the APU system** and its subsystems was developed following a multi-step development procedure to ensure late APU process modification/optimization. The CS provides **strategies for control of individual components and subsystems at laboratory environment as well as for the integrated APU system**. The CS software has a four level hierarchical structure, ensuring safe operation in all states, including startup, shutdown and emergency procedures. Along also two HMIs were developed: **a comprehensive SCADA-like HMI for system testing and optimization**, and a simple end-user HMI. The CS hardware consists of an **APU Electronic Control Unit (ECU) unit with close to 100 analog and digital I/O ports**. It offers **Ethernet and CAN communication and supports remote access**.
- Power conditioning components were built: **a highly efficient DC/DC converter, with voltage smoothing functionality**, and a **power distribution board** for BoP power supply, **featuring precharge function and load dump protection for shielding ECU, BoP components and battery**.

“FP commissioning and APU demonstration”

- A critical task was to **test the fuel processor and tune its operational procedures**, as high quality reformate is prerequisite for operation and longevity of the FC and the APU. Many challenges were faced during this task, including component failing, design updates and ATR replacement after unexpected incident, but all were overcome.
- Finally, the main project goal, the **demonstration of completely autonomous and efficient APU operation using commercial diesel** has been reached.

Expected final results and impact

The vision of the FCGEN project was to move the FC-based APU systems a major step towards industrialization. The project was targeting several issues which make this possible among others: system cost, improved system design for better performance, better efficiency and durability, reduced system size and weight. Efficient, durable and cost effective FC-based APU systems provides clean electricity (less CO₂ and extremely low NO_x and HC emissions) and less noise to the driver cabin during stand still conditions compared to the condition when electricity is generated by engine idling.

- The FCGEN APU system provides around 80% fuel saving when it is used as electrify source to the truck cabinet under stop phases compared to electricity provided via Internal Combustion Engine (ICE) idling. The reduced consumption results also in same level of reduced CO₂ emissions.
- Due to the catalytic technologies used in the FCGEN for system heating at start-up, fuel reforming, reformat purification and anode off-gas combustion, the level of emissions NO_x, non-methane hydrocarbon, CO and SO_x are < 1ppm which are significantly lower than the corresponding emissions produced during ICE idling.
- Within the FCGEN project, cheaper fabrication techniques such as embossing has been developed to reduce the production costs of a future micro channel coated heat exchanger reactors compared to the currently employed fabrication methods. Further cost reduction is expected via the reduction of precious metal loadings in the fuel processor catalysts and the selection of some cost effective BoP components. A detailed cost analysis has been carried out to investigate where further savings can be made.
- As the FCGEN is one of the first projects which focus on integration of FC-based APU systems targeted for on-board a vehicle and tested under close to real conditions with logistic fuels, the project provides valuable data and findings to vehicle OEMs with respect to various aspects of APU integration on-board the vehicle: mechanical, electrical, communication, safety. This is a powerful step for the commercialization of FC-based APU systems for on-board power generation and may open the path for additional utilization areas for these systems (e.g. electrifications of auxiliaries, H₂ supply for other application, etc.).
- Project partners have detected commercial interest from OEMs in various transport fields, and are pursuing ways to jointly further increase the TRL level with gained experience: to reduce cost, significantly increase the efficiency, improve reliability, ensure serviceability and durability

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