PEMBeyond

PEMFC system and low-grade bioethanol processor unit development for back-up and off-grid power applications

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FCH JU project officer, e-mail address Nikolaos Lymperopoulos, FCH JU nikolaos.lymperopoulos@fch.europa.eu		**Grant agreement no** 621218
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Summary This public report will present the current status after the second year of the implementation phase of PEMBeyond project. Information in this document may be used for dissemination purposes to different project stakeholders. Similar brief status reports will be given after every year of the project.		
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Contents

1. Project overview

Main objective of PEMBeyond project (http://pembeyond.eu/) is to develop an integrated Proton Exchange Membrane Fuel Cell (PEMFC) based power system for stationary back-up and off-grid power generation with the following targets:

- Using crude (80-95%) bioethanol as primary fuel
- Cost-competitive (complete system < 2 500 €/kW @ 500 units)
- Energy-efficient (> 30% overall system efficiency)
- Durable (> 20 000 hours system lifetime in continuous operation)

Back-up and off-grid power generation is one of the strongest early markets for fuel cell technology today. Wireless communication systems are rapidly expanding globally, and the need for reliable, cost-competitive and environmentally sustainable back-up and off-grid power is growing, especially in developing countries.

Fuel cell technology has already proven to be competitive with conventional technologies - diesel generators or batteries - in these applications in terms of total cost of ownership (TCO). However, the growth of the fuel cell industry in this sector has been modest at least partially due to high initial investment cost and fuel logistics problems. Cost-competitive PEM fuel cell power system compatible with crude bioethanol would allow direct use of easily transported and stored, locally produced sustainable and low-emission fuel also in developing countries, further adding value and increasing the number of potential applications and end-users for fuel cell and hydrogen technology.

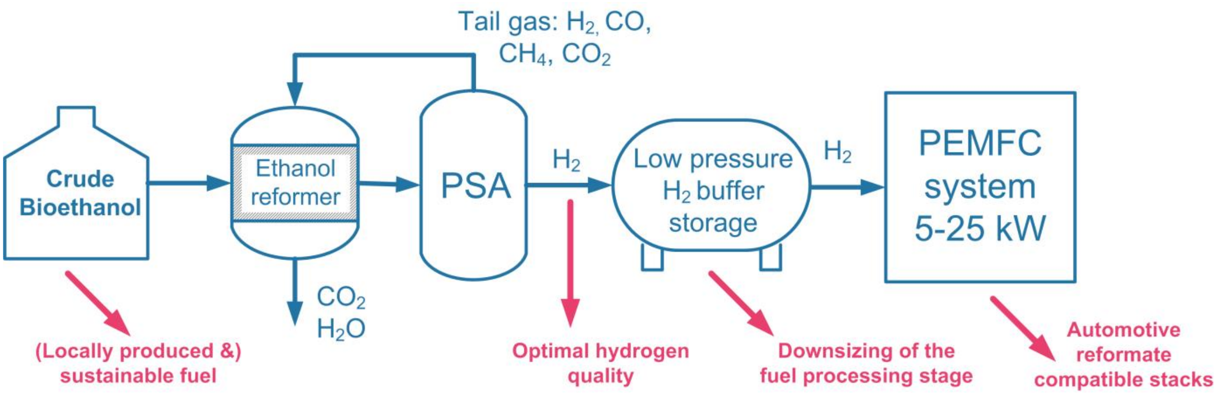

Figure 1: Overall concept developed in PEMBeyond project.

Error! Reference source not found. shows the overall concept of the system developed in PEMBeyond project. The Reformed Ethanol Fuel Cell System (REFCS) will consist of the following functions integrated as a one complete system:

1. Reforming of crude bioethanol in Fuel Processor (FP),
2. Hydrogen purification in Pressure Swing Adsorption (PSA) unit,
3. Power generation in PEM Fuel Cell System (FCS).

Optimized overall system design combined with use of improved system components and control strategies will lead to improvements in cost, efficiency and durability throughout the complete system. Latest automotive reformate compatible PEMFC stacks will be used, possessing high potential to reducing stack manufacturing costs. On top of this the stacks, as a part of a low-grade H_2 compatible fuel cell system design, will allow both FCS simplifications (e.g. no anode humidifier needed) and complete system simplifications (e.g. higher CO ppm and lower H_2% allowed) leading to decreased cost. Optimizing the target H_2 quality will be an important task with the regard to overall system cost, efficiency and durability. An extensive techno-economic analysis will be carried out throughout the project to ensure attractiveness of the concept. A roadmap to volume production will be one of the main deliverables of the project.

In addition to the complete REFCS, development of separately utilizable subsystems is another main outcome of the project. This includes PEMFC system for back-up and off-grid application using low-grade hydrogen directly as a fuel, low-cost state-of-the-art PEMFC stack for various applications, and crude bioethanol processing unit for distributed hydrogen generation (e.g. at hydrogen refuelling stations).

Serious market penetration of fuel cell technology and renewable fuel into back-up and off-grid power generation will have a high impact on energy consumption, and particulate and greenhouse gas emissions worldwide. Use of crude bioethanol as fuel would enable the use of low-cost, easily transported and stored, and locally produced sustainable and low-emission fuel also in developing countries.

PEMBeyond consortium consists of five partners from 5 different European countries:

1. VTT Technical Research Centre of Finland (VTT) – coordinator
2. PowerCell Sweden Ab (PCS)
3. Genport srl (Genport)
4. Fraunhofer ICT-IMM (IMM)
5. University of Porto (UPorto)

2. Progress to date

In the second year of the project, the main focus has been on the development of robust stack hardware and subsystem prototypes fulfilling the specifications set during the first year of the project. The project is currently exiting this development phase, as partners are assembling and preparing their subsystems to be sent for initial testing and integration.

After setting the initial specifications for the REFCS, system integration work has continued with finalizing the hydrogen quality specifications and securing a site and container for the integration work. Higher level control system has been designed and installed into the container. Initial testing of the subsystems will start in June and proceed with integration work in September.

Techno-economic and environmental analyses are ongoing throughout the project duration to give feedback on competitiveness and attractiveness of the developed concept.

Based on recommendations given in the project mid-term review in January 2016, the consortium has applied for a 6 month extension to the project duration to re-align the project schedule, which faced challenges in the design and development phase of the stacks and subsystems. Figure 2 shows an overview of the current schedule and project status.

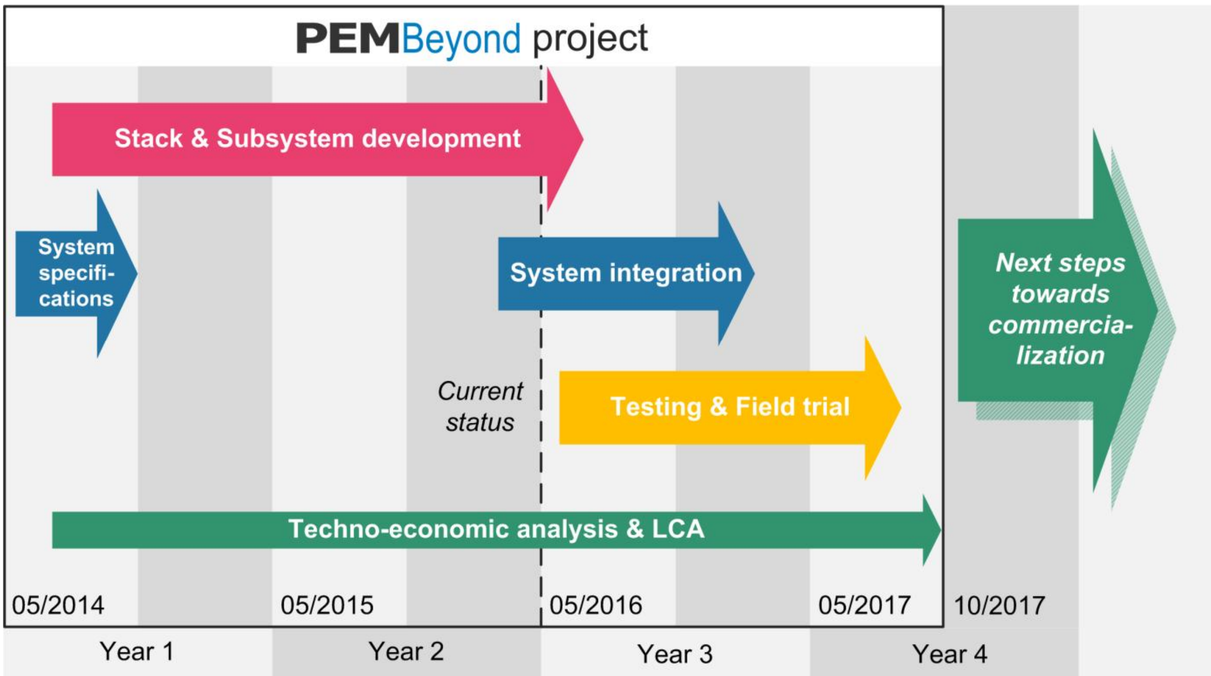

Figure 2: Overview of PEMBeyond project schedule and current status.

Overview of project progress by work package during the second year:

- WP2 – Fuel cell stack development (WP leader: PCS)

  Following the results of first year, second generation fuel cell stack BoS (Balance-of-Stack) has been validated with a 1000-hour test at PCS. The stack CO-tolerance was evaluated at VTT, following freeze tolerance evaluation first by leakage measurements under thermomechanical cycling, and secondly by freeze start-up trials, in which a 10-cell stack was started from temperature of -25 °C relying on stack internal heat production. As a curiosity, the said stack also survived a fire while being stored for the freeze trials. Figure 3 shows the stack under impurity and freeze tolerance characterization.

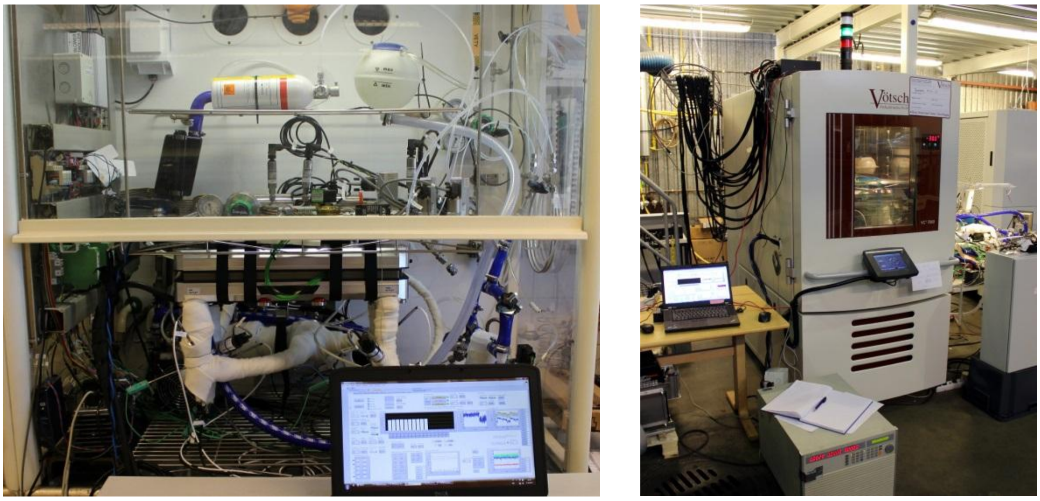

Figure 3: The S2 stack on impurity tolerance measurements (left) and under thermal stabilization preceding cold start-up (right).

  In the second year PCS has continued assembling, end-of-line testing, and delivering stacks as well as providing integration support to partners. To date, four 100-cell product version stacks have been delivered to Genport for system integration. In addition, two prototype and three product version 10-cell stacks have been delivered to VTT for characterization.

Due to the possibility of using new 2nd generation reformate MEAs in the existing FCSs and the opportunity to verify the in-project-developed ejector functionality at system level, the remaining stacks to be delivered in 2016 are sized and assembled on demand for optimal use of the remaining hardware resources. Apart from the aforementioned task, the stack development phase is concluded.

- WP3 – Fuel cell system development (WP leader: Genport)

During the second year, the fuel cell system design and simulation tasks were completed. Design and construction of the FCS subsystems, including air supply, H_2 supply, water and heat management, power electronics and instrumentation was also concluded. The subsystems were tested as part of a benchtop prototype FCS and specifications for the integrated FCS were reported. The integrated FCS prototype assembly and testing was started to deliver the FCS for system in June-July for integration into the REFCS.

The low-pressure ejector study for anode recirculation including manufacture, experimental characterization and modelling work of the ejector has been completed. Figure 4 shows the CAD design and a photograph of the 3D laser sintered ejector. Due to the promising results, the work is continued at VTT by testing the ejector as part of a FCS together with an S2 stack.

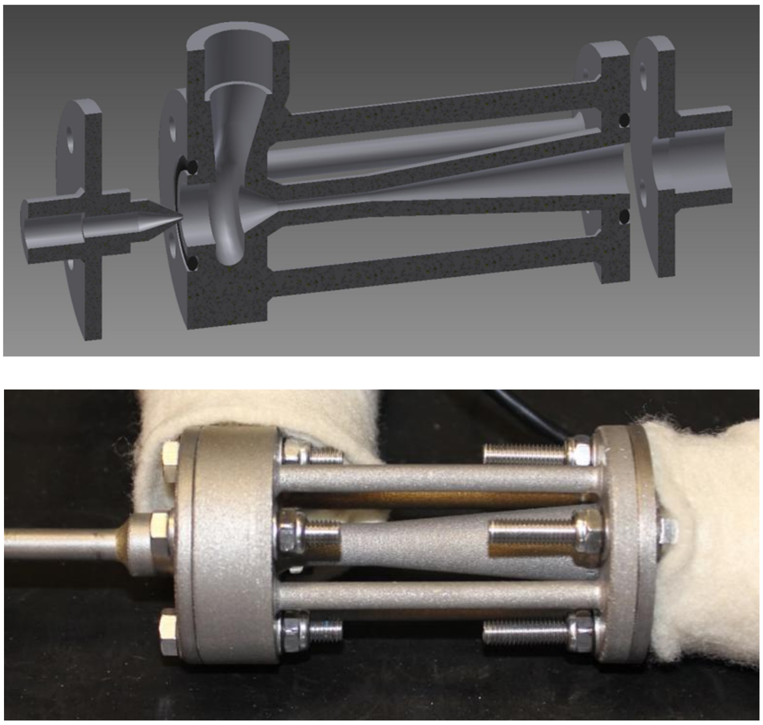

Figure 4: Cross-sectional view of the custom ejector CAD model (top) and a photo of the manufactured ejector installed in experimental set-up (bottom).

- WP4 – Reformer development (WP leader: IMM)

  During the second year, the reformer catalyst stability was tested for 1000-hour uninterrupted run on pure bioethanol and 280-hour run with crude bioethanol. The fuel processor design was fixed and the reformer control strategy was finalized.

  Most of the effort was focused on the design and manufacturing of the individual microstructured components, which was completed in February. The integrated fuel processor is currently being assembled to a test rig, where the fuel processor is evaluated with crude bioethanol in start-up and steady-state modes, before shipping to VTT in June.

  At UPorto, characterization of Cu-based catalysts for low temperature water gas shift (LT-WGS) was completed with the best catalyst composition identified. IMM has manufactured a microstructured reactor coated with the catalyst for prototype scale testing at UPorto.

- WP5 – PSA development (WP leader: UPorto)

  Following the first year, negotiations with commercial PSA suppliers were concluded as UPorto and HyGear agreed on a collaboration protocol in December 2015. The PSA unit specified by UPorto and manufactured by HyGear is expected to ship on August.

  In parallel with acquiring the commercial PSA unit, work continued with characterisation of adsorbents. Following the first year, a total 5 activated carbon and 4 zeolite adsorbents were characterized by measuring adsorption isotherms. The best samples were further characterized by mercury porosimetry and breakthrough experiments. In addition to the already characterized ones, promising copper impregnated activated carbon adsorbents are currently under study.

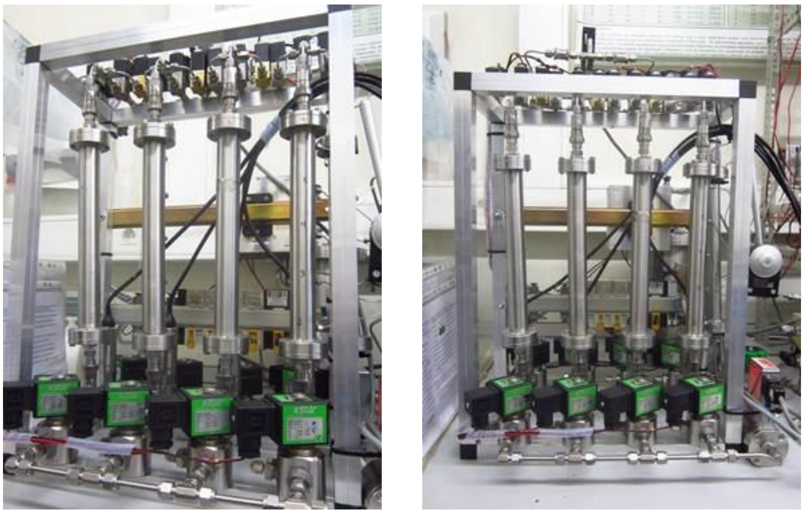

Figure 5: Lab scale PSA unit at UPorto.

The lab PSA unit () was further used in optimization studies and investigation of layered bed configuration with both activated carbon and zeolite adsorbents. PSA simulator using Aspen code was developed, with validation against lab PSA experimental data continuing.

- WP6 – Complete system integration (WP leader: VTT)

  Following the overall system specifications set in the first year (), the system level hydrogen quality optimization studies on single-cell and stack level were concluded and specifications given in deliverable D6.2. Based on the measurements a 5 ppm CO-level would be preferable for long-term operation of the stacks under nominal power. As the REFCS will function at nominal power only until the H_2 buffer capacity is drained (3.3 h), the level of < 20 ppm should be sufficient. As recommended in the D6.2, if major discrepancies between the product hydrogen purity and stack tolerance arise, FCS-level mitigation methods will be applied for bridging the gap.

Table 1: Main target system specifications.

Fuel Cell System (FCS):	
Electric net output	7 kW / 48 V DC
Start-up time	few ms (buffered by Li-ion battery)
Efficiency	> 45%
Bioethanol processor (Reformer + WGS + PSA):	
Product H_2 feed to buffer storage	0.135 kg/h (corresponds to ~2 kW net electric output)
Expected product gas characteristics	> 98 % H_2 and < 20 ppm CO, at 40 °C / 10 bar
Start-up time	< 45 min (buffered by hydrogen storage)
Complete Reformed Ethanol Fuel Cell System (REFCS) prototype:	
Electric net output	> 5 kW / 48 V DC (for 3.3 h hydrogen buffer storage capacity, after that limited to 2 kW)
Efficiency	> 30%
Fuel consumption	1 kg/h bioethanol
Back-up time	7 days (with 190 litre ethanol vessel)
Physical footprint	10ft. ISO container (not including the hydrogen buffer storage)
Ambient temp range	-20 to + 40 °C
Start-stop cycles	> 1000
Availability / reliability	> 98%

Design of the higher level control system has been completed, with automation cabinets and hardware acquired. The system layout modelling has continued, with the subsystem dimensions received from partners. Mapping and purchasing of system integration related auxiliary components has been concluded.

Site at VTT has been secured for integration and commissioning testing of the REFCS. A container (Figure 6) for the system has been acquired and installed with the automation cabinets. Evaluation of the safety requirements and standard compliance has been started and the work will continue by implementing the safety measures into the container.

Figure 6: REFCS container layout (left) and photo with the automation system installation in progress (right).

- WP7 – Testing and field-trial (WP leader: VTT)

  This work package will officially start in June when first subsystems are delivered to VTT from other partners. However, negotiations with local bioethanol suppliers for acquiring crude bioethanol for field trials has already started as well as surveys for suitable field trial locations. Hardware for initial testing of the subsystems has also been acquired.

- WP8 – Techno-economic and environmental analysis (WP leader: Genport)

  Genport is responsible for the techno-economic analysis (TEA), and VTT for the environmental analysis (LCA). Following the first year, collection of data continued for both techno-economic analysis and life-cycle analysis. The first data set should be completed soon, with the final component lists available from partners developing the subsystems.

- WP9 – Dissemination (WP leader: VTT)

  The project website (http://pembeyond.eu/) has been kept up-to-date and work continues to deliver an updated dissemination plan. An Industrial Advisory Group (IAG) has been formed, which consists of around 25 stakeholders from telecom and energy industry. Two annual IAG workshops have been held, first in September 2014 at VTT in Finland and at second at Genport in Italy in May 2015. The third workshop is scheduled in November 2016 in conjunction with the semi-annual project meeting at VTT. The last workshop is planned in 2017 to showcase results obtained in the field trial and to discuss future opportunities.

  In the first year, the project was presented in World Hydrogen Energy Conference, South Korea, June 2014. During the second year of the project, presentations followed in European Fuel Cell Forum 2015 and Annual Meeting of German Catalysis 2016. Abstracts have been prepared for two more international conferences in 2016.

  Articles are under preparation from characterization of LT-WGS catalyst developed in UPorto and on the development of system level fuel impurity measurements at VTT. An article concerning the ejector studies was submitted to International Journal of Hydrogen Energy. At least two more publications are planned based on reformer development and commissioning of the REFCS.