PEMBeyond

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

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Deliverable 6.6

Analysis of different start-up fuel options

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Summary

For starting up the reformed ethanol fuel cell system in locations where no electricity is available, an additional boost of energy is needed, to heat up the reformer, start hydrogen production and fill up the buffer tank to a level where the fuel cell system can start producing electricity.

This report describes the amount and types of energy needed to start-up the system and reviews three options as the energy source: bottled hydrogen, sodium borohydride and a large start-up battery. The pricing and availability are also reviewed for each option.

As the electrical energy needed for the reformer and PSA start-up was much lower than anticipated, using a Li-ion battery is the most straightforward and economically viable option for starting up the system in off-grid locations.

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1. Introduction

The basic scheme of the complete system is shown in Figure 1. When this system is started for the first time in the application site, or after the low pressure hydrogen buffer storage has been emptied completely, some energy source is needed for starting the operation of the system. This type of event can be considered to be quite infrequent.

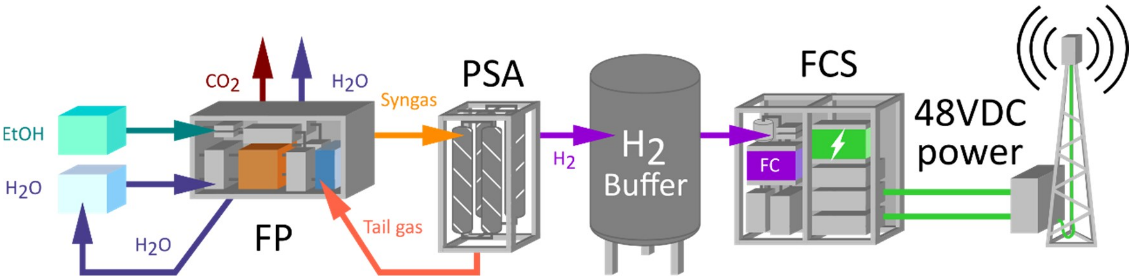

Figure 1: Basic scheme of the complete system.

The main options for the start-up energy source considered are bottled hydrogen, sodium borohydride and a large start-up battery.

From these options, bottled hydrogen and a large start-up battery are straightforward to apply, however, bottled hydrogen may not be available in all locations.

Sodium borohydride in a catalyst reactor releases hydrogen for the fuel cell until the reformer reaches its operating temperature and starts to produce hydrogen. Hence, the start-up fuel would help minimize the auxiliary battery size and the start-up capability of the system would be secured in all situations.

Use of solar energy to increase system efficiency during operation will be evaluated. Recent decrease in solar cell cost has made it a viable option for auxiliary use in this kind of back-up and off-grid systems. If found viable and implemented, solar energy would be used when available in e.g. charging auxiliary battery, preheating process streams etc.

2. Start-up energy needs and start-up energy options

2.1 Start-up energy needs

When the system was planned in the application phase, it was estimated that up to 10 kWh start-up energy (as combined electrical and thermal energy) could be needed for the start-up of the reformer and PSA system, before any hydrogen could be produced to run the fuel cell system. This estimate was based on the thermal mass of the system components.

In one planned system configuration option, all this energy would be electrical energy (electric heaters used). In that option, the size and cost of auxiliary Li-ion battery would become a major cost issue, as in remote locations lead acid batteries would not be a viable option. In 2012 the cost of 10 kWh Li-ion battery would have been close to 10 000 euros, but the cost of Li-ion battery is decreasing rapidly.

However, in the actual system configuration a lot of the thermal energy needed can be produced by burning ethanol. The calculated start-up energy needed is 1.16 kWh electrical energy and 3.94 kWh thermal energy from ethanol.

In addition to start-up, the system must produce some hydrogen for the buffer storage as a start of FC system operation requires some (about 1 bar) overpressure in the hydrogen buffer storage, which takes approximately 1 hour of operation of the reformer and PSA. The estimated electrical energy needed is 1.02 kWh and 1.22 kWh thermal energy from ethanol burning.

The start-up of the system to the stage that FC system is operating requires 2.28 kWh electrical energy and 5.16 kWh thermal energy, totalling 7.44 kWh. The availability of electrical energy is the critical parameter for the start-up, as ethanol is much easier to store. Moreover, if the buffer tank is filled completely to a pressure of 7.5 bar(g) total 5 hours of operation is needed. The required electrical and thermal energy for the different stages are shown in Figure 2.

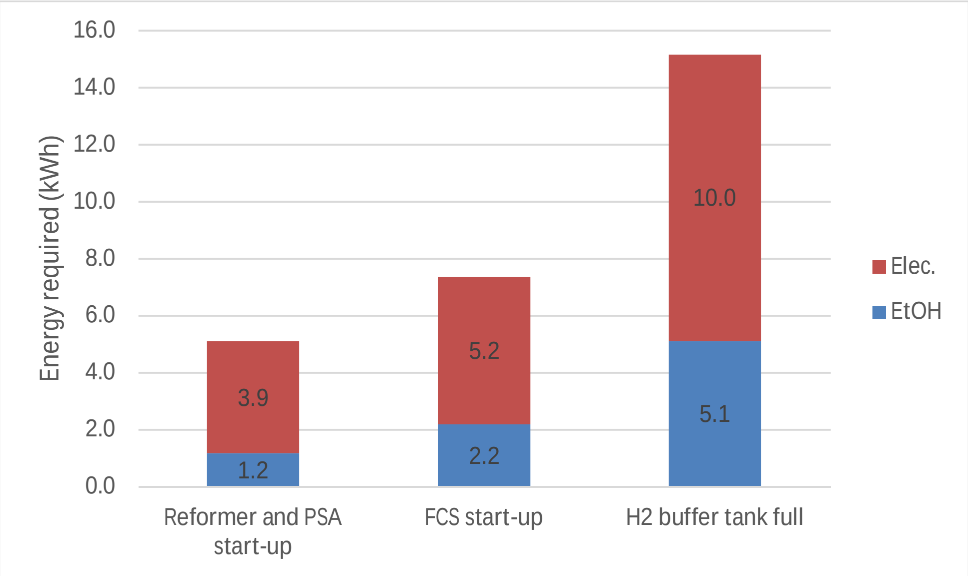

Figure 2: Electrical and thermal energy required for system start-up.

This electrical energy needed for start-up can be produced by using a FC system with a different hydrogen source or a large start-up battery. These options are discussed in the following chapters.

2.2 Bottled hydrogen

A separate hydrogen source can be used to start-up the system. A single standard bottle of hydrogen contains 8.9 m3 hydrogen, which is sufficient for 6-7 start-ups (13.5-16 kWh).

A cost of a standard hydrogen bottle with all necessary pipes and pressure reducer can be estimated to be in the range of 500-1000 €. The corresponding cost for the start-up energy would be 40-80 €/kWh.

The main issue for the bottled hydrogen option is the maturity of hydrogen infrastructure. If a single standard bottle is sufficient for the start-ups of system lifetime, the delivery of additional hydrogen is not an issue. If start-ups are needed more frequently, the delivery of hydrogen may form a major cost factor and cause a problem for the availability of the system.

2.3 Sodium borohydride

Sodium borohydride is one potential hydrogen source and it has been used in number of applications such as unmanned aerial vehicles (UAV), portable power and sensors [1–3]. Recently, there has a study for the use of sodium borohydride for a residential stand alone PEMFC system [4].

Sodium borohydride price is in the range of 20-50 €/kg and stored hydrogen would then have a cost of 100-250 €/kg. This would correspond a cost of 6-15 €/kWh, which is clearly under the cost of bottled hydrogen if a reactor cost is excluded.

The issue with a sodium borohydride solution is to build a safe reactor with sufficiently high hydrogen release rate. In the application of PEMBeyond project one sodium borohydride storage could be used for a single time (storage capacity 3 kWh electricity) and this could enable simplifying the reactor.

The state-of the art and challenges of sodium borohydride solution has been reviewed by Demirci et al., Mao and Gregory, Retnamma et al. and Yadav and Xu [5–9]. However, a reactor solution suitable for the purposes of the system in PEMBeyond project has not been studied.

Therefore, while the option of sodium borohydride is attractive in terms of sodium borohydride price, the real evaluation is possible as there are no commercially available reactor suitable for the PEMBeyond system

2.4 A large start-up battery

A large start-up battery is the most simple solution for providing the start-up energy. However, since the potential locations of the ethanol based systems are in warm climate the use of lead acid battery is not a good solution.

The only major drawback of a large start-up battery compared to other alternative is the initial capital cost of Li-ion battery. However, the cost of Li-ion batteries has decreased significantly in recent years and further cost reductions are expected [10,11]. The expected cost for 2.5 kWh Li-ion battery can be 1000-1500 €.

In addition, as the FCS is already equipped with a Li-ion battery, this provides the most simple way to enable start-up of the system without additional electricity.

3. Conclusions

The required start-up energy needed for the PEMBeyond system is slightly lower than initially estimated (7.44 kWh vs. 10 kWh). In addition, only 2.28 kWh electrical energy is needed. The rest of the energy is thermal energy, which can be supplied by ethanol burner.

Due to this low start-up energy requirement, the most viable option for start-up energy source is a large start-up battery based on Li-ion chemistry. This choice is further supported by the rapidly falling cost of Li-ion battery technology, and the fact that the FCS will anyways be incorporated with a battery system.

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