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# System Cost Uncertainty of Micro Fuel Cell Cogeneration and Storage

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**Abstract**

In this paper, the effectiveness of support schemes for micro fuel cells (FC) in Germany is analyzed with regard to the latest market conditions and legislative changes. We analyze whether polymer electrolyte membrane fuel cells (PEMFCs) are a feasible investment option for domestic usage, or whether they are likely to become so soon. Furthermore, electrical energy storage could be a complement to the system by supplying short-term peak demand, and thus increasing self-consumption and potentially the overall economic merit. We find that PEMFCs will not have become a competitive technology by 2020, and it may take even more time to achieve a substantial market diffusion. Also, electric energy storage in combination with an FC system is found not to be a worthwhile investment in a grid-connected scenario.

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## 1. Introduction

Combined heat and power (CHP) plants simultaneously produce electrical and thermal energy, the latter of which is used on-site or by district heating. They are a focus of research due to their potential primary energy savings in comparison to conventional power systems with separate electricity and heat production [1].

In Germany, reaching the emission reduction target by 2020, which was set by the Paris Agreement of 2015, seems unrealistic at the moment [2]. Promising Micro CHP technologies include Stirling engines, gas turbines, and FCs [1]. FCs stand out, because they can achieve substantially higher efficiencies than those of other mature small-scale CHP technologies [3], and they rival even the most efficient large-scale power plants. [4] state a 21% to 27% $CO_2$ emission reduction compared with a modern reference gas-condensing boiler (RGB) in a partially renovated single-family house using the current German power mix. The German government has therefore set the goal of achieving a share of at least 25% of CHP electricity production by 2020 in Germany.

Prices of FC systems are still very high due to high material costs, low production volumes, and system complexity when compared to engine- or Stirling-based micro CHP systems [5]. Although the German government promotes micro FC CHP plants, no widespread adoption is taking place in Germany for private users, with only 1,000 deployments until now [6]. In Japan, with governmental policy support, already more than 120,000 FCs had been installed for domestic use by the end of 2015 [7].

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The most recent study concerning the German market which analyzes the economics of micro FCs is that of [4]. The authors foresee a market competitiveness by 2020 with the other CHP and heating technologies if FC system prices decrease up to 2020 at the study's estimated rate, and assuming an average electricity price increase of 4% per year. The situation has changed by now: micro FC systems have shown a slower deployment rate than projected and a slower cost development than assumed; the stock price for gas and electricity has decreased, which was neither expected by most forecasts nor was it considered in the authors' scenarios. New support schemes have led to a different investment environment. This makes clear the need for a new, refined assessment.

**Nomenclature**

| | |
|---|---|
| CHP | Combined Heat and Power |
| FC | Fuel Cell |
| HT | High Temperature |
| HHV | Higher Heating Value |
| LHV | Lower Heating Value |
| NPV | Net Present Value |
| PEMFC | Polymer Electrolyte Membrane Fuel Cell |
| RGB | Reference gas-condensing boiler |
| SOFC | Solid Oxide Fuel Cells |

## 2. Methodology

The main contribution of our paper is the development of a detailed white-box simulation model of a current domestic micro FC system. Two different technical systems are modeled: (1) Standard FC system; (2) Standard FC system with the addition of an electric energy storage system. Based on the created simulation model, a calculation of the current economic status of domestic micro FCs in Germany is carried out by comparing the above systems with an up-to-date RGB. This is analyzed both with and without subsidies granted. For the economic model, the net present value (NPV) methodology has been adopted, i.e. a static approach that allows the calculation of an investment's market value in a certain timeframe. The NPV represents the time value of a project, determined by the present value of the expected future net cash flows of costs and revenues. [5] have shown that the cost development of FCs can be well described with a learning curve. According to the learning curve model, marginal cost decreases with cumulative production of a new technology. To estimate the necessary future installations for achieving market competitiveness, the learning curve concept is applied, assuming a learning rate of 16% [5] and the economic results of the study.

## 3. Model specification

### *3.1. Selection of technology and operating strategy*

For domestic micro CHP plants, two main FC technologies are currently being deployed [8]: (1) Polymer Electrolyte Membrane Fuel Cells (PEMFCs) and (2) Solid Oxide Fuel Cells (SOFCs). The most widely deployed technology is the PEMFC. PEMFCs presently account for approximately 90% of the globally installed micro FC devices [8]. They offer the highest guaranteed operating hours (70,000-80,000 h) [9,10] and a comparably low electric power degradation [8]. Consequently, in the following, a PEMFC system is simulated in detail.

[11] analyze the optimal selection of a battery technology to support grid-integrated renewable energy. They provide a detailed status of the currently most spread and promising battery technologies. Lithium-based batteries, and in particular the mainly used lithium-ion batteries, offer a high power capability, good cycle life, high energy density, and high efficiency. Therefore, a lithium battery storage unit is analyzed as a supplement to the PEMFC system.

There are two main operating strategies for CHPs which need to be considered when selecting the technology and dimensioning the system: (1) electricity-oriented plant operation and (2) heat-oriented plant operation. Based on results of [12] and our own economic comparison evaluating the operating strategies (1) and (2) including available price premia in Germany, the electricity oriented plant operation is analysed because it showed the better economic performance.

### *3.2. Model assumptions*

First, daily load profiles in 1-minute resolution from the VDI Guidance 4655 [13] were aggregated into a yearly profile and scaled to the assumed household demand. Furthermore, based on the input of the load profiles, a plant control system was created which enables the simulation of the operational capabilities of a PEMFC following the electric load of a household. The PEMFC system characteristics are summarized in Table 1.

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