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Short communication

Stationary fuel cells—Results of 2 years of operation at EnBW

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Abstract

Several fuel cell systems have been installed and run at customers' sites using natural gas. Operational results from different field tests are presented to demonstrate the state of the art of fuel cell systems, which can be used successfully to generate heat and electricity. The most urgent challenges for commercialization of this innovative generation system are improved reliability and cutting costs.

Keywords: Fuel cell; PEMFC; MCFC; SOFC

1. Introduction

The direct conversion of chemical into electrical energy with high efficiency, no noise or hazardous emissions has been an engineer's dream since the discovery of the fuel cell concept in the 19th century. Fuel cells of today have many technological advances and can be run safely for the production of both heat and electricity. However, fuel cells are considerably more expensive than comparable conventional technologies. But fuel cells have the potential to fundamentally alter the energy supply system if all the technological objectives can be realized at competing prizes. For example, decentralized power plants may become competitive and beneficial to the environment.

The supply of heat and electricity to our customers using the latest, environmentally sound technologies at competing prizes is one of EnBW's ambitions. Fuel cells are considered to be one of the key energy conversion technologies of the 21st century. Therefore the applicability of fuel cell systems as energy conversion device needs to be thoroughly investigated. The fuel cell testing and demonstration program of EnBW aims at the different energy needs of our customers. From our point of view these different energy needs may also establish different fuel cell technologies. EnBW planned to gather own know-how in all relevant fuel cell technologies. Therefore those fuel cell technologies are included in the field test which significantly advanced during the previous years and which should have a convincing cost cutting potential.

In the following three chapters results from our fuel cell projects to supply heat and electricity for private customers' homes, for a public swimming pool, and for an industrial production process will be discussed. Summary and outlook in the last chapter.

2. Sulzer Hexis HXS 1000 fuel cell for the production of heat and electricity in private homes

The Sulzer Hexis HXS 1000 premiere fuel cell (Fig. 1) is a high temperature, solid oxide fuel cell (SOFC), which is operated with natural gas. The system has an electrical output of up to 1 kW and a thermal output of up to 24.5 kW (inclusive auxiliary burner). The dimensions are about 1 m wide, 1.80 m high and 0.7 m in depth, corresponding therefore to a conventional heating system.

In an advertising campaign in March 2002, EnBW looked for some customers to become pioneers for one of the pre-series fuel cell system Sulzer Hexis HXS 1000 Premiere. The overwhelming response of more than 6000 customers applying for the fuel cells available represents a good base

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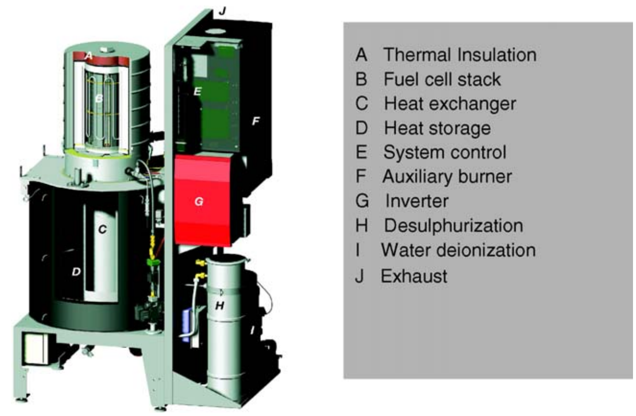

Fig. 1. Sulzer Hexis HXS 1000 Premiere.

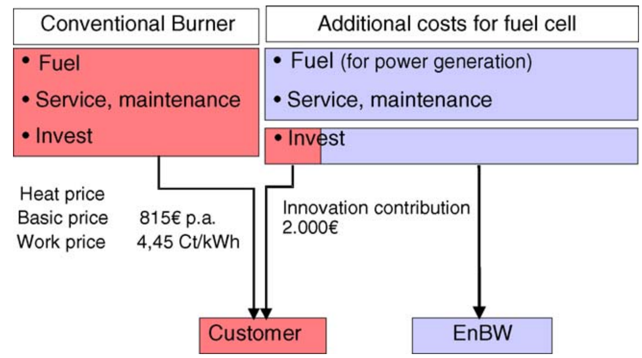

Fig. 2. EnBW Cell plus contracting.

for finding the ideal locations for the pre-series plants and documents a high public interest in fuel cells [1].

Since the year 2000 EnBW has pursued an integrated strategy in the context of its business activities for the promotion of the fuel cell technology. For convincing results it is necessary to test different fuel cell plants under real operating conditions directly in customer buildings. In numerous fuel cell projects EnBW will set up specialized technical know-how. First pre-series fuel cell plants have already proved their suitability for the installation and integration into the house energy supply. In December 2001 EnBW installed the first fuel cell plant, until now EnBW has installed 14 plants at selected locations and continuously gains valuable experience. Until 2006, a total of approximately 55 fuel cell systems are planned.

The Sulzer Hexis HXS 1000 pre-series system is manufactured only in very small numbers and for the first time for direct energy generation at the customers' homes. Today the fuel cell systems are not for sale. EnBW installs and operates these plants at the customers' homes who applied to become "pioneers" for such a system. Therefore we created the heat supply package *EnBW Cell plus*. The customers pay a leasing contract only for the actual use, which is generated by the plant—which means in this case heat for heating and warm water. The electrical power which is produced when heat is needed in the household only covers the basic need. Depending upon demand, the electrical power is being fed back into or delivered by the grid.

In order to promote the development of this innovative technology the costs for pioneer customers are calculated in their favour. At present, they come close to an investment into a new conventional heating system plus service and fuel costs (Fig. 2). Actual substantial extra costs, which as a matter of fact still exist in the current pre-series phase, are not shifted on to the customers. As they are born by EnBW we and not the customer carries the financial and technical risk.

So far, EnBW has installed – apart from different plants at private pioneers' homes – two systems in the education centers of the chambers of handicrafts in Stuttgart and Karlsruhe. Obviously these are not the typical single family house conditions which the plants are designed for (Fig. 3). However, the crafts should be integrated and instructed in this new technology at an early stage—but also in meaningful steps.

Today the fuel cell is still in its pre-series phase, thus not quite ready yet for the introduction into the market. The electrical efficiency reached is between 25 and 30%. The life span of the stacks, however, is the main challenge for the development—and this is likely to be so in the years to come. As with each technology, which is to be introduced into a market, it is absolutely necessary to develop this process carefully and step by step. However, only when the plants

- reach the reliability of conventional heating and power systems
- can be offered at competitive prices
- offer clear advantages to the customers

only then a broad introduction of such a product into the market is viable. The experience we gather now from the installation, operation, service, maintenance, remote monitoring as well as from the co-operation with the local crafts, directly influence the development of the technology and

Fig. 3. Near Karlsruhe, EnBW operates a fuel cell plant in an own administration building. This was the first installation of such a plant, so we decided not to give this to a private customer but to collect the first experiences of installation and operation of a fuel cell within our facilities.

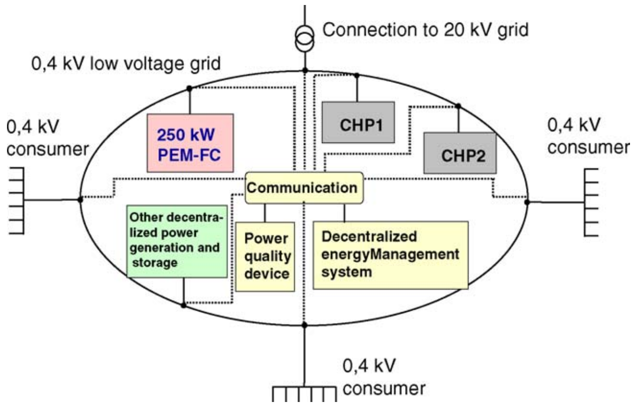

Fig. 4. Network structure in the EDISon project.

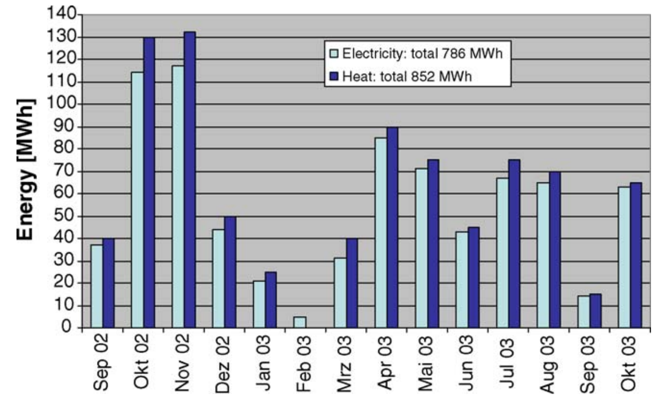

Fig. 5. Monthly generation of the 250 kW PEM fuel cell.

facilitate series production which is envisaged to start around 2009/2010 by various fuel cell manufacturers.

3. A 250 kW Alstom-Ballard PEM fuel cell in a decentralized energy distribution network

The development and testing of innovative concepts for the operation of distribution networks with decentralized generation and storage units were the aim of the lead project EDISon, funded by the Federal Ministry for Economy since 1999. These components of a new type are connected by an intelligent control and regulating system and thus are to enable the optimized operation of the distribution network. Together with Alstom-Ballard EnBW tested in the frame of this lead project a 250 kW PEM-fuel cell demonstration plant in the practical use.

The fuel cell was integrated into the supply installations of the thermal spa in Mingolsheim; it fed the heat into the heating central and the power into the electrical grid, see Fig. 4. The plant was operated in parallel with two combined heat and power plants and a peak load boiler. The way of operation was optimized by a so-called decentralized energy management system. The fuel cell was operated from September 2002 to October 2003; it delivered during this time about 786 MWh power and about 852 MWh heat [1].

Fig. 5 shows the monthly generation of the 250 kW PEM fuel cell during the year of operation.

The best production of the whole period was realized during October and November 2002. In the beginning of 2003 there were severe problems with the reformer, which as a consequence had to be changed. During the summer 2003 we had a very high ambient temperature. This led to the fact that several times we could not deliver full load because we could not use the heat. In September 2003 due to new problems with high reformer temperatures this component had to be changed again. But the goal was to shut down the plant officially and not as a result of some kind of trouble.

Between net performances of about 150 up to 212 kW an electrical efficiency of 28–38% could be reached. The thermal efficiency in this field was between 30 and 42%. All of this led to a total performance of about 60–80% at maximum.

Fig. 6 exemplifies the generation and time availability of the fuel cell in two selected months. In June 2003 there were

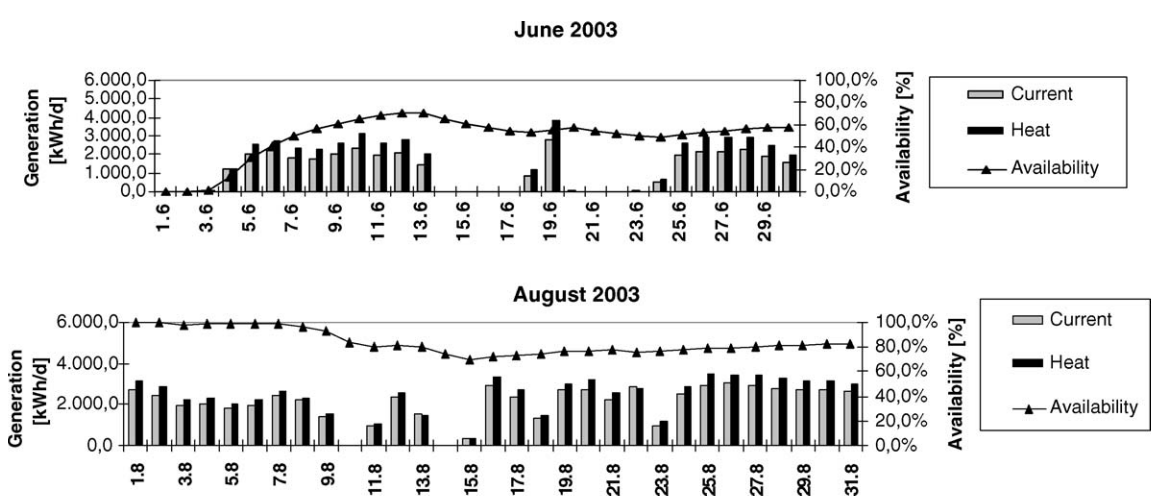

Fig. 6. Generation and availability in the EDISon project.

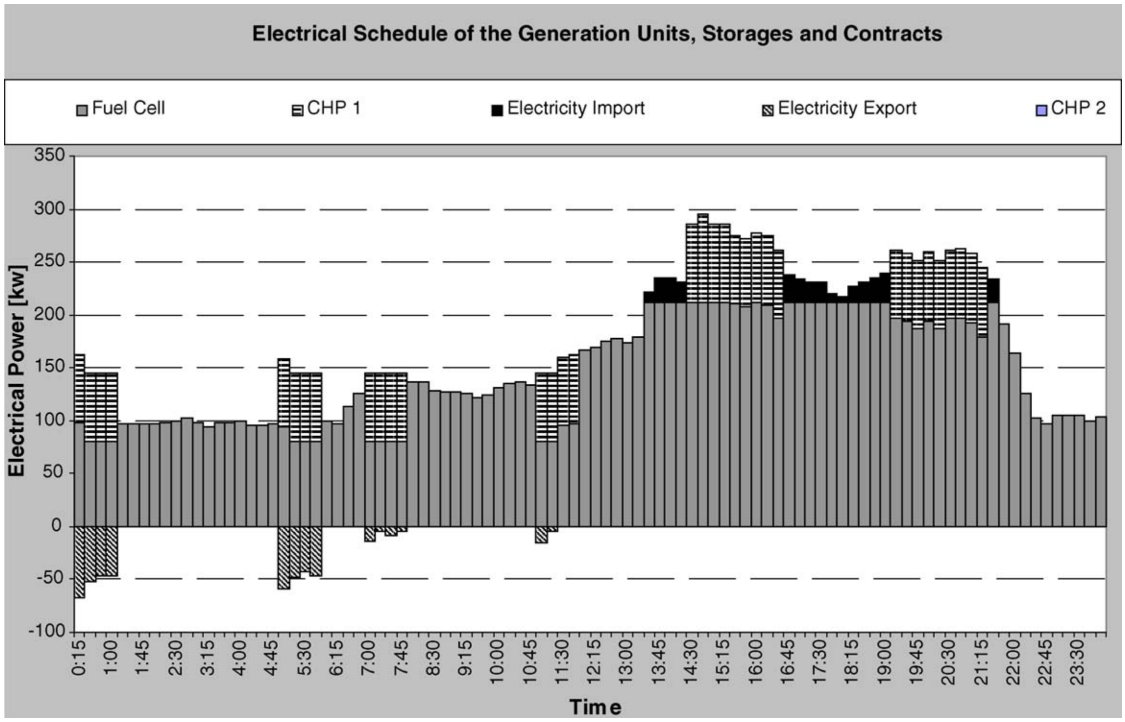

Fig. 7. Electrical load curve in the EDISon project, timetable of the decentralized energy management system.

several days of standstill between 15 and 25. These standstills lead to a monthly availability of about 60%. In comparison, the plant was nearly completely in operation during the month of August 2003 and thus reached an availability of about 80%. The average availability in the year of operation was about 60% due to various times of standstill. These times of standstill were primarily caused by problems with the reformer and peripheral installations, whereas during this year of operation the fuel cell enabled a plant operation without any problems.

Fig. 7 describes the typical electrical load curve on a Monday. During the night hours the fuel cell delivers about half-load. At some times, the system expects a power consumption resulting from previous days, for example for the ventilation, and hooks up the combined heat and power plant. But as no power is consumed, the energy has to be fed into the grid. The decentralized energy management system DEMS is a learning system, which uses such experiences to improve the forecast for the next day, in order to guarantee a generation as optimal as possible within the grid area.

The minimum power of the fuel cell has been adjusted at 80 kW. In order to run the combined heat and power plants gently, they have to be operated for at least 1 h; afterwards an off-period of 1 h has to be observed.

In the morning the spa is closed for cleaning and opens at 2 p.m. The power of the fuel cell is continuously increased until full load. During the opening hours between 2 and 10 p.m. the combined heat and power plant 1 partly is in operation, partly the power is obtained from the grid. After the end of the opening hours, the fuel cell is shut down to half-load again, in order to cover the base need during the night.

After the operation time of roughly 1 year the operating dates are currently evaluated by the academic institutions, which are involved in this project. World-wide only nine companies had the opportunity by means of such a project to gain know-how concerning the operation of a 250 kW PEM fuel cell demonstration plant. The test program proved the operation behaviour and the suitability of use of the plant. Unfortunately, this kind of plant will not be further developed in the foreseeable future; therefore the operation experiences can only be used for the operation of fuel cell plants of another type.

4. A 250 kW MCFC fuel cell in an industrial energy supply system

This fuel cell project started in July 2001 and will finish in 2006. The official commissioning in February 2003 was a first important milestone. The aim is to collect operation experiences from a 250 kW molten carbonate fuel cell (MCFC), which is delivered from MTU (Motoren- und Turbinenunion, Friedrichshafen, Germany).

EnBW is the consortium manager, owner and operator of the plant. Michelin, Stadtwerke Karlsruhe and DaimlerChrysler are partners in that consortium. The project is funded by the ministry of economics and labour (BMWA) within the "Zukunftsinvestitionsprogramm, ZIP" with a 50% share.

Fig. 8. Hot Module at Michelin, Karlsruhe (*Source*: MTU).

The plant delivers electric power and steam to the tire factory. It is integrated in the local infrastructure, see Fig. 8. Steam is used all the year round in the base load. The tire production runs in 3-shift operation 8500 h a year. The steam generator is directly above the media supply and the exhaust air is in the counter current flow to the feedwater or steam. From the feedwater with 102 °C the SG produces 216 kg steam per hour with 16 bar and 200 °C, which means a capacity of 143 kW.

All relevant operating data from the MCFC process are collected, stored and evaluated via data communication from MTU and EnBW. The EnBW power plant company (EnBW Kraftwerke AG) as a 100% subsidiary of EnBW AG is in charge to operate the Hot Module. On site EnBW is assisted by the Michelin shift operators. In case of operating trouble they call EnBW in the "Rheinhafendampfkraftwerk" (RDK), a fossil power plant not far away from Michelin. In urgent cases MTU is attainable with a 24 h hotline. EnBW is responsible for the maintenance with aid of MTU. All operators (two from Michelin and four from EnBW) are qualified for that.

The activated charcoal filters have to be replaced several times (instead once a year) with expenses of about 15 k€ in the first 9 months of operation. The requested gas measurement every 10,000 m^3, respectively, every 10 days is also very unpleasant. MTU tries to find an optimized charcoal and we have been testing several types in the past without success.

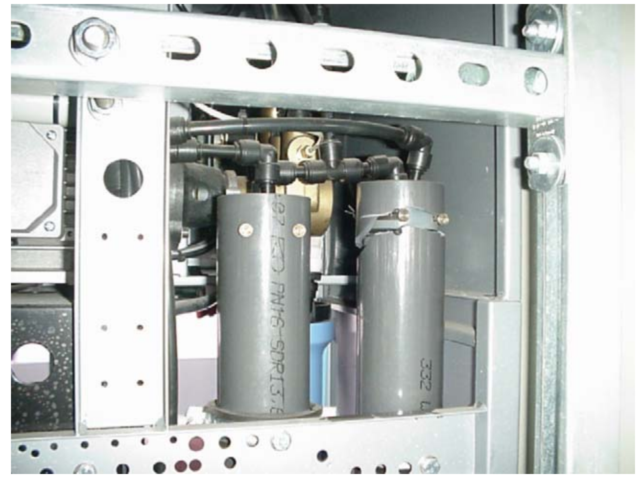

Fig. 9. Reverse osmosis pipe rupture (April 2003).

Maybe the rapid charcoal consumption is due to the discontinuous odour treatment from the gas supplier.

Due to the approval of operation an emission measuring was necessary between 7 and 9 July at different loading conditions with the results as follows, see Table 1. The total carbon and the carbon monoxide concentration are even in the part load conspicuously above the specified value. To the opinion of MTU a leakage at the catalytic burner could be the reason but it cannot be clarified during the operation of the plant.

Until June 2003 the load of the fuel cell could not surmount 185 kW (80%) due to a bug at the inverter software. The trouble shooting was very difficult but in June 2003 a new software version was loaded and so the operation of the plant was very successful.

At 100% load the current density is 130 mA cm^{-2} and the net load is about 230 kW. A proper measuring of the net efficiency was not possible due to an imprecise gas flow measuring. To avoid a damage of the stack it always has to be operated with hydrogen. Due to manufacturing tolerances and gas flow tilt the fuel cell has to be run with a gas overplus. At the end of October a new gas flow measuring was installed. The maximum electric efficiency was 45% at 215 kW and 46.7% at 203 kW net power.

Inside the water treatment two pipe ruptures occurred in April and June 2003. The fractured reverse osmosis pipe is shown in Fig. 9. The reason was a design failure. The new pipes have an optimized design and no more failures happened. The pipes were also changed in the other MTU plants.

Table 1
Mass concentration based on dry exhaust air under standard conditions

Parameter (mg N m^{-3})	50% load (108 kW net)	70% load (167 kW net)	Circa 100% load (219 kW net)	Specified MTU
CO	35	48	66	14
NO_x	<2	<2	<2	<2
Total C	16	26	30	5
Total C, nonmethane	<1	<1	<1	–
Ammonia	0.13	0.16	0.34	–

Table 2
Overview of the shutdowns

Date	Shutdown category	Comment	Duration
10 January 2003	Instrumentation/control	Incorrect inverter software	20 min
23 January 2003	Operation failure	Emergency stop button by an oversight	1 h
6 March 2003	Instrumentation/control	Load collapse due to incorrect inverter software	0 h
25 March 2003	Instrumentation/control	Incorrect inverter software	2 h
23 April 2003	Water treatment	Pipe rupture	26 h
20 May 2003	Electrical grid/media supply	Fresh air controller defect	No data
5 June 2003	Instrumentation/control	Mounting of new inverter software	1 h
13 June 2003	Electrical grid/media supply	Replacement gas-safety valve	5 h
22 June 2003	Water treatment	Pipe rupture	22 h
16 July 2003	Electrical grid/media supply	Power grid failure	40 min
17 July 2003	Instrumentation/control	Inverter alarm	8 h
25 July 2003	Water treatment	Replacement of pressure controller	5 h
23 August 2003	Water treatment	Pump leakage	2 h

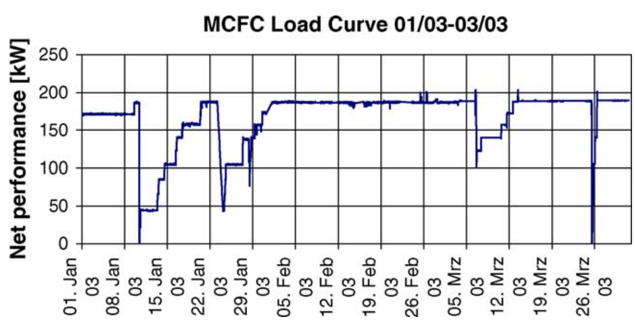

Fig. 10. Load curve from 1 January 2003 until 30 June 2003.

The first start-up was finished at 30 November 2002. Since operation has started several shutdowns or load reductions occurred, see Table 2. Fig. 10 shows for example the load curve from 1 January 2003 to 30 June 2003.

Up to now during over 8000 h of operation 1400 MWh of electrical and 400 MWh of thermal work have been generated. The time availability was at 98%. The different failures are revealing the complexity of the whole Hot Module and the media supply especially. We are looking forward if the promising results will continue in the further operation [1].

5. Summary and outlook

EnBW has three different fuel cell systems in various numbers installed and run at customers' sites. Natural gas has been the energy carrier for the generation of heat and electricity. The field test program showed that fuel cell systems could be operated according to customers' needs; the experiments showed also that there is ample space for improvements concerning reliability. Before full commercialization of the plants component life times of various subsystems of the fuel cell plants also need to be improved significantly.

Increased electrical efficiencies would be highly desirable whereas overall energy efficiencies are acceptable to both the customer and the environment. It is envisaged that the gap between theoretical and actually realized efficiencies can be closed with improved technologies or components. At current levels efficiency gains dwindle compared to "conventional" technologies.

In recent years a lot of technical improvements rendered lower prizes for fuel cell plants. However, plant prizes still need to further drop by about an order of magnitude to be commercially viable. It is foreseeable that technologically mature fuel cells at competing prizes will gain a significant market share due to the high public interest in fuel cell technologies.

Reference

[1] M. Edel, H. Frey, A. Kessler, W. Münch, Stationary fuel cells at work—an interim report, Fuel Cells 2004, No. 4, Wiley-VCH/Verlag GmbH & Co. KGaA, Weinheim, Germany.