European Virtual Fuel Cell Power Plant

System Development, Build, Field Installation and European Demonstration of a Virtual Fuel Cell Power Plant Consisting of Residential Micro-CHP's

(EUVPP, NNE5-2000-208)

A Project funded by the 5th Framework Programme of the European Commission

Management Summary Report

Content

1 Summary

The aim of “The Virtual Fuel Cell Power Plant” (NNE5-2000-208) was to develop, to install, to test and to demonstrate a virtual power plant consisting of 31 decentralized stand-alone residential fuel cell systems. The project was funded by the 5th Framework Programme of the European Commission.

The grid connected residential microCHPs produce both, electricity and heat for the individual use as well as electrical energy for the grid (4.6 kW_{el}, 9 kW_{th}). The field test should deliver important experiences of the installation and operation of the prototypes and to identify major hurdles on the way of commercialisation of microCHP Fuel Cells. The consortium consists of the following European partners: Vaillant (DE), Plug Power Holland (NL), Cogen Europe (BE), Instituto Superior Téchnico (PT), TEE University of Duisburg-Essen (DE), DLR (DE) through its department at Plataforma Solar de Almeria, Sistemas de Calor S.L. (ES), Gasunie Research (NL), E.ON Ruhrgas AG (DE), and E.ON Energie AG (DE).

One major objective was the development, installation and test of a Virtual Power Plant. The development of intelligent Energy Manager with various communication techniques as integral element of the virtual power plant was essential to make sure that the virtual power plant can be operated with benefits for both individual end-users and grid pursuer. For the operation of the residential CHP-units a Central Control System (CCS) was developed. This CCS communicates with the on site Energy Manager and allows the utilities to control the microCHPs in the case of a power peak demand and defined load profiles. The load profiles were sent by using wireless technologies as the mobile phone standard GSM and the radio ripple control.

The project was completed within the foreseen timeframe and has fulfilled the expectations of the consortium. All 31 field test systems were successfully installed and operated; no system has to be shut down during the project. The consortium has successfully demonstrated the operation of decentralized microCHP fuel cells as a Virtual Power Plant as well of fuel efficiencies of up to 90% and electrical efficiencies of greater than 30%. Within accumulated 138.000 running hours the low temperature (LT) PEM microCHP systems have produced nearly 400.000 kWh of electricity. About 50.000.000 measurement data were collected, checked and analysed.

Within the operation as a Virtual Fuel Cell Power Plant the capability to follow defined load profiles without relevant time delay has been successfully demonstrated.

Project status and results were disseminated and communicated in more than 150 speeches and presentations. Press-events as the start of the Virtual Fuel Cell Power Plant on 23 January 2004 have taken place. A number of press-releases were sent out and television, radio, newspapers and magazines have reported about the project. A final presentation of the project results has taken place in Brussels on 11 May 2005.

The project identified three major hurdles to be overcome in the development of a product for the residential mass market:

1. The costs must be reduced significantly to increase the technology's economic viability,
2. The system must be simplified to improve reliability,
3. The temperature of the heat output must be increased to become compatible with existing heating systems, and to give opportunities for tri-generation.

As one major result of the project further development efforts are already undertaken in order to overcome the identified hurdles. The high temperature (HT) PEM Fuel Cell, based on PBI (Polybenzimidazol) high temperature PEM membrane technology, offers a break through technology that has great potential to overcome the hurdles described above.

2 Aim and objectives of the project

From 2001 to 2005, under the EU 5th Framework Programme, Vaillant and Plug Power, together with distinguished European partners, successfully demonstrated the field operation of a “Virtual Fuel-Cell Power Plant” (EUVPP, NNE5-2000-208). The low temperature (LT) PEM microCHP fuel cell systems were installed in apartments, houses and small businesses across Europe.

The aim of “The Virtual Fuel Cell Power Plant” was to develop, to install, to test and to demonstrate a virtual power plant consisting of 31 decentralised stand-alone residential fuel cell systems. The grid connected residential microCHPs produce both, electricity and heat for the individual use as well as electrical energy for the grid (4.6 kW_{el}, 9k W_{th}). The field test should deliver important experiences of the installation and operation of the prototypes and to identify major hurdles on the way of commercialisation of microCHP Fuel Cells.

One major objective was the development, installation and test of a Virtual Power Plant. The development of intelligent Energy Manager with various communication techniques as integral element of the virtual power plant was essential to make sure that the virtual power plant can be operated with benefits for both individual end-users and grid pursuer. For the operation of the residential CHP-units a Central Control System (CCS) was developed by the University of Duisburg-Essen. This CCS communicates with the on site Energy Manager and allows the utilities to control the microCHPs in the case of a power peak demand and defined load profiles. The load profiles were sent by using wireless technologies as the mobile phone standard GSM and the radio ripple control.

The consortium consisted of the following 11 European partners:

Vaillant (DE) (project co-ordinator), Plug Power Holland (NL), Cogen Europe (BE), Instituto Superior Téchnico (PT), TEE University of Duisburg-Essen (DE), DLR (DE), Sistemas de Calor S.L. (ES), Gasunie Research (NL), E.ON Ruhrgas AG (DE), and E.ON Energie AG (DE) teamed up locally with partner EWE AG.

Figure 1: project consortium Virtual Fuel Cell Power Plant

The overall project costs have been kept nearly within the estimated costs at the start of the project. The total project costs came up to 8.337.571 Euro, with an EU contribution of 36 % which means 3.035.171 Euro.

Project status and results were disseminated and communicated in more than 150 speeches and presentations. Press-events as the start of the Virtual Fuel Cell Power Plant on 23 January 2004 have taken place.

Figure 2: Official start of EUVPP at Vaillant in Remscheid together with international guests from politics, academia and media on 23 January 2004

A number of press-releases were sent out and television, radio, newspapers and magazines have reported about the project. In the framework of the test location at BMW in The Hague the BMW Group launched the so called “The H_2ague project” and published a brochure, which describes the project in some more details. In 2004 the German Fuel Cell Initiative (IBZ – Initiative Brennstoffzelle) has added some information about the EU-VFCPP-project on their website (www.ibz-info.de). A final presentation of the project results has taken place in Brussels on 11 May 2005. Final presentation slides are available at contact’s address at the end of this management summary.

Figure 3: Final project presentation in Brussels in May 2005

3 Work packages and partners contribution

The project was structured into 8 work packages:

Workpackage 0: Coordination
Workpackage 1: Environment Analysis
Workpackage 2: Basic/Detail Engineering
Workpackage 3: Procurement
Workpackage 4: Production of Test Units
Workpackage 5: Preparation of Field Test
Workpackage 6: Field Demonstration Test
Workpackage 7: Dissemination Strategy

The following table shows the work related to the partners of the project.

	Vaillant	Plug Power Holland	Cogen Europe	Instituto Superior Téchnico	University of Duisburg-Essen	DLR	Sistemas de Calor	Gasunie Research	E.ON Ruhrgas AG	E.ON Energie/EWE AG
Corodination	L									
Development of the Central Control System	■				L					
Development, Adaptation and Operation of the Communication System	■				L					
Dissemination	L	■	■	■	■	■	■	■	■	■
Environment Analysis			L			■	■			
Euro Reformer Development		L								
Field Test in Germany	■	■			■				L	■
Field Test in Portugal	■	■		L	■	■			■	
Field Test in Spain	■	■			■	L	■		■	
Field Test in The Netherlands	■	■			■	■		L	■	
Installation in field Test Objects	■			■		■	■	■		
Measurement analysis and evaluation					L	■	■	■	■	■
Measurement Equipment				■	■	■	■	■	L	■
Non-technical training	L		■							
Preparation of field test	■			■	■	■	■	■	■	■
Procurement	■	■								
Production of test units	■	■								
System Development for micro CHPs	■									
System simulation and optimization						■				
Technical Training	■	■								
The Virtual Fuel Cell Power Plant	■	■	■	■	L	■	■	■	■	■

participation …. ■
Lead …. L

Figure 4: work and project partners

4 Function and technical description of the Fuel Cell Heating Appliance

A Fuel Cell Heating Appliance is build up from a fuel cell generator device with an additional peak boiler, hot water storage and total energy management module (see Figure 5). The system generates electrical power and heat (microCHP). An Energy Manager matches the heat production of the system to the heat demand of the object, communicates with the fuel cell, peak boiler and hydraulics. The energy manager also functions as the primary communication interface between the FCHA and the "outside world".

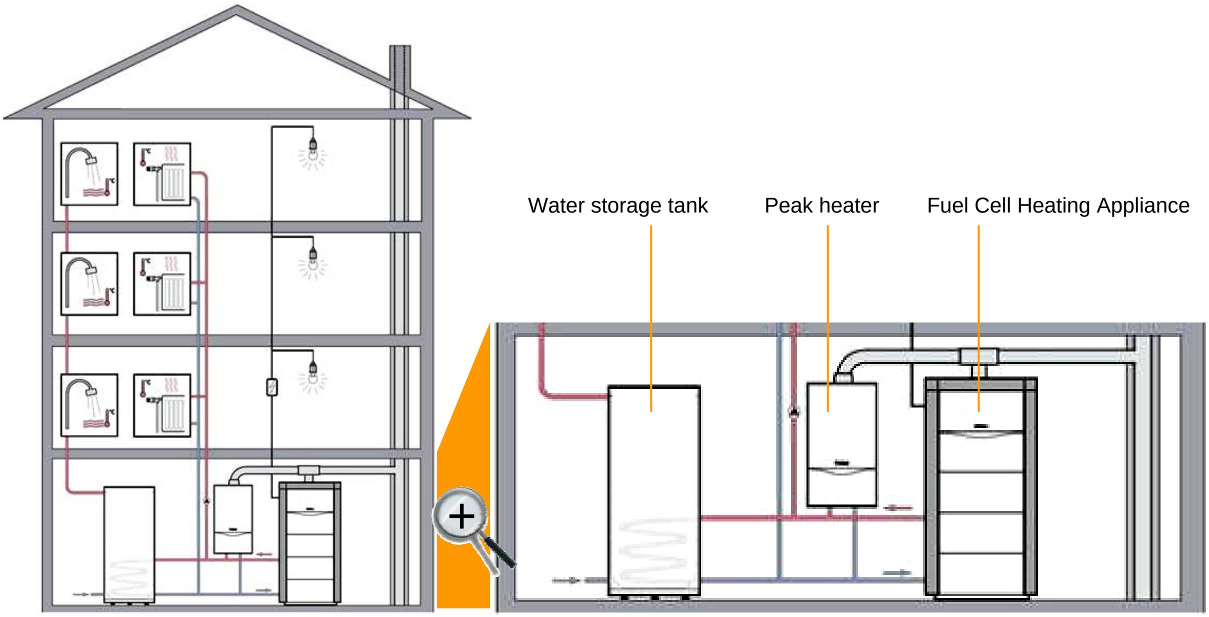


Figure 5: Principle of domestic microCHP fuel cell heating appliances

The Fuel Cell system is fed by natural gas, which is converted in a fuel processor into hydrogen rich reformat. The reformat reacts in the power generation module with air into water. In this reaction the electricity and heat are produced. The heat is used to heat the hydraulic loop of the house, while the DC electricity is led to the inverter. The inverter is connected to the public grid of the house and converts the DC power into 230V, 50Hz AC power.

Heart of the fuel cell unit is the fuel cell stack, which is located in the power generation module. In the cell, hydrogen and oxygen undergo an electro-chemical reaction and change into pure water. The structure of an individual cell consists of a plastic membrane coated on both sides with a catalyst – the electrolyte membrane. This is arranged between two conductive plates, which discharge the current and supply the gases. Due to the catalytic effect, the hydrogen gives up it electrons on one side of the membrane. The positively charged cores of the hydrogen (protons) pass through the electrolyte membrane, and on the other side they meet the oxygen, with which they react to form water. In the process, an exchange of electrons takes place; the flow of DC current is converted into AC current by an inverter, before being supplied to the building's mains network. In addition, heat of reaction is generated, which can be utilized for heating purposes. In order to achieve a higher output, the cells are connected together, 88 cells one behind the other, and combined into a cell stack.

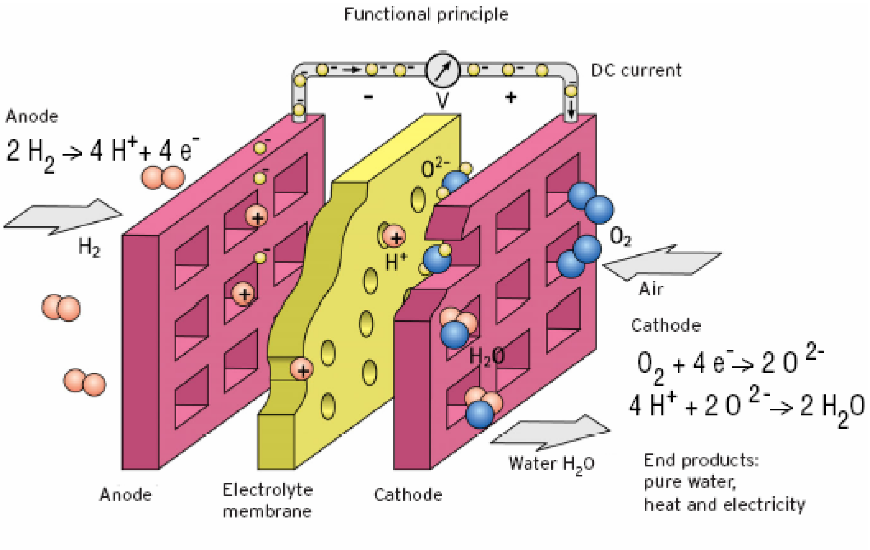
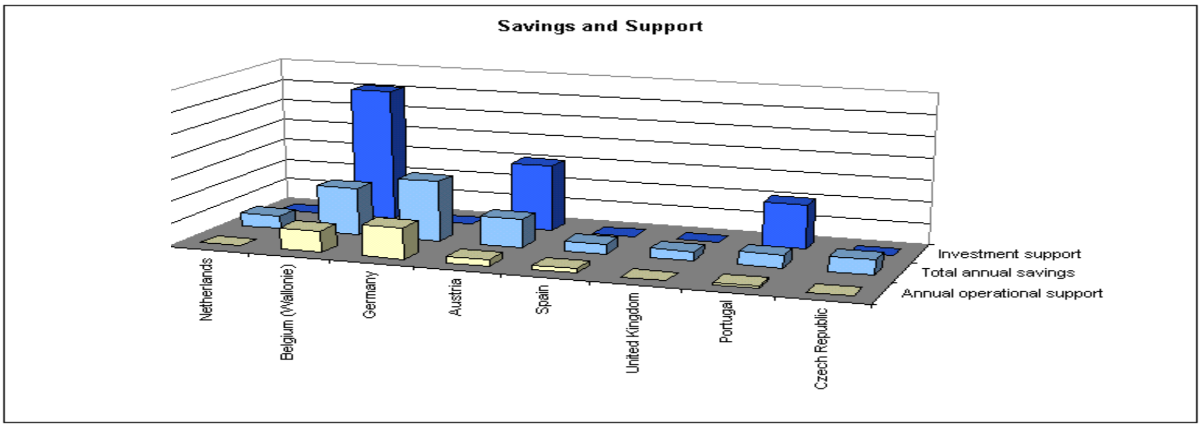


Figure 6: function of a fuel cell

The hydrogen required for the PEM cell is produced by reforming the natural gas. In the presence of a catalyst, the hydrocarbons (C_nH_m) are exothermally, partially oxidised with oxygen (O_2) or endothermally reformed with water vapour (H_2O). During both reactions, carbon dioxide (CO_2) and hydrogen (H_2) are produced.

5 Environment Analysis

One main outcome has been the establishment of a micro-CHP economic model developed by COGEN Europe, notably by using the expertise of the COGEN Europe working group on micro-CHP. The application allows to model and to compare the economical performance of identical micro-CHP units in different European countries. The results help to benchmark national support frameworks for micro-CHP and they support decision-making of equipment suppliers in relation to investment decisions. The model covers the following countries: Austria, Belgium, Germany, Netherlands, Spain, United Kingdom, Portugal and the Czech Republic.



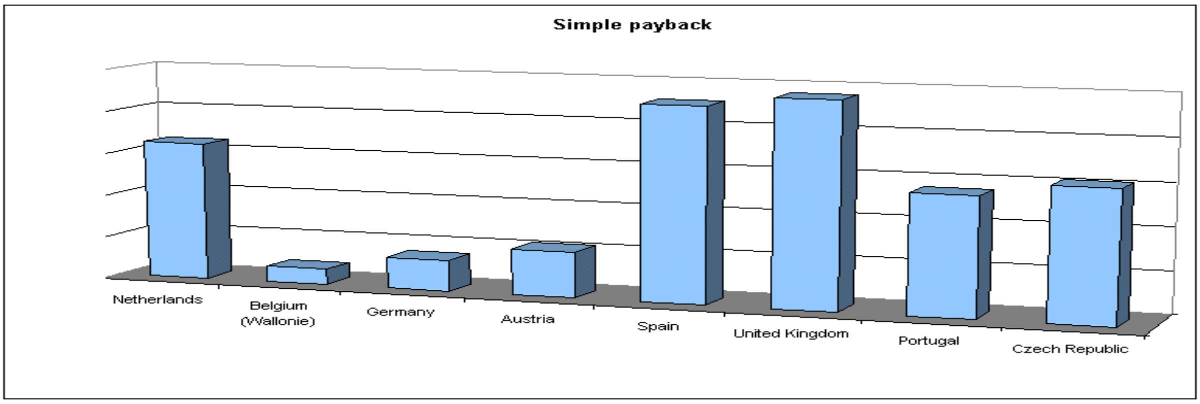


Figure 7: example of the microCHP economic model of COGEN Europe

6 Selection of field test facilities, installation of field test systems

Main objective for the selection of the field test facilities was to find buildings that would enable fuel cell running times providing real operation conditions. Besides that, a number of technical restrictions due to the development status of the fuel cell heating appliances had to be taken into account. In preparation for the search for proper field test facilities, a criteria catalogue was established. The existing installations in the field test facilities had to be adapted to include the components necessary for the fuel cell systems. For this purpose, a general hydraulical and electrical lay-out for the integration of fuel cell units was developed.

To prepare the installers and the service personnel for the installation, operation and service of the fuel cell heating systems, a technical training had to be completed. For this purpose, there were two courses at Vaillant in Remscheid in 2002. Additional training was given at the locations during installation and start up of the systems. The following figure shows the locations of EURO 1 and EURO 2. In summary there were installed 6 EURO 1-systems and 23 EURO 2-systems. 2 systems were installed at Vaillant in Remscheid as Verification built.

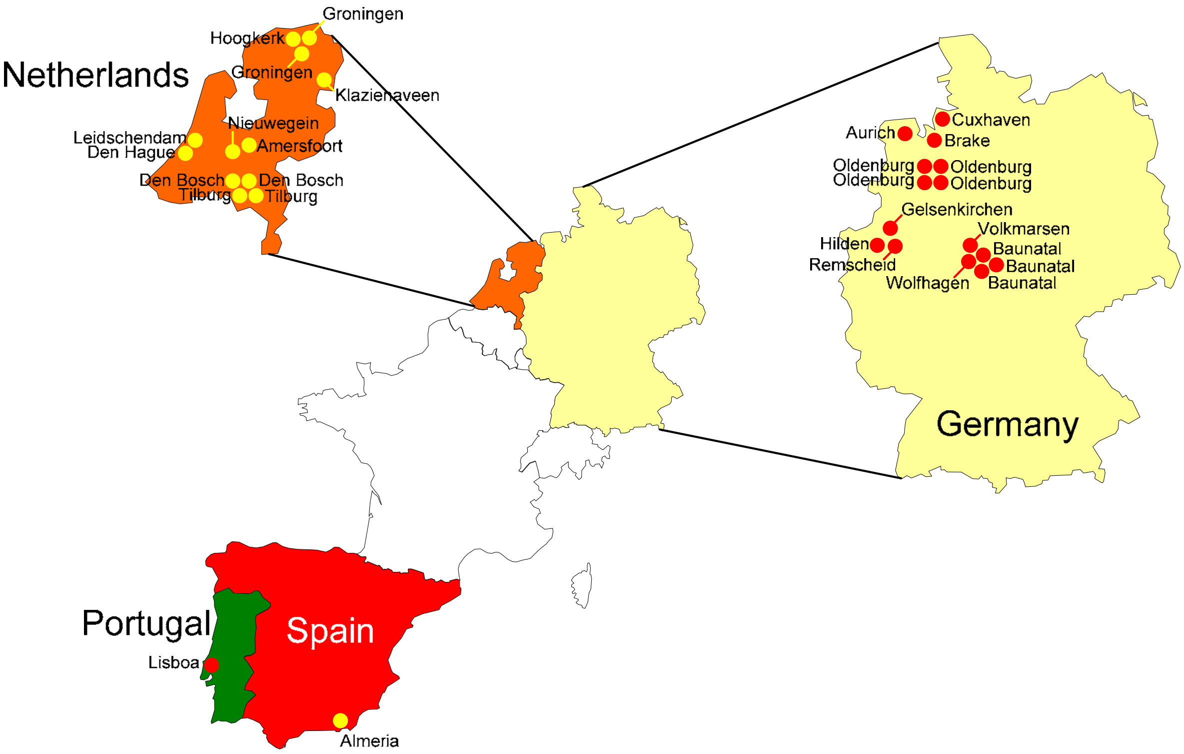


Figure 8: map of field test locations in EUVPP

Figure 9: Field test system in Baunatal near Kassel (Germany)

Parallel to the search of objects the concept for the measurement system and the communication within the fuel cell network had to be developed. This means that after inspection of the hydraulic scheme the number of measuring points as well as the interval used to store the data had to be fixed. After that the necessary hardware had to be chosen and in parallel to that either the concept of how to make sure the gathered data is correct (plausibility checks) as well as the wanted results (e.g. energy balances) that had to be calculated with the single values has been developed. The number of measurement points was dependant on either what results to gain but the costs for the procurement for the number of installations had also be taken into consideration.

It was decided, taking the number of all systems, the number of measurement points and the overall system running time into account, that a 15 minute interval would be useful to keep the total amount of data in a manageable size. Also this is common standard in Germany for the exchange of data related to energy (e.g.: hub-schedule). On one hand load peaks are flattened using this interval – a shorter one would be useful – on the other hand the amount of data doesn’t get too large. The hardware selection followed the demand from either the use of the systems in the Virtual Power Plant as well as reliability and minimal running costs. Another option wanted from the utility side was the possibility to get a message in case of an emergency and to respond to it.

Therefore the hardware solution offered by partner EWE was chosen. It fulfilled all needs just described. In case of an emergency call from the system, it would be handled by a person in the control room of the utility. This service was available 24 hours a day.

7 Virtual Power Plant

Communication chain within the VFCPP

The components on site communicated via a LON field bus protocol whereas the further communication between the system on site and the control system located at partner EWE was across a telephone line using either an analogue or ISDN modem. Data logger on site stored the values and was read out by the central building control system of EWE once a day. The server is connected via the internet to the central control system at TEE which also comprehends a data base. The following figure shows the principle of the communication chain in EUVPP.

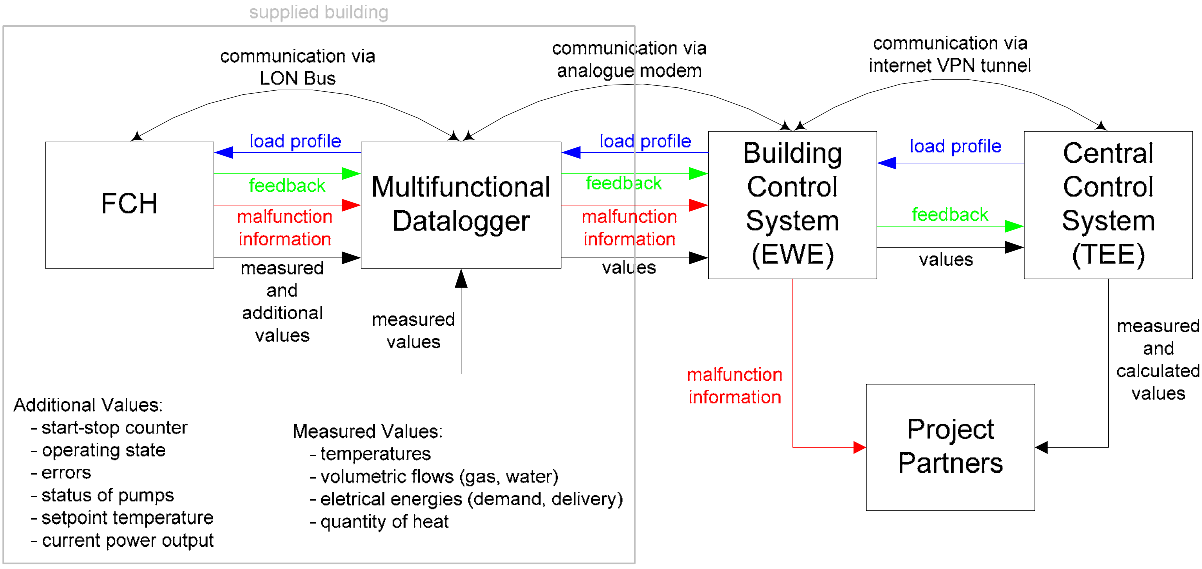


Figure 10: Complete principle of the communication chain within the VFCPP field test

Since the communication between the utility control system at EWE and the central control system at TEE was carried out via a Virtual Private Network (VPN) tunnel using the TCP/IP protocol the according hardware and software respectively had to be purchased and prepared.

When the preparation was finished extensive communication tests had to be done from one end of the communication chain (the central control system at TEE) to the other end (the FCHA on site). This of course applied to both directions.

Implemented Communication

To test different communication ways than just the analogue or ISDN modem line for the control of the systems within the VFCPP it was decided to install the radio ripple control (RRC) of the company ‘Europäische Funkrundsteuerung’ EFR (www.efr.de) at five fuel cell systems.

The principle of the radio ripple control is basically the same as with other ripple controls which are used for storage heating and other appliances which only need a plain on or off signal. The communication between the controlling and the controlled system is happening via long wave radio signals.

The main difference to the modem line is that the RRC is a one way communication system (unidirectional). It is not possible to get information about the system status or any other answer from the fuel cell system on site back to the control system. The implementation within the field test was such that different settings of the RRC's receiver relays either forced a fixed electrical load level or one out of five predefined load profiles stored within the energy manager of the fuel system was selected. These load profiles had to be developed and further refined during the project. Another option was the general switch of the fuel cell system between heat or power oriented mode. Theoretically the six relays of the receiver offer 26 = 64 settings which could cause a certain incident.

The allegation of a certain power output level for the fuel cell allows the system to follow externally generated long term load profiles, which in this case don't have to be sending all at once, as well as immediate power demand changes. In case of a load change the single fuel cell system gets a signal from the central control system via the radio ripple control to change its power output.

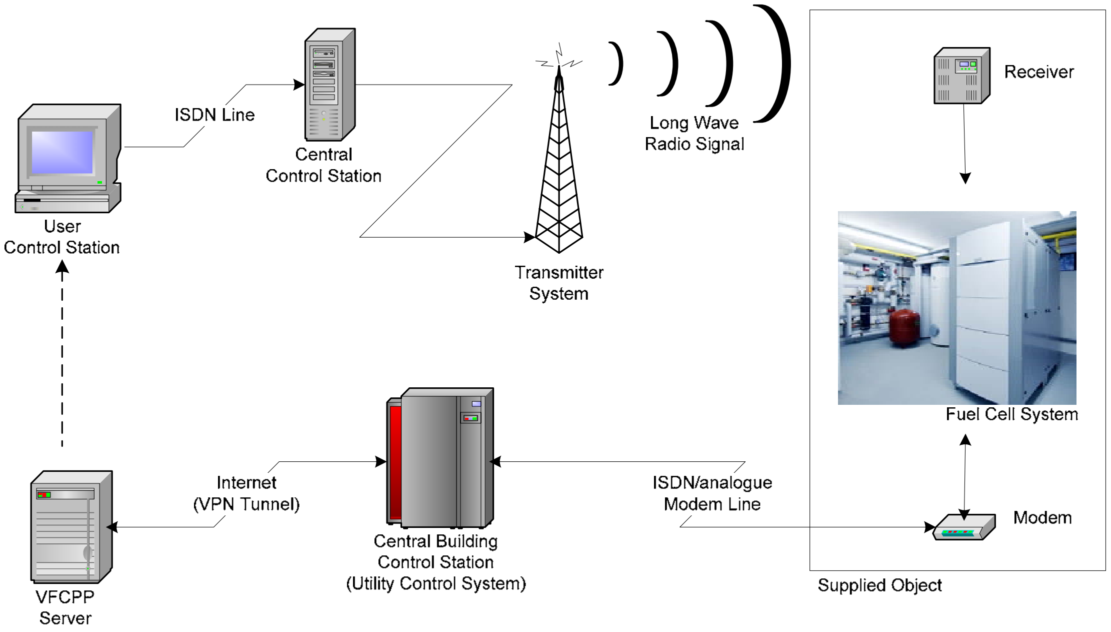


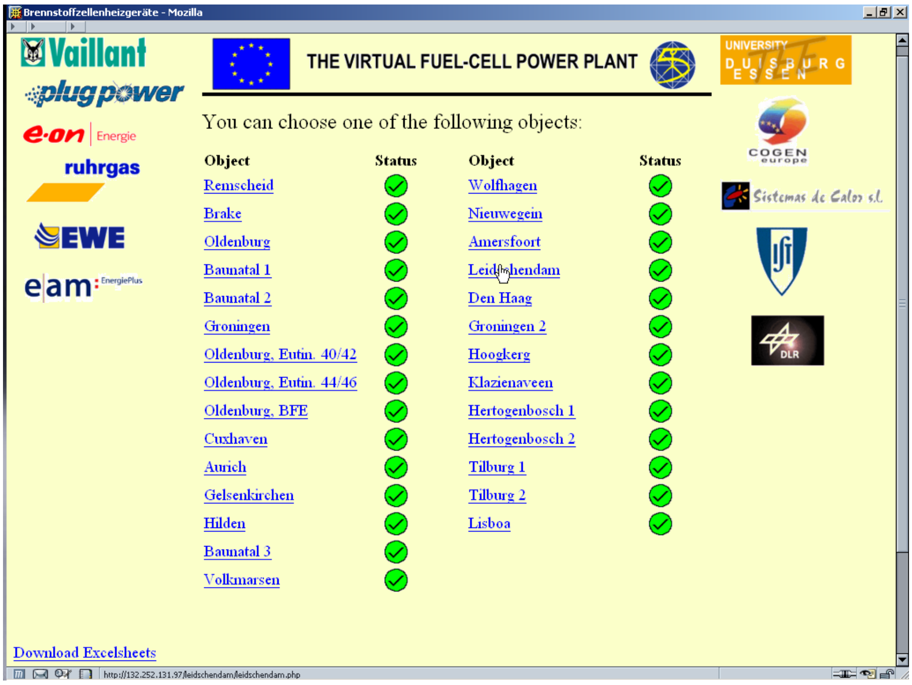
Figure 11: The two communication ways within the VFCPP project

The user control station for the RRC as well as the VFCPP server is located at TEE, whereas the RRC central control station is located at EFR and the central building control station at EWE. Tests showed that the technology works without any problems.

Web based access to measured data

Parallel to the tasks explained above a web-based system was installed at TEE to give all the project partners access to the measured data from any location via the internet. The status of the system can be checked, the error message in case of a downtime and the operational mode at one glance. For a more detailed analysis the time interval (number of days) of all different measuring points and calculated values can be selected and will be displayed as a figure (Figure 13).

To give all partners the opportunity to work with the measured values themselves a mechanism to download excel files containing the wanted values for the desired time period has been implemented.



THE VIRTUAL FUEL-CELL POWER PLANT

You can choose one of the following objects:

Object	Status	Object	Status
Remscheid	✓	Wolfhagen	✓
Brake	✓	Nieuwegein	✓
Oldenburg	✓	Amersfoort	✓
Baunatal 1	✓	Leidschendam	✓
Baunatal 2	✓	Den Haag	✓
Groningen	✓	Groningen 2	✓
Oldenburg, Eutin. 40/42	✓	Hoogkerg	✓
Oldenburg, Eutin. 44/46	✓	Klazienaveen	✓
Oldenburg, BFE	✓	Hertogenbosch 1	✓
Cuxhaven	✓	Hertogenbosch 2	✓
Aurich	✓	Tilburg 1	✓
Gelsenkirchen	✓	Tilburg 2	✓
Hilden	✓	Lisboa	✓
Baunatal 3	✓		
Volkmarsen	✓		

Download Excelsheets

Figure 12: Web interface to check system status

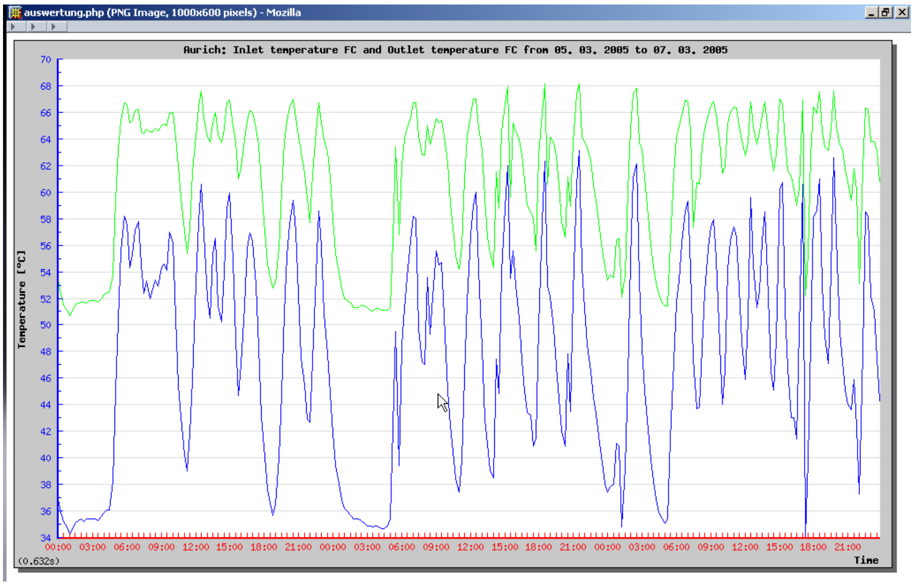


Figure 13: Web interface to check measurement values

Results of the test week in the end of 2004, where selected systems received a load profile, are shown in Figure 14. If the system doesn't have any technical problems it can follow the requested demand very good.

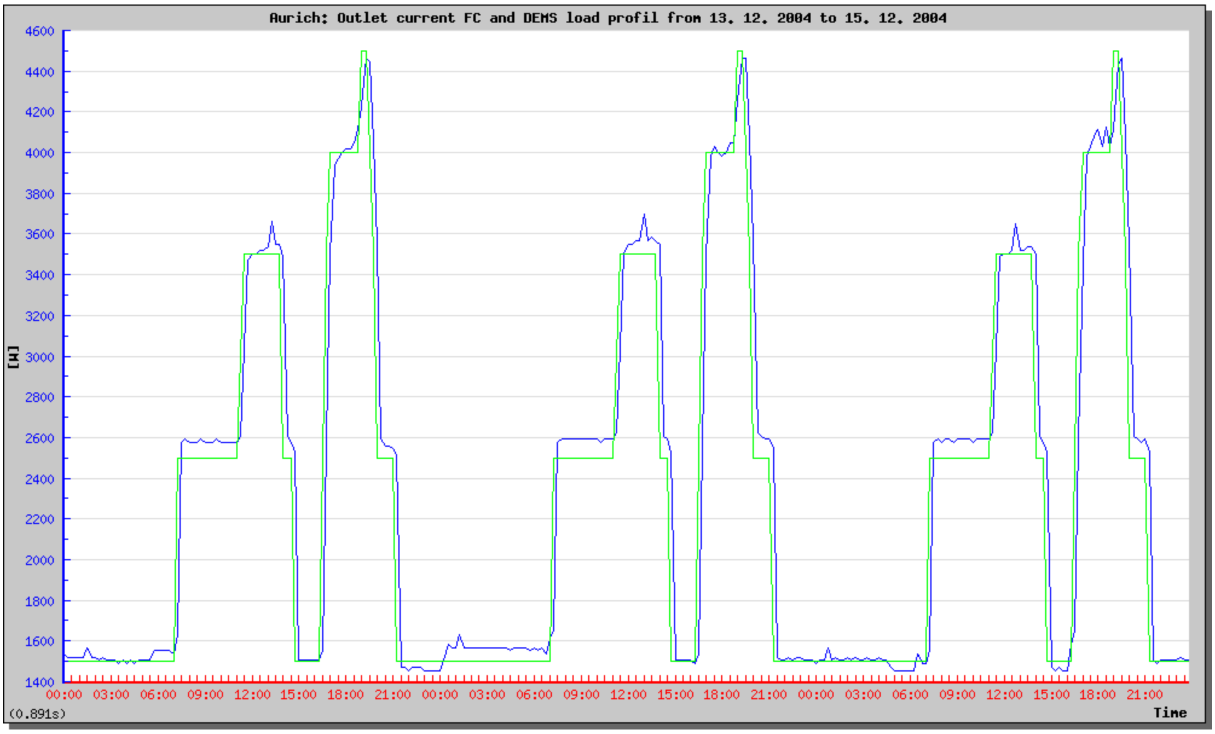


Figure 14: Comparison load profile actual fuel cell output (Aurich)

8 Field Test Experiences, Conclusion And Outlook

The project was completed within the foreseen timeframe and has fulfilled the expectations of the consortium. All 31 field test systems were successfully installed and operated; no system has to be shut down during the project. The consortium has successfully demonstrated the operation of decentralized microCHP fuel cells as a Virtual Power Plant as well of fuel efficiencies of up to 90% and electrical efficiencies of greater than 30%. Within accumulated 138.000 running hours the low temperature (LT) PEM microCHP systems have produced nearly 400.000 kWh of electricity. About 50.000.000 measurement data were collected, checked and analyzed.

Total project costs	**8.337.571 Euro**
EU contribution	**3.035.171 Euro**
share of EU contribution	**36 %**
share of partners contribution	**64 %**

Table 1: Project costs and financial contribution of the European Commission in FP 5

Within the operation as a Virtual Fuel Cell Power Plant the capability to follow defined load profiles without relevant time delay has been successfully demonstrated

In summary EURO 1 and EURO 2 systems have achieved the following operation data:

period	**EURO 1**	**EURO 2**	**TOTAL**
Number of systems	6	23	29
operating hours	46.814	91.311	138.125
MWh el	133.492	265826	399.318

Table 2: Overall field test operation data

With regard to maximum efficiency and modulation range the field test has shown the principle suitability of fuel cell heating appliances in domestic applications. With regards to system integration and reliability/durability the field test results led to improvements which were already performed during the field test or in the requirements for further developments.

Important general outcome is that there is not ***one*** mayor technical hurdle or problem but several components within the whole fuel cell system have to be optimized towards a reliable and cost effective system.

The project identified three major hurdles to be overcome in the development of a product for the residential mass market:

1. The costs must be reduced significantly to increase the technology's economic viability
2. The system must be simplified to improve reliability
3. The temperature of the heat output must be increased to become compatible with existing heating systems, and to give opportunities for tri-generation

Within the operation as a Virtual Fuel Cell Power Plant the capability to follow defined load profiles without relevant time delay has been successfully demonstrated. Based on the experiences gained out of EUVPP Vaillant and its partners are now working on a High-Temperature PEM Fuel Cell system in order to overcome above mentioned hurdles.

9 Contact

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Partner's websites:

1	Vaillant (DE) (project co-ordinator)	www.vaillant.de
2	Plug Power Holland (NL)	www.plugpower.com
3	Cogen Europe (BE)	www.cogen.org
4	Instituto Superior Téchnico (PT)	www.ist.utl.pt
5	TEE University of Duisburg-Essen (DE)	www.uni-duisburg-essen.de
6	DLR (DE)	www.dlr.de
7	Sistemas de Calor S.L. (ES)	www.sistemasdecalor.com
8	Gasunie Research (NL)	www.gasunie.com
9	E.ON Ruhrgas AG (DE)	www.eon-ruhrgas.com
10	E.ON Energie AG (DE)	www.eon-energie.com