The role of fuel cells in buildings as a part of sustainable energy systems

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1. SYNOPSIS

Fuel cells offer interesting opportunities to open up the market for small-scale domestic cogeneration and incorporate the potential for a paradigmatic re-organisation of electricity systems.

2. ABSTRACT

In the near future, fuel cells (FC) will be introduced into the market as decentralised, highly efficient energy sources (electricity and heat) both for single-family homes and larger buildings. However, FC are only one component of a wide range of options for sustainable energy supply in buildings, so that their possible contribution has to be analysed within the context of the building as a whole and the surrounding (local) energy system. This paper investigates the role of FC in buildings as part of the overall energy system and discusses the implications for energy policies. It is the objective

- To provide a brief overview of the state of the art of fuel cell heating systems and the operation conditions;
- To analyse the performance of fuel cells compared with other options of domestic energy supply;
- To investigate the interdependencies and new relations which result from the integration of fuel cells into the energy system, especially into the power grid;
- To point out decisive determinants of market introduction; and
- To identify policy implications and recommendations on how to enhance the diffusion of fuel cell heating systems.

3. INTRODUCTION

A new old star is born – in recent years the idea of generating electricity in fuel cells by a "cold combustion" of hydrogen and oxygen has attracted rapidly growing scientific and political attention. Drawing on an electrochemical mechanism discovered already in the 1830's, fuel cells are now seen as a key technology for a sustainable energy supply and they are considered to become part of the backbone of a solar hydrogen economy in the second half of the 21st century.

As opposed to carnotic engines like the internal combustion engines, the electrochemical reaction within fuel cells is characterised by much higher theoretical efficiency and better load performance, e.g. with regard to load shifts. Moreover, the process itself produces nothing but water vapour and is practically free of noise and vibrations, which limits the local emissions (FCCG 2000, FETC 1999). Environmental impacts, however, occur in relation with the fuel processing (reforming) either directly within the module or at an earlier stage of the fuel chain (e.g. related to H_2 production). Although the question how to organise a sufficient and environmentally benign fuel supply based on renewable sources still remains open, fuel cells offer an efficient source of electricity and heat production which promises to reduce significantly resource consumption and greenhouse gas emissions.

Stimulated by the prospect of a clean energy generation, all over the world public and private R&D efforts are directed to a further improvement of the technology and the breakthrough is expected within the next 15-20 years (Winter 2000). In its recently published Work Programme Update of Energy Research, for example, the EU Commission strongly emphasises the strategic role of fuel cells (EU 2000).

When looking at the predicted benefits of fuel cells it appears to be justified to attribute a key role to this technology. But do they really represent the "salvation technology" which delivers available solutions to all problems, in every situation? As in the case of other "golden solutions" in the past, the answer can hardly be taken from unreflected euphoria. Any sound strategy demands a closer look at the limits and interdependencies of application.

Hence, in this paper we want to make a contribution to the necessary critical discussion of the future role of fuel cells as a part of sustainable energy systems while focussing on the aspect of small-scale stationary applications, namely on their use as energy source for private households. Fuel cell heating systems (FCHS) for single and multi-familiy homes represent a technology which has the potential to open up a new era of domestic energy supply. By providing a highly efficient option for small-scale combined heat and power production (CHP) they offer offers interesting opportunities to decrease the overall energy consumption and GHG emissions of private households compared to separate supply of electricity and heat.

4. FUEL CELL HEATING SYSTEMS: STATE OF THE ART AND CURRENT PROJECTS

Fuel cell heating systems (FCHS) have entered the stage of technical demonstration and first field tests have demonstrated the technical viability of the concepts. Currently, German and Swiss R&D activities play a leading role in Europe, and activities concentrate on two different concepts of fuel cell heating systems, i.e. the high-temperature, SOFC-based approach and a low-temperature, PEMFC-based concept:

The **Polymer-Electrolyte-Membrane fuel cell (PEMFC)** concept is only suitable for low-temperature heating systems (heating rooms, hot water). It can be turned off like any conventional combustion engine. Moreover, this cell technology will be used in mobile and portable applications, too, so that most probably synergetic effects can be expected in terms of cost reduction due to mass production.

Vaillant (Remscheid, Germany) is one of the leading European manufacturers of gas-fired heating systems. In co-operation with the fuel cell manufacturer Plug Power (USA), a fuel cell heating system has been developed which aims at substituting gas-fired heaters and boilers (Klinder 2000). In order to benefit from normal re-investments cycles of traditional technologies, full compatibility of size, dimensions and geometrics of fittings to existing installations has been a guiding design principle. The system consists of a fuel processor for the reformation of natural gas to pure hydrogen, the PEMFC stack, which produces DC electricity and heat of ca. 90°C, a power conditioner to transform the generated DC into AC, an additional burner to cover heat demand peaks during wintertime, and a standard heat exchanger and warm water storage.

The decision to build on a Polymer-Electrolyte-Membrane fuel cell (PEM) was motivated by the sufficient heat level (90°C) and the prospects of benefiting from synergies with portable and mobile applications. As a disadvantage of the PEM concept, however, the fuel processing (reforming of natural gas to hydrogen) causes technical problems and still represents the critical bottleneck for commercialisation. On the other hand, most components of the peripheric infrastructure such as heat exchangers are taken from conventional systems, others are sufficiently developed like the DC/AC inverter stemming from photovoltaics.

In the year 2002 Vaillant plans to introduce a first fuel cell heating system suitable for multi-family dwellings (4-10 units) which produces 4,6 kW_{el} and 7 kW_{th} up to 50 kW_{th}, depending on the size of the additional burner. The system is expected to achieve an efficiency of electricity generation of η_{el} = 35-40% and a total system's efficiency of some η_{total} = 80%. Due to the technical characteristics of fuel cells, load can be varied between 20-100% without major losses. A smaller unit designed for single family homes should be launched in 2004.

As a very important implication of decentralised power generation, Vaillant explicitly emphasises the integration of the private fuel cell system into the public grid. In co-operation with the German utility RWE and other European partners, a field test has started in 2001 which explores the possibilities to aggregate 50 FCHS to a "virtual power plant" which is centrally controlled and monitored by the utility (see below) (Vaillant 2000).

The **Solid-Oxyd Fuel Cell (SOFC)** concept can be used for generating domestic heat as well as industrial process heat due to its high temperature level of up to 1000°C which requires continuous operation, i.e. the cell has to run permanently. Due to the high exhaust temperature, it can be combined with a conventional gas turbine or gas and steam process plant but this option is still in an early stage of R&D.

The consortium of Sulzer Hexis AG and Hoval (Vaduz), the Swiss market leader of boilers, draws on this concept of a high-temperature fuel cell of the Solid-Oxyd Fuel Cell (SOFC) type (Sulzer Hexis 2000). Since September 1998, 6 prototype units have accumulated some 50,000 hours of operation during field tests (until 2001) which underline the technical feasibility of the technology (Raak 2000).

Operating at 950°C, the SOFC stack is less dependent on fuel gas quality and less susceptible to a catalytic contamination by CO. This reduces the technical complexity of the system and decreases the costs for fuel processing. Exploring this advantage, other fuels such as reformation of light oil and biomass or the direct use of biogas are being tested as alternatives to natural gas.

The Sulzer Hexis fuel cell heating system aims at providing electric power between 0,05-1 kW_{el} and heat between 4 - 25 kW_{th}, the current electric efficiency of η_{el} = 25-30% should increase to 40-50%, corresponding to a total system's efficiency of some η_{total} = 90%. A market introduction is foreseen for the second half of 2001 but the system still suffers from technical problems e.g. related to material problems caused by high temperatures, which are not yet sufficiently solved.

5. FUEL CELL SYSTEMS AS DOMESTIC ENERGY SOURCE

Characteristics of fuel cell heating systems and compatibility with demand-side requirements of domestic applications

Contrary to other new technologies without comparable alternatives, fuel cells are facing sharp competition from existing and well-established technologies for domestic heat supply. So the question is, what additional benefits or which better performance does the FC technology promise? As a starting point for the following discussion, Table 1 describes the major characteristics of (prototypes of) fuel cell heating systems.

Apart from the technical feasibility of fuel cells, it is important to obtain an overview of the end-use requirements of the market they want to step into. Table 2 compares the energetic demands of several house types as an example for illustrating the compatibility with fuel cell heating systems.

Table 1. Characteristics of fuel cells for domestic applications

		Polymer-Electrolyt Fuel Cells			Solid-Oxid Fuel Cells		Conventional block-type CHP
		in general	Vaillant/ Plug Power	HGC/ Dais Analytic	in general	Sulzer Hexis	
Power Range (kW)	Electric	< 0.1 … > 250	4.6	3	< 0.1 … > 1.000	1.05	> 20 … > 3.000
	Thermal	s.a.	7	8	s.a.	3	40 ... 4.000
Electr./Heat Ratio		Ca. 1			Ca. 1		0.5 ... 0.9
Working & usable Temperature	°C	< 100			Ca. 1.000	Ca. 800	< 500
System Efficiency	Electric	> 40%	> 35-40%	< 37%	> 50%	> 25-30%	20-40%
(status)	Total		90%	85%		90%	75-95%
(target)	Electric	40%-50%			55-60%	40-50%	
Oxydable Fuel		H_2			H_2, CO		(Hydro-) Carbons
Used Fuel		Natural Gas			Natural Gas and others		Gas, Gasoline
Fuel Reforming		External			(partially) internal		-
Gas Cleaning		S, -OH, < 10-20 ppm CO			yes (simpler)		-
Advantages		· Cold-start feasibility · Dynamic · Lighter than SOFC			· High Efficiency · Compatible to various fuel gases		· Cheap · Light · See PEFC
Disadvantages		· Gas Reforming & Cleaning · Dynamics of Reforming · Catalyst (precious metals)			· No Shut down · High-Temperature materials		· Less efficient · Emissions
Remaining Problems		· Durability · Efficiency · Costs · early demonstration status			· Durability · Materials · Costs · Early demonstration status		· Emissions

Sources: Gummert 2000; Vaillant, Sulzer Hexis (2000); Schmitz, Koch 1995.

Table 2. Requirements of domestic applications in middle Europe

		Single-family home					Multi-Family home	(Local) Heating Grid
	House Types (Germany)	Passive	Low Energy	Standard 1995	Standard 1984	Average of stock		
Annual Requirements								
Heating	*kWh/(m²a)*	< 15	30-70	100	150	220	146	114
Hot Water	*kWh/(cap.a)*	750-900						
Electricity	*kWh(cap.a)*	(300+300 kWh basis)	ca. 950 + basis of about 600 kWh/a					
Reference Case		*4 Persons, 120 m² Floor*					*see [1)]*	*see[2)]*
Heating	*kWh/a*	< 1.800	3.600-8.400	12.000	18.000	26.400	213.500	2.575.000
Hot Water	*kWh/a*	3.300					44.700	675.000
Heating & Hot Water	*kWh/a*	< 5.100	6.900-11.700	15.300	21.300	29.700	258.200	3.250.000

	House Types (Germany)	Single-family home					Multi-Family home	(Local) Heating Grid
		Passive	Low Energy	Standard 1995	Standard 1984	Average of stock		
Perc. Hot Water	*%*	> 65%	48%-28%	22%	15%	11%	21%	21%
Electricity	*kWh/a*	1.500	4.300				56.500	1.400.000
Loads (kW)								
Heating	*design load W/m^2*	10	30	50	68	> 100	70	67
Hot Water	*Permanent load W/cap*	85-100					105	102
Electricity	*Base load W/cap*	25-100					52	60
	Peak load W/cap	750					350	533
Reference Case		*4 Persons, 120 m^2 Floor*					*see[1)]*	*see[2)]*
Heating	*base load kW*	Zero						
	peak load kW	1,2	3,6	6	8,16	> 12	98	1.500
Hot Water	*perm. load kW*	0,375					5,1	77
Heating &Hot Water	*base load kW*	0,375					5,1	77
	peak load kW	1,575	3,975	6,375	8,535	> 12,375	103,1	1.577
Electricity	*base load kW*	0,1 - 0,4					2,5	45
	peak load kW	3 *(36 sec. Average)*					17	400
Design of Fuel Cells, exemplarily								
to meet basic heating requirements[3)], kW_{th}		0,75					10,2	154
to meet basic electrical requirements[4)], kW_{el}		0,33 -1,33					8,33	150

1) Assumption: 20 apartments, 48 persons, 1460 m^2 floor, 1968 standard.

2) Assumption: 300 apartments, 750 persons, 22.500 m^2 floor.

3) Reasonable partial load factor assumed to be 50% of maximum thermal power.

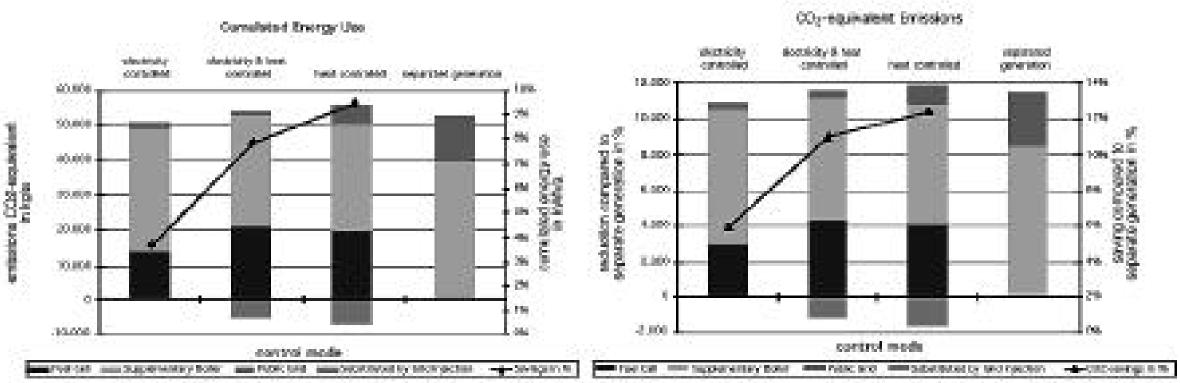
4) Reasonable partial load factor assumed to be 30% of maximum electrical power.

Sources: Vaillant, VDI 1988, Hutter 2000, Prognos 1995, Feist 1998, Feist 2000

Environmental benefits of fuel cell based domestic energy systems

Simulation calculations for an average single-family home[1], taken from Hutter, Krammer (2000) and combined with our own calculations, compare a 1kW_{el} PEFC[2]-system with conventional supply. Interestingly, as a result of the simulations under different FC control strategies, environmental benefits in terms of reduction of cumulated energy use and CO_2 are less convincing than one might have hoped and expected; they are in the range of 10 percentage points (Figure 1). All in all, advantages of the fuel cell system compared to modern conventional CHP are estimated to be in the range of 5% (Dienhart 1998).

Figure 1. Cumulated energy use and CO_2-reduction by a FCHS in a single-family home



Conclusions

It can be stated that, although still in a pre-market phase of development with unpredictable costs of mass production, fuel cell heating systems promise to be **at least as efficient as today's electricity generating system**, especially when including the net losses of the grid up to customer's door. Moreover, it has to be kept in mind that the major share of the domestic electricity needs (60-90%) of a single-family home can be supplied by the fuel cell. If fuel cell's electric efficiency goes up only a few percentage points, total efficiency and related savings will rise significantly.

Furthermore, the following conclusions can be derived:

· *No technical restrictions for an application:* as illustrated, there is no general technical restriction in using fuel cells as a heating system because they can be built small enough to adapt to even the smallest demand. From a technical point of view fuel cells can support or replace nearly every heating and hot water supply system.

· *Favourable electricity-to-heat ratio:* the high electricity-to-heat ratio of fuel cells of nearly 1 seems to be just the right specification to meet the base loads both of electricity and hot water for households, which are of the same dimension independent of the insulation standards. Whereas the electricity demand up to peak loads can probably still be served by the fuel cell in this case, a considerable part of heating demand has to be satisfied by a supplementary (conventional) burner. Due to this decoupling from heating requirements fuel cells are not restricted to middle- or northern-European space heating markets but could in principle also be used to provide hot water in southern countries.

· *Hot-water storage required:* sufficiently large hot-water storage is a necessary precondition for adapting the fuel cell system to the hot water and electricity demand and to act as a buffer to changes in electric demand and the related load shifts.

· *Other hot-water systems deteriorate efficiency:* it is obvious that alternative hot water generation, e.g. by solar collectors, affect the base load and thereby the degree of utilisation of FCHS. In this regard, strong technical competition can be identified.

· *Bigger means better*: in multi-family homes and local heating grids, the base loads increase relatively (to single-family homes) while peak loads decrease because of the equalising effect of combining statistically fluctuating demands. Hence, the conditions improve both for combined heat and power use in general and for fuel cells in particular.

- *Environmental performance depends on the integration into the energy system:* energy efficiency gains, greenhouse gas abatement and the impact on the whole energy system strongly depend on the control mode of fuel cell systems. Taking interactive links into consideration, sophisticated steering algorithms under the umbrella of interlinked power plants could offer interesting options for future use. In this respect, fuel cells offer great flexibility due to their favourable partial load performance, i.e. down to a load of 20% hardly any losses in generation efficiency occur.

6. INTERRELATIONS OF FUEL CELL HEATING SYSTEMS WITH OTHER TECHNOLOGIES

Installing fuel cell heating systems is only one of the options to reduce household heating's carbon dioxide emissions, and only one of the chips in the heating system game. Due to the fact that money only can be spent once it has to be investigated what other options exist and relationships between them: Where are the competing technologies in the market? What is the potential for positive interdependencies and synergies? In principle, strategic competition can be found between various concepts:

Fuel cells vs. conventional combined heat and power generation

Block-type CHP units provide basically the same service as FCHS and thus represent competition. From a realistic point of view, however, it has to be considered that the market entry (on larger scales) of cost-effective and competitive fuel cell systems (especially high temperature systems) is perhaps ten years away. In the meantime another generation of conventional block-type heat and power plants can be built and paid back. Therefore it is more likely that conventional CHP will not prevent the future installation of fuel cells, but, on the contrary, will prepare and provide the CHP infrastructures into which fuel cells can be integrated.

Fuel cells vs. renewable energies and saving technologies

As seen above, fuel cells „need“ the base load of producing hot water in order to run in an efficient way. But, for example, hot water can be produced by solar thermal technology and heating demand can be substantially reduced by better insulation and other saving measures:

- *Restoring houses: expensive and effective*
  In typical middle European buildings three quarters of heating needed can be saved by an energetic restoration. Examples show that nearly every building can reach the low energy house standard in this way (ASEW 1995). But as seen in the table above, even if heating is reduced, the demand for hot water normally is sufficient to run a fuel cell. In reality, however, there will surely be massive competition between investing the money in insulation on the one hand and paying extra costs for a high-tech "toy" like a fuel cell on the other.
- *Building passive houses: lost ground for fuel cells?*
  Newly built passive houses have ultra low energy needs for heating. Although this low energy need together with hot-water heating demand could generally be covered by a sufficiently small-scaled fuel cell system, other systems would be more adequate because passive houses are usually heated by warm air and not warm water. Recovered exhaust air is still warm enough to feed a small heat pump system and money can be spent more efficiently by installing solar collectors or photovoltaic modules, which is already done by most passive house owners. If several passive houses are aggregated to "low-energy" settlements, however, the common heat generation via a local heat grid has to be reconsidered.
- *Solar energy for hot water (and heating) purposes: a killing factor for FCHS*
  As already mentioned, providing hot water by solar energy erodes the potential for fuel cells. Because of the FC's higher investment costs (compared to conventional heating systems) from today's point of view, they seem to be forced to meet a high percentage of utilisation. This is in contradiction to the use of solar systems, for example in single-family homes or other dwellings with advantageous "roof-surface-to-hot-water-need" ratios, which provide nearly all hot water during the summer period and a share of it the rest of the year. In this case, base load of heat is set at zero a long period of the year. Under these conditions, fuel cell heating systems have to be shut down or have to dispose all of the produced but unwanted heat in the atmosphere (which might still be ecologically reasonable under the particular condition when the fuel cell surpasses the local public electricity grid in terms of electrical efficiency).

In our latitudes, meeting heating requirements by solar thermal energy is a question of seasonal heat storage. Until now such systems are still too expensive to penetrate the mass market. Hence, in the future it is quite possible that seasonal heat storage will become an integrated part of energetically self-sustaining housing, which will then eliminate the need for any kind of fossil-based heating system.

Stationary vs. mobile application of fuel cells

In the long term, fuel cell vehicles could, at least theoretically, be used as „Power Vehicles“ when parked, i.e. as power (and heat) generating plants which are connected to stationary grids at their parking lots equipped with heat (and electricity) storage (Nurdin 2000, Kissock 1998). Due to the premature state of the concept, a sound evaluation cannot be made yet, but in the case of a widespread application, the use of mobile energy sources will surely compete with stationary technologies.

7. THE NEW DIMENSION: INTERDEPENDENCIES BETWEEN FUEL CELL HEATING SYSTEMS AND THE ENERGY SYSTEM

Due to the innovative nature of FCHS, we do not yet know enough about the costs and benefits of real fuel cell heating systems, or such systems that we could perhaps envisage as serial products of tomorrow. However, it appears that fuel cell heating systems will not offer the one and only optimal technological solution for every application. Rather, it will be necessary to search for the optimal strategy case by case depending on the various surrounding conditions, like the possibility of solar thermal integration (sufficient roof area), potential for heat pumps, passive house standards (for new buildings), installing heat grids (together with newly built settlements) and so on.

In our view, however, the particular importance of FCHS cannot be seen in its function as an isolated appliance alone. More than the heat supply itself the predicted side-effects of decentralised, small-scale heat and electricity generation incorporate the potential for becoming a key issue. Distributed power generation is one of the strategic elements of future, more sustainable energy systems because a large number of small units would require less stand-by capacity, less fixed capital, faster technical progress due to the system's shorter life cycles, and, altogether, more flexibility. Moreover, widespread generation units facilitate market entry of and transition to renewable energies, which mostly are of a distributive nature. Installing decentralised CHP already prepares appropriate technical structures and establishes the needed organisational framework. In this respect, the impact of FCHS can be quite substantial:

Linking the heating market with the power market

So far, the energy system has been divided into two parts: a mainly locally organised heating market with autonomous users that interact with local heating equipment constructors and sellers, installers and fuel suppliers on the one side, and a previously monopolised and now partially liberalised electricity market with few big producers and regional distributors on the other. Combining heat and power generation breaks up this division, and mass produced fuel cell heating systems could significantly change the electricity market’s playing field. As a first sign, the big electricity utilities in Germany are trying to keep the leading role by entering strategic partnerships with fuel cell heating constructors, organising field tests and trying to predefine the fuel cells control strategies (e.g. to avoid grid feed-in of electricity). On the other hand, new operation models (e.g. third-party financing) could open new opportunities for energy service enterprises (see below).

“Virtual Power Plant”

Linked together, controlled and co-ordinated in their power generation, a various number of small generation units can build a so called "*virtual power*" plant. If installed with sufficiently dimensioned heat/ hot-water storage, fuel cells as well as conventional heat and power systems can provide or buffer peak load demands. On the road to and within an electricity system based on renewables they can furthermore level out natural fluctuations in renewable energy supply. This would provide the desperately needed backbone for renewable energy sources such as photovoltaics and wind power. Investigations have already been undertaken, for example in Denmark, and a joint project of Vaillant and some electricity and gas suppliers is being started (see above).

Fuel cells as the bridge to the solar age?

There is a common understanding that today's fossil-based energy system has to be changed into a renewable-based one within the next century where the future fuel for transportation and storage purposes could be hydrogen (Winter 2000). Due to the fact that fuel cells are the most efficient energy converters both with regard to hydrogen fuel and to natural gas they promise to serve as a technology bridge between today's and tomorrow's energy system. However, in the context of domestic energy supply of a solar hydrogen economy it can be questioned in how far

- Future renewable hydrogen is produced locally (from local energy sources) or centrally (e.g. from imported solar electricity). In the last case it could be reasonable that houses are served directly with solar electricity instead of hydrogen, and therefore use heat pumps instead of a fuel cell for heating purposes.
- Future homes need a heating system at all. Perhaps we will see such sophisticated storage systems so that all active heating and hot water systems become irrelevant.

8. IMPLICATIONS FOR MARKET INTRODUCTION

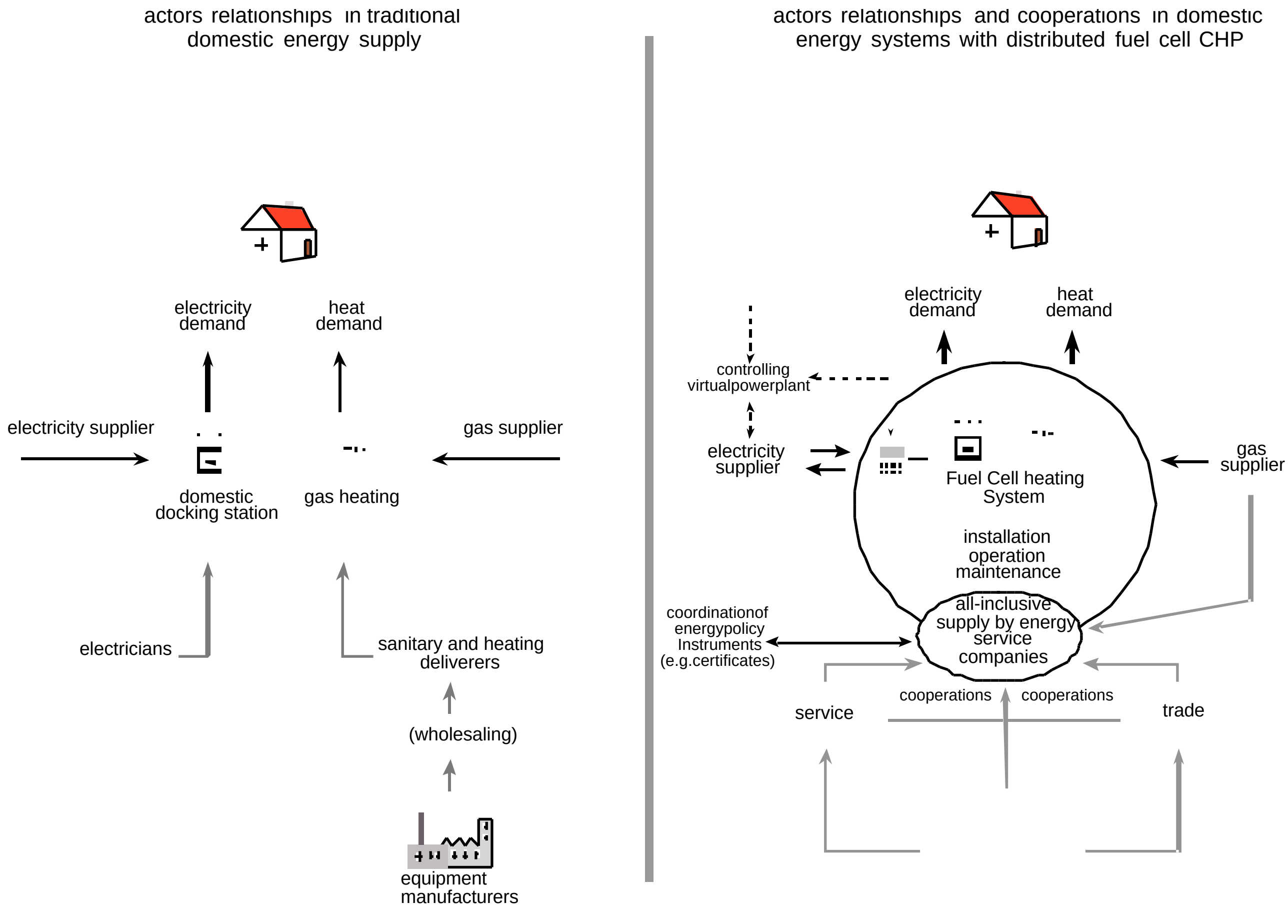
As we have seen, fuel cell heating systems offer a wide range of interesting implementation cases and some exciting prospects for the future. In any case, they represent an innovation to the traditional market for heating systems. As opposed to areas like consumer electronics, however, at the moment the end-user is barely interested in the technical aspects of his heating system and only little knowledge about efficiency, emissions, etc. can be found. Today, the heating system is a black box without any further appeal; it is hidden in the cellar. Accordingly, the specific value added and the environmental benefits of a fuel cell heating system – especially from a system's perspective - will hardly motivate customers to pay higher prices or to take technical risks during the market introduction phase. Therefore, technical reliability, convincing performance and a competitive price will be mandatory preconditions for a broader market introduction of fuel cells.

Obviously, prices have to be comparable to alternative options such as condensing boilers, heat pumps, conventional oil fired boilers, etc. Considering the premature stage of the fuel cell technology at the moment, the first field test units correspond to investment costs of some 50,000 Euro per kW_{el}. According to Vaillant, this level has to be reduced to 1,500 Euro per kW_{el} in order to meet market requirements. A cost reduction of such dimension, however, can only be achieved through learning effects related to mass production. Vaillant estimates that a total accumulated output of 100.000 units has to be achieved before this target can be passed, assuming a cost reduction in the order of 20% per doubling of accumulated production. Once this initial phase will be overcome, Vaillant predicts an output of 100,000 units p.a. in the year 2010 which corresponds to 2% of the current European market for boilers of ca. 5 Mio. units p.a.

A competitive price alone, however, will hardly be a sufficient precondition for market success. As seen in the case of condensing boilers, the conservative attitude of buyers and installation contractors can hinder the penetration of innovative technologies. This is even more true if the new option represent a highly complex solution. As seen above, a fuel cell is not only a substitute for traditional equipment but represents a remarkable shift of paradigms in the field of domestic energy supply (Figure 2). Compared to the conventional situation of separate supply of electricity and heat, fuel cells

- Introduce an innovative, unknown technology which demands new qualifications in terms of installation, operation and maintenance of the contractors involved,
- Make the private home owner become an independent power producer, and
- Turn the family home's celler into a knod of a decentralised power generation network (virtual power plant).

Figure 2. Shift of paradigms in the field of domestic energy supply induced by FCHS



Taking into account that a self-activating demand for fuel cell systems without specific value added to the end-user cannot be expected, the market introduction of the FCHS will depend on a supply push. The manufacturers and other involved parties have to take a pro-active role in order to increase the attractiveness of the new solution. For this reason, the key to the market success of FCHS is commonly seen in "one-stop solutions", providing a complete service package to the customer. It is foreseen that manufacturers, licensed installation contractors and/or utilities will take care of installation, operation and maintenance of the device and will co-ordinate the integration of the CHP into the public grid. Obviously the widespread dissemination of such energy services will represent the precondition for realising the concept of a virtual power plant (see above).

The starting conditions for such service offers are quite favourable since heat related energy services have already been introduced to the market so that necessary competence and experience is available (MBW 1999). Compared with other approaches of third-party financing and performance contrasting schemes, heat services which demonstrate the highest growth rates and most favourable market prospects might push the introduction of FCHS.

9. CONCLUSIONS AND POLICY IMPLICATIONS

The implementation of fuel cell heating systems in buildings can provide a useful contribution to sustainable energy systems. The small-scale production of heat and power promises to be a convincing solution for significant shares of the domestic heat market which cannot be served by solar heat. Moreover, the widespread installation of grid connected fuel cells will contribute to a paradigmatic re-organisation of the electric power system. A self-maintaining market introduction, however, can hardly be expected. As seen, initial extra costs and other barriers will most probably impede a fast diffusion of this option. In order to realise the assumed benefits, therefore, public market-transformation policies are needed.

Information activities can benefit from the current high-tech image of fuel cells as a clean technology. In this regard, fuel cells might become as "sexy" as PV panels, this effect should be deliberately exploited for social marketing. Moreover, the fundamental electrochemistry can easily be integrated into the curricula of schools and universities, preparing the next generation of customers.

A market breakthrough within the next decade appears to be realistic if the learning effects can be met and the cost target reached. Corresponding to initiatives in the field of renewable energy, the **acceleration of mass production** can be supported through temporary subsidy schemes which aim at mitigating the initial cost hurdle. In analogy to the 100,000 roof programmes to promote PV cells, a 100,000 cellars initiative could contribute to accelerate the accumulation of sales up to the break even value mentioned above.

As a decentralised CHP plant, FCHS are subject to the related **energy policy regulation**. In some countries, policy schemes provide additional incentives to increase the share of CHP that might be applied to FCHS as well. In this context, national experience a mix of instruments to enhance the market penetration of renewables strongly emphasises the advantages of an integrated approach, combining investment support with variable incentives such as guaranteed feed-in compensation (BMU 2000). The German Renewable Energy Act (Erneuerbaren Energien Gesetz EEG) and the resulting boom in solar power capacity represents an illustrative example of such a politically driven market development.

The necessity to design "one-stop solutions" concerning the installation, operation and maintenance of FCHS induces **new qualification requirements** for contractors who are traditionally divided into electricians, plumbers, etc. A FCHS combines many aspects and therefore demands an interdisciplinary qualification that is not yet delivered by the conventional structures of professional education and training. Comparable to the IT business, totally new professions and the related curricula, institutions and so on have to be created. The energy agency of North Rhine-Westphalia, for example, has recently established the new qualification of a "solarteur", specifically trained for solar energy systems (EA NRW 2000).

10. REFERENCES

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11. END NOTES

[1] Assumptions: 4 persons, building standard 1968, 146 m2 living space, 4,500 kWh/a electricity consumption, 23,900 kWh/a heating energy demand, 3,230 kWh/a demand for hot-water (Hutter, Krammer 2000).

[2] Assumption: electrical efficiency between 30 and 37%; minimal partial load factor of 20%