# ADVANTAGES OF DECENTRALIZED ELECTRICITY AND HEAT SUPPLY FOR BUILDINGS, USING FUEL CELLS.

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***Abstract.*** *The fast development of fuel cells technologies helps to consider their use in decentralized energy supplies. They have an advantage over solar power: In addition to investments by a handful of start-ups, several corporations are spending more than \$1 billion annually on fuel cell research. This technology is tout as a way to wean nations*

*off foreign oil, as fuel cell systems extract their hydrogen from natural gas, and to rid the countries of coal-fired and nuclear power plants. Fuel cells are also money-savers. Given the cost benefit of natural gas over gasoline and the fuel cell's more efficient extraction technology, experts predict that fuel cell systems will become attractive when they reach $1,000 a kilowatt in the next seven to 10 years. Fuel cells will then save money in places where utilities are charging more than 10 cents per kilowatt-hour, offering energy security, energy quality, and environmental quality.*

## 1. General description of the proposal in countries with access to Natural Gas NG resources.

For several reasons, in certain countries natural gas is commercialized at very low prices. Argentina is one of those countries. For long years, electricity had been generated in Argentina by hydro energy (some 50%), by thermal energy (some 40%) and by nuclear energy (some 10%). The resulting mix was commercialized at the gross electricity market at about 32 mils per MWh (US$ 0,032/kWh). Nowadays, using the combined cycle generation (gas turbines plus steam turbines using the former wasted process heat from the gas turbine cycle) in about 33% of the total argentine active generation park of some 17 GW, the resulting mix can be commercialized at only 28 mils.

Normally, small households as well as big office or apartment houses, are connected as well to the electric grid as to the natural gas distribution system, using simultaneously both energy services, for lightning and powering electrical devices the former and for heating and cooking purposes the later. Consequently, as analyzed in some papers by different authors, a typical middle class household pays for both energy services together, as a yearly average, some US$ 120 per month.

The expected presence of PEM fuel cells on the market (to be used in combination with reformers producing hydrogen from natural gas, in small 10kW units with an output capacity of some 7 kW thermal and 3 kW electricity and at prices in the order of about US$5.000 per unit) will substantially modify the commercial energy demand. As analyzed by the same authors, the mentioned typical middle class household will be able to reduce the energy services bills to only some US$ 70 per month, using only the gas connection and the combination of PEM fuel cell and reformer described later.

The same criteria may be applied to the energy consumption prognosis for large buildings. In this case, a very careful study must be done in each case, analyzing the required balance between thermal and electricity needs, in order to optimize the size of the fuel cells to be installed, and, consequently, the overall costs of the energy provision to the building.

Some guidelines for developing a mathematical model to be used in each case are also proposed, contemplating the specific thermal and electricity demand and assuming current costs for the kWh of electricity and for the cubic meter NG, in order to obtain the price-optimal system (fuel cell - commercial energy provision).

## 2. Strategic advantages.

A flexible, decentralized energy system allows the simultaneous generation of both electricity and heat, exactly covering the user's demand. A service based on fuel cells fed by NG is the first step to an integrated Hydrogen Energy System. The second step would be the use of renewable primary energy sources, for instance, wind energy, to produce pure $H_2$ by electrolysis. This alternative is of particular interest for countries with the possibility of implementing large wind farms (onshore or offshore). The strategic advantage becomes evident once the no dependence of fossil fuels for electricity generation is considered. Besides that advantage, hydrogen may be used as an energy accumulator as well as an energy vector. If hydrogen is produced using a renewable primary energy source and stored as pressurized gas, or in the liquid phase or by means of metallic hydrides, the entire prime energy offer may be used time independent and electricity and heat may be generated only when really needed. And last but not least, the possibility of a decentralized electricity generation system eliminates the necessity of transmission lines. Resuming, no more dependence of fossil fuels coming from abroad, as well as a more rational use of electricity, as it is generated in accordance with the real demand and without losses due to transmission lines.

## 3. Increased anti-terrorist security

Doubtless, high pressure NG-ducts are less vulnerable to sabotage as power lines are, or as any nuclear or thermal powerhouse. It is relatively easy to produce severe damage to a power line and black out even several big cities for a considerable time extension. In the case of an underground high-pressure gas duct, not only the sabotage would not be so easy, but also the rehabilitation of the service would demand less time. The same could be said for a distribution network.

## 4. Schematic lay out of a fuel cell.

In the next section, different fuel cells operating nowadays will be presented. All of them act according to the same principle, shown in the following diagram (Fig.1). Cathode and anode are separated by an electrolyte and are covered on the inner face by a catalyst. On the anode, molecular hydrogen is atomized, adsorbed by the catalyst and split into a proton $H^+$ and an electron $e^-$ On the cathode, oxygen, in most cases coming from the air input, is also atomized and adsorbed by the catalyst. It recombines then with the proton $H^+$ that traveled through the electrolyte and the electron $e^-$ that traveled through the electric load. Surplus air or oxygen as well as water vapor is liberated at the cathode and excess hydrogen is liberated at the anode. Also a given amount of heat is liberated and may be used.

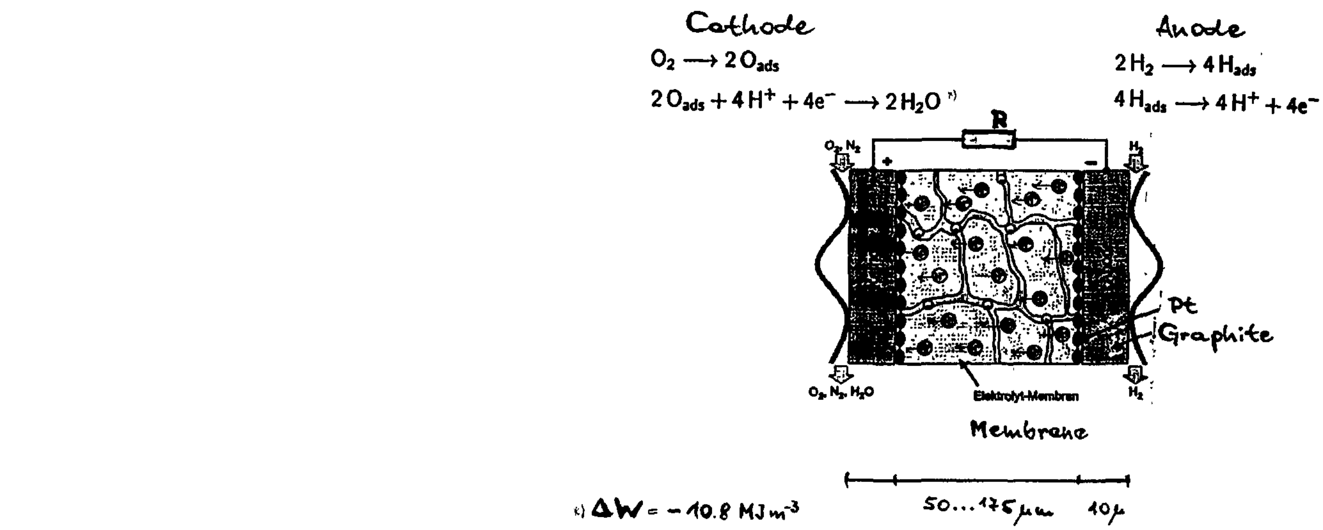


**Figure 1.**

## 5. Different types of fuel cells.

The different types are presented in (Fig.2). Values and composition of the input gases are given, as well as the average operating temperature, type of electrolyte used in each case and their average efficiency. Historically, the alkaline cell, AFC, is the oldest developed and has been used and is still widely used in quite different applications. The first space missions had been equipped with this type of cells.

The Proton Exchange Membrane Cell, PEM, (Fig.3) is the other known low temperature cell. Several automobile producers are experimenting with this type of cells and their cars will most probably be in series production in the very near future. This type of cells is also of great interest for its use in the theme of this presentation. The BEWAG utility of the City of Berlin in Germany has a 250 kW unit of this type currently in operation.

FUEL CELL

| | | Fuel | Temperature | Electrolyte | Electrical efficiency |
|---|---|---|---|---|---|
| LOW | | | | | |
| | Alkaline AFC | pure $H_2$ pure $O_2$ | 60-90 °C | 30 % Potash lye | Cell: 60-70 % System: 62 % |
| | Membrane **PEM** | $H_2$ $O_2$, air | 50-80 °C | Proton exchange membrane | Cell: 50-68 % System: 43-58 % (Supply of the air loader) |
| MEDIUM | Direct methanol **DMFC** | $CH_3OH$ $O_2$, air | 80-130 °C | Proton exchange membrane | Cell: 20-30 % |
| | Phosphoric acid **PAFC** | Natural gas, Biogas, $H_2$ $O_2$, air | 160-220 °C | Concentrated $H_3PO_4$ | Cell: 55 % System: 40 % |
| HIGH | Molten carbonate **MCFC** | Natural gas, coal gas, Biogas, ($H_2$) $O_2$, air | 620-660 °C | Molten $Li_2CO_3$, $K_2CO_3$ | Cell: 65 % System: 55-60 % (intern reforming of natural gas) |
| | Solid oxide **SOFC** | Natural gas, coal gas, Biogas, $H_2$ $O_2$, air | 800-1000 °C | $ZrO_2/YO_3$ | Cell: 60-65 % System: 55 % (intern reforming of natural gas) |

Figure 2.

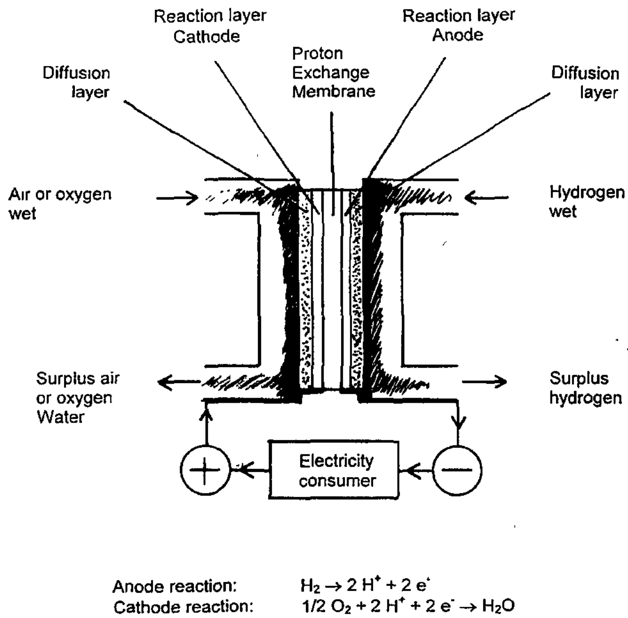


Figure 3.

In the range of medium temperatures, the PEM cell may also be used fueled with CNG in cars, provided that they have a reformer unit on board, for splitting the methanol into $H_2$ and $CO_2$.

It should be noted that the Proton Exchange Membrane is made of very special materials, with different names and covered by patents by their manufacturers, characterized by its property of being only permeable to protons. In this type of cells, the catalyst is Pt, very sensitive to CO and $CO_2$, gases that should be avoided in order to improve the lifetime of the cell.

The membrane, covered by patents by their manufacturers, are, as shown in Fig. 4, molecules containing only one hydrogen atom, loosely linked to the molecule and therefore permitting an easy hydrogen transport through the electrolyte.

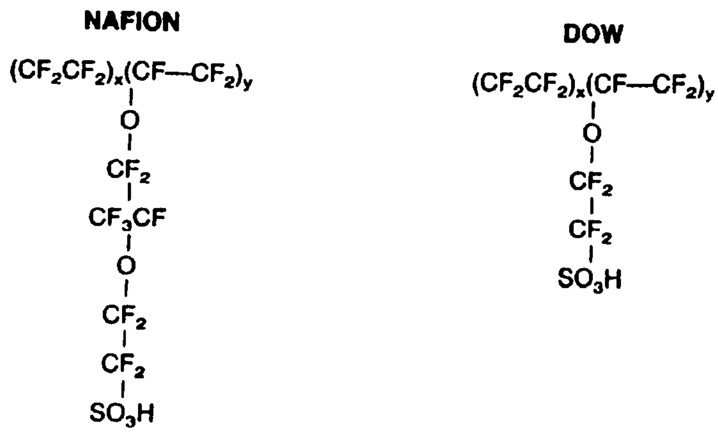

Figure 4.

The Phosphoric Acid (PAFC) is another medium temperature cell, already extensively used for combined electricity and heat production. The trouble is the high aggressivity of the phosphoric acid at the working temperature; the assumed lifespan of this type of cells is therefore of no more than some four years.

In the high temperature range, lot of research is done nowadays with the Molten Carbonate (MCFC) and the Solid Oxide Fuel Cells (SOFC). As at these high temperatures both the emitted CO and the$CO_2$ are cracked, coal gas as well as biogas may also be employed as fuel, with no reasonable fear of contaminating the catalyst with these gases.

# 6. Cell and System Costs.

First of all (Fig.5), the definition of efficiency in fuel cells has to be considered. It is also necessary to keep in mind the impossibility of generating electricity or heat separately, as both of them are produced simultaneously.

**Electrical efficiency ($\eta E$)**

$$\eta E = \frac{P \times 3600}{F \times K} \times 100\%$$

| | | |
|---|---|---|
| Where, | P (kW): | electrical output at sending terminal |
| | F ($Nm^3/h$ or kg/h) | consumption of raw fuel per hour |
| | K ($kJ/Nm^3$ or kJ/kg) | calorific value of fuel |

**Overall Energy Efficiency ( $\eta T$ )**

$$\eta T = \frac{(P \times 3600 + H)}{F \times K} \times 100\%$$

| | | |
|---|---|---|
| Where, | P (kW): | electrical output at sending terminal |
| | F ($Nm^3/h$ or kg/h) | consumption of raw fuel per hour |
| | K ($kJ/Nm^3$ or kJ/kg) | calorific value of raw fuel |
| | H ( kJ/h) | calorific value of recovered waste heat |

Figure 5.

At present, costs are relatively high as fuel cells are produced one by one. The goals to be attained in the next years are:

- A power-to-mass ratio of some 1 kg/kW.
- A specific cost around 100 US$/kW for the cell stack.
- A service life of at least 2.500 operating hours (in the case of mobile use, 5 years with an average of 30.000km/year).

The current cost of the membrane foil (in the case of a PEM cell stack of only 1kW electric power, about 1 $m^2$) is around 500 US$.

If the mentioned goals were attained, the decentralized use of those devices for simultaneous electricity and heat supply will be able to compete favorably with the current commercial electricity and heat prices. It is not necessary to mention the important reduction of the environmental impact for any given amount of commercial energy used, specially the reduction of the green house effect due to the less intensive $CO_2$ emissions.

For each case, the demands of electricity and heat must be carefully analyzed, in order to optimize the design of the system, reducing the number of fuel cells required for each particular application. The peak seasonal demands of electricity and of heat (respectively during summer and winter) must be carefully studied. A mathematic model should be developed in order to perform this optimization.

## 7. Examples of uses in buildings in a decentralized energy supply.

The typical complete fuel cell power system is shown in Fig.6. In certain applications, some of the components may loose significance and could not to taken into account. Also, not all of the emissions should necessarily be evaluated in a first approach.

Fuel Cell Power System

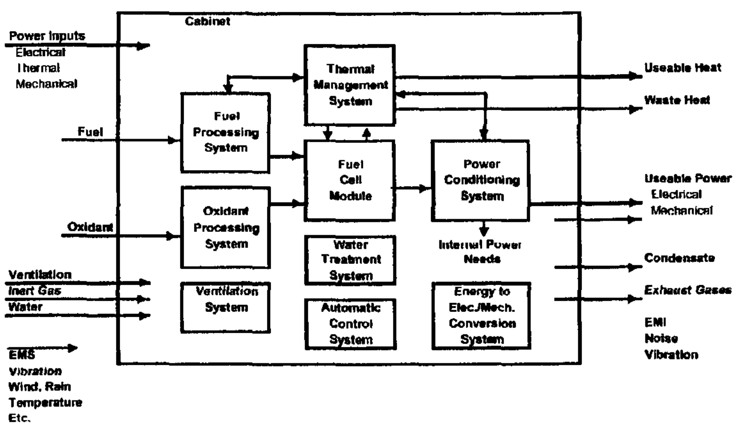


Figure 6.

## 8. Steps to be followed for an adequate system proposal.

Normally, one should analyze the possible utilization of fuel cells for the decentralized co-generation of electricity and heat, connected to the natural gas net. After studying different extreme summer and winter conditions, the requirements for a mathematical modeling to optimize the quantity of fuel cells should be stated. This optimization is of an economical nature, since its main aim is to obtain the price-optimal system (fuel cell - commercial energy provision) for different values of the variables.

The following items must be taken into consideration for establishing this mathematical model. First of all, it is to point out that this is really one of the first historical analyses of a combined decentralized electricity and heat supply for buildings. No significant previous experiences are therefore available.

A careful balance of the electric and thermal demand as a function of time must be established. Proper use of the eventual excess of electricity or heat must also be carefully studied. As previously pointed out, both energy forms, electricity and heat, will always be produced simultaneously by the fuel cell, and this is why the ENERGY demand must be optimized. But, at the same time, peaks in the electricity and heat demands must be diminished, in order to optimize also the POWER demand.

The designer must also take into account different possible technological alternatives related to each energy demand (for instance, refrigeration, lightning, etc.).

Lots of variables appear simultaneously in the problem; all of them are easy to analyze one at a time, but sometimes very difficult to evaluate while acting together, due to their interactions. Optimizing means that both, energy offer and energy demand, need to be simultaneously dimensioned, in accordance one with the other.

## References.

Barlow R. "Residential Fuel Cells: Hope or Hype?" Published by *Homepower Magazine N° 72*, August 1999. Available under *http://www.humboldt1.com/~michael.welch/extras/homefuelcells.pdf.*

Hart David L. *"Hydrogen Power – The commercial future of the 'ultimate' fuel"*. Published by Financial Time Energy Publishing, London, UK, 1997.

Lehmann J. "Costs an niches – hydrogen prices today". *Proc. HYPOTHESIS IV*, The 4th International Symposium on Hydrogen Power, University of Applied Sciences, Stralsund, Germany September 2001.

Lehmann J. "Fuel cells and hydrogen". *Proc. Fuel Cell Seminar*, Universidad Tecnológica Nacional, Unidad Académica Concordia, Argentina, March 2002.

Ogden Joan M. and Nitsch J. "Solar Hydrogen", Published as Chapter 22 of *"Renewable Energies – Sources for fuel and electricity"* by Island Press, Washington DC, U.S.A., 1993.

Ogden Joan M. and Williams R.H. *"Solar Hydrogen – Moving beyond fossil fuels"*, Published by the World Resources Institute, Washington DC, U.S.A., October 1989.

Reidpath M.M. *"Fuel Cell Technology Overview"*. Federal Energy Technology Center, U.S. Dept. of Energy, U.S.A., August 1999.

Schnurnberger W. "Technologies for a sustainable energy economy: renewable energy resources and hydrogen". *Proc. HYPOTHESIS IV, The 4th. International Symposium on Hydrogen Power*, University of Applied Sciences, Stralsund, Germany, September 2001.

Spinadel E, Gracia Nuñez S.L., Maislin J., Wurster R. and Gamallo F. "Domestic Electricity Generation by means of hydrogen and fuel cells", *Proc. Conference of Technological Innovations in Electricity Distribution Systems*, School of Electrical Engineering, Catholic University of Valparaiso, Valparaiso, Chile, October 1999.

Spinadel E., Spinadel V., Gamallo, F. "Mathematical Model for Optimizing Sizes of PEM Fuel Cells in Combined Natural Gas and Electricity Energy Supply". *Proc. M&D2001, The Third International Conference*, Deakin University, Geelong, Australia, July 2001.

Sun Media GmbH *"$H_2$ Tec – The Magazine for $H_2$ and Fuel Cells"*. Published by Sun Media GmbH, Hannover, Germany, April 2001.

Tetzlaff K.H. "The better way to an energy economy without emissions". *Proc. HYPOTHESIS IV, The 4th. International Symposium on Hydrogen Power*, University of Applied Sciences, Stralsund, Germany, September 2001.

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