# A TECHNICAL AND ECONOMICAL COMPARISON OF FUEL CELL TECHNOLOGIES USED IN MICRO-CHP


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***Abstract*: Fuel cell is identified as a modern technology of conversion chemical energy to electrical energy in the world. Nowadays secondary energy provision depends on great value of fossil fuels combustion in the world. But fossil fuels combustion has low efficiency and received gases of the combustion are considered as a main element of environment pollutions. Nevertheless, phosphoric acid fuel cells have been considered as a most perfect fuel cell type and are utilized in large scale CHP arena successfully. Several micro-CHP systems using SOFC technology have been developed and tested that could indicated Ceramic Fuel Cells Limited (CFCL) has been developing flat plate SOFC technology for recent years. Each fuel cell type has both advantages and disadvantages in comparison with other fuel cell technologies and DER equipments in various locations. In this paper, major type of the fuel cells advantages and disadvantages have been compared. The selection of the "best" fuel cell will depend upon the details of the application. Also fuel cell characteristics are given in this paper.**



***Keywords- micro-CHP, Fuel Cells, Distributed Generation, Investment Costs***


## I. INTRODUCTION

Fuel cell is identified as a modern technology of conversion chemical energy to electrical energy in the world. Being compatible with environmental issues and high efficiency generation are the main reasons that many developed countries have supported the technology in their budget programs. Presently, providing secondary energy is dependant on the fossil fuels combustion to a large extent. But fossil fuels combustion suffers from low efficiency and the produced gases are the main reasons of the environmental pollution. For having less pollutions and more efficiency, new technologies like fuel cells can be used instead of fossil fuels Ease of Use

## II. FUEL CELLS IN MICRO-CHP

### A. *phosphoric acid fuel cells (PAFC)*

Nevertheless, phosphoric acid fuel cells have been considered as a most perfect fuel cell type. One of the most important applications of this kind of fuel cell is in power plants with high capacity. The power range changes from 1kW to 15MW in these plants. Of course, the PAFC has been implemented in distributed generation with a 200kW power that seems to be a good and suitable power. PAFC in CHP arena has produced successful results and is following the potential for micro-CHP market with PAFC primary stimulant but most of the inclinations are toward solid polymer and solid oxide fuel cell. The reason that can justify the above sentence is that the PAFC feeds from for purified hydrogen as the fuel but other fuel cells such as PEMFC and SOFC are able to use impure hydrogen as the fuel. PAFC selection can lead to potential danger so that the acid leakage may harm the local residents.

### B. *solid oxide fuel cell (SOFC)*

B Solid oxide fuel cells use an oxide ion-conducting ceramic material as the electrolyte. The anode of a SOFC is usually cermets composed of nickel and yttria-stabilised zirconia. Cermet is a mixture of ceramic and metal. The cathode is a porous structure typically made of lanthanum magnetite. All of the materials used to construct a SOFC are solid state. SOFC's operate in the temperature range of 800 – 1100 C. Either hydrogen or methane can be supplied at the anode, and a SOFC can accommodate both oxygen and air at the cathode. In the SOFC reactions, hydrogen or carbon monoxide in the fuel stream reacts with oxide ions traveling through the electrolyte. SOFC electrical efficiency is 45%-60%. The reactions that occur within a generic SOFC are illustrated in fig1.

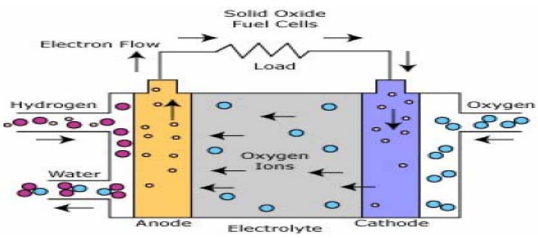



Fig1. Reactions in SOFC

There is a lot of a lot expected from solid oxide fuel cells for micro-CHP applications. High temperature range and the quality of the heat that is obtained in the reaction has made this fuel cell the most efficient and environmentally the best way to get to cogeneration and distributed generation. A few of the micro-CHP systems which use SOFC technology has been developed and tested which can refer the ceramic fuel cell limited (CFCL) accompanied by superficial SOFC technology which has been developed in recent years. In 2004, a CFCL design with a full ceramic stack which was capable of founding a 1 kW capacity with fuel cell was introduced. This SOFC stack which has been developed by CFCL has been designed for the commercial needs. This stack is capable of reforming the fuel in anode, without using another reformer and operates in the temperature range of 800-870C. The range of power production varies between 1 kW to 10kW.

For instance, a SOFC which is installed for a residential micro-CHP, in a Canadian center in Ottawa can be named. This unit is a 5 kW system which uses natural gas. This unit is able of using fuel with low pressure and includes an inverter which meets the demands and standards of residential parts and output control of the system. This SOFC system is placed in home which is closely monitored. Researchers are trying to monitor heat and air conditioning in developing control methods of systems and network connections. Energy research institute in Netherlands is testing micro-CHP by using a SOFC with a 1 kW power. This system works with a fuel cell system of HXS1000premier which has been installed in September 2002. The fuel that is used in this unit is natural gas and the temperature of the operating is approximately 900C. It is shown in fig.2. Micro-CHP system with a SOFC technology has an electrical efficiency of 25% to 32% in full load and thermal efficiency of 53% to 60% according to LHV and general efficiency of 85%. It is seen that the electrical efficiency has decreased excessively in this system. This decrease is much more and quicker for dynamic state and for steady state, it is so noticeable and conspicuous.

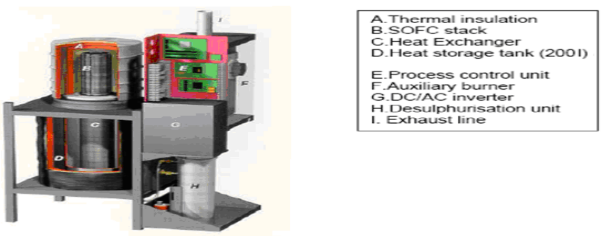



Fig2. SOFC cells are manufactured by InDEC

### C. *molten carbonate fuel cell (MCFC)*

In this type of fuel cell, alkaline molten carbonate is used as the electrolyte porous electrodes are put in this electrolyte. Anode is made of a kind of alloy which comprises of nickel accompanied by 1-2% chromium. In sophisticated systems, small bits of metal oxides such as LiAlO2 and AlO2O3 are used to make anode plays in MCFC is very important, because it should play role of barrage in front of the gas diffusion and have a electrocatalystic behavior and acts thin large keeper of the electrolyte in stack.

### D. *solid polymer fuel cells (SPFC)*

In the fuel cell with a solid polymer electrolyte, a solid polymer membrane is used as the electrolyte. These membranes are conductive of proton. These fuel cells are known as the "proton exchange membrane fuel cell". This membrane concurrently plays the role of the electrolyte and the separator of the gases in the fuel cell. Membrane is in the middle of the porous electrolyte and the platinum catalyst. Solid polymer fuel cell operates in the temperature range so much lower than PAFC & MCFC and SOFC.

Temperature range of this device varies between 60C and 120C, and depends on the conduction specifications and the membrane stability. This temperature allows a quick start.

## III. ADVANTAGES & DISADVANTAGES & APPLICATIONS

Each type of fuel cells has got its own advantages and disadvantages in different places and in comparison with other fuel cell technologies. Table 1 shows a few of advantages and disadvantages of the fuel cells.

TABLE 1 FUEL CELL ADVANTAGES & DISADVANTAGES

| Fuel Cell Type | Advantages | Disadvantages |
|---|---|---|
| PAFC | Quiet, Low emissions, High efficiency, proven reliability | High costs, Low energy density |
| PEMFC | Quiet, Low emissions, High efficiency, | High costs, Limited field test experience, Low temperature waste heat may limit cogeneration potential |
| SOFC | Quiet, Low emissions, High efficiency, High energy density, Self reforming | High costs, Resent developments in low temperature operation for planar SOFCs show promise |
| MCFC | Quiet, Low emissions, High efficiency, Self reforming | High costs, Need to demonstrate long term reliability |

state the units for each quantity that you use in an Fuel cells convert the chemical energy to electrical energy directly without combustion process. As a result the fuel cell doesn't undergo the dissipations which are the result of the mechanical inefficiencies. Fuel cells have the potential to get to high efficiencies of energy conversion especially if the dissipated heat in the fuel cell to be used for cogeneration. In a fuel cell system, the fuel cell itself is smaller than the other parts of the system such as reformer and inverter.

According to their natural process of operating, they are very mute during operating which is an advantage for than to be installed in residential regions. Unfortunately, the first disadvantage of the fuel cells is the high cost related to them. The first reason is the high costs of the ingredients in comparison with other energy systems and the second is the high cost of providing the full which is a continuous progress. The fuel cell type is determined by the recovered heat temperature during the operating and is directly related to micro-CHP usages. Fuel cells with low temperatures of the dissipated heat may produce boiling water and in some cases, they can produce low pressure steam. Fuel cells with low temperatures such as PAFC and PEMFC which produce dissipated heat with lower quality may be used in industrial cogeneration systems. equation and SOFC operate in high temperatures and can produce enough heat which makes enough steam to move a turbine or micro turbine in a combined-cycle power plant. If space cooling is considered and an absorption chiller is to be used, the recaptured heat should be at a temperature of at least 85C.

Recent researches in developed countries in micro-CHP arena are towards residential power generation (3-5 kW plug powers unit) and commercial power generation (250 kW Ballard's unit). The selection fuel is natural gas. Especially by using the recovered heat of these units and boiling water production, these units are suitable for cogeneration.

A few of fuel cells such as PEMFC are taken into account to be used automobile industry. PAFCs are widely used across United States in medical, industrial and commercial instruments and the 200 kW is suitable for distributed generation. The developers are arriving for industrial applications in power range of 100-200 kW for electrical power generation or cogeneration.

The first advantage of PEMFC is the progress that has been made in increasing the electrical efficiency and reducing the size of the device. So many benefits can be seen for using a PEMFC in micro-CHP systems.

SOFC have a few disadvantages. High temperatures have effect on structure and difficulty of the materials. The result of the high temperature is the decrease that this device experiences in open circuit voltage. The decrease in open circuit voltage reduces the electrical efficiency. So the advantage of the dissipated heat quality causes little reduction in system efficiency.

SOFCs are considered for difficult applications with power range of 5-250 kW. These applications include small buildings industrial instruments and micro-CHP.

High operating temperature of the MCFC has advantages and disadvantages of its own in comparison with other fuel cells such as PAFC and PEMFC which have lower operating temperature. High operating temperature of the MCFC enables the fuel reforming right inside of the fuel cell and so there is no need of outer reformer. MCFC can be made by standard material rustproof steel for structure and catalysts based upon nickel. Heat will be used as the minor production of the MCFC to provide warm water of the residential regions, cooling, heating and steam production with high pressure.

The high operating temperatures and the electrolyte chemistry of the MCFC also lead to disadvantages. The high temperature requires significant time to reach operating conditions and correspondingly slow response time to changing power demands. These characteristics make the MCFC less attractive for dynamic power applications and restrict it to constant-power supply applications. The carbonate electrolyte can also cause electrode corrosion problems. Due to the use of the carbonate ions as the charge carrier, the supply of carbon dioxide to the cathode must be carefully controlled in order to achieve optimum performance. High efficiency and high operating temperature of the MCFC units has made them so suitable both for electrical power generation or cogeneration. MCFC potential applications include industry, office, universities and hospitals. The selection of the “best” fuel cell will depend upon the details of the application. An overview of fuel cell characteristics is given in Table2.

Electrical efficiency and power generation comparisons in fuel cells are shown in fig3 and fig4.

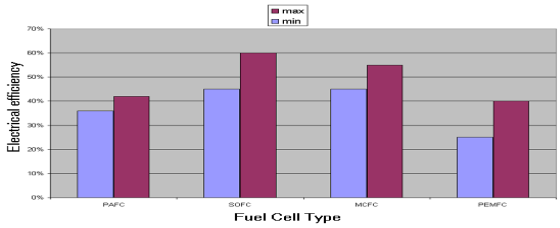



Fig3. Electrical efficiency comparison in fuel cells

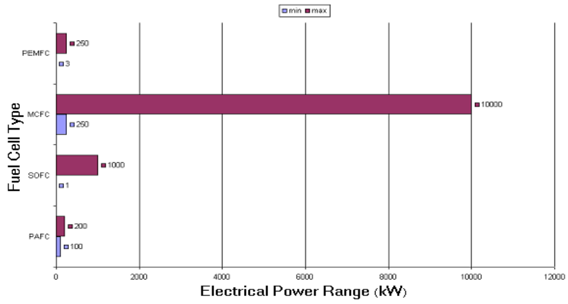



fig4. Power generation comparison in fuel cells

TABLE 2 OVERVIEW OF FUEL CELL CHARACTERISTICS

| FC Type | PAFC | SOFC | MCFC | PEMFC |
|---|---|---|---|---|
| Commercially Available | Yes | Yes | Yes | Yes |
| Size Range | 100-200 kW | 1 kW- 10 MW | 250 kW- 10 MW | 3-250 kW |
| Fuel | Natural gas, landfill gas, digester gas, propane | Natural gas, landfill gas, hydrogen, fuel oil | Natural gas, hydrogen | Natural gas, propane, hydrogen, diesel |
| Electrical efficiency | 36-42% | 45-60% | 45-55% | 25-40% |
| Environmental | Nearly zero emission | Nearly zero emission | Nearly zero emission | Nearly zero emission |
| Other Features | Cogen(hot water) | Cogen (hot water, LP & HP steam) | Cogen (hot water, LP & HP steam) | Cogen (80C water) |

## IV. COST

The initial cost of fuel cells is higher than those of other electricity generation technologies. The only product available commercially today is the Pure Cell 200 (formerly PC-25) ™ built by UTC Power. The cost of the unit is approximately $4,000/kW. The installed cost of the unit approaches $1.1 million. At a rated output of 200 kW, this translates to about $5,500/kW, installed (200*5500=1100000) The American Council for an Energy Efficient Economy (ACEEE) Emerging Technologies & Practices (2004) performed a theoretical study on a residential CHP system using a 2-kW PEMFC as the power generation device. The economics indicated that with the estimated costs of the PEMFC unit and maintenance cost, the cost of the electricity generated would be $0.18/kWh. Therefore the installation of the 2-kW PEMFC unit would only be advantageous

In an area that has an electrical cost higher than $0.18/kWh, or in an area where grid electricity is unavailable.

The Entergy Centre of the Netherlands (ECN) experimented with a 2 kW PEMFC m-CHP system. The system uses natural gas, and the fuel cell operates at approximately 65 C. For system operation, natural gas is desulphurised and converted to hydrogen rich gas in the reformer. The study showed that a start-up time of 2.5 hours was needed when starting from cold conditions to steady operating conditions where the rejected heat could be used to aid the reforming process. This start-up time was reduced to 45 minutes when transitioning from hot stand-by conditions. Characteristics demonstrated by the system include:

a) Gross (electrical + thermal) efficiency of fuel processor varies from 70% at 1 kW to 78% at full load (10 kW).

b) Stack electrical conversion efficiency of 40% at 2 kW and 42% at 1 kW

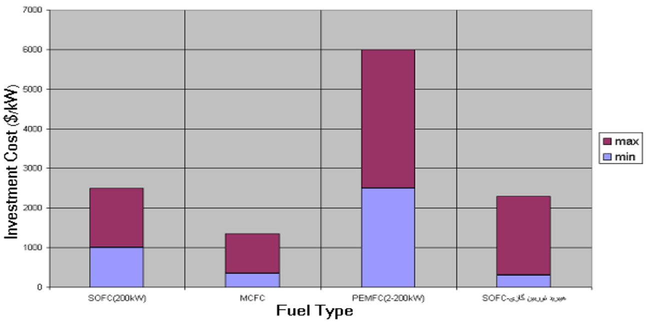
c) Recovered 53% of the waste heat (LHV basis)

The results of this study predicted a payback period of five years for a 1 kW m-CHP system costing 1000 – 1500 EUR ($1300 - $2000), taking into account the market value of Dutch natural gas, electric rates in the Netherlands, and local energy tariffs. System costs of $1300 - $2000 are a theoretical value the manufacturers hope to achieve. Investments costs for PEMFC with power range of 2-200 kW will change between 2500-3500 $/kW and the maintenance cost varies between 0.01-0.03 $/kWh.

For SOFC with 200 kW power, the investment cost is 1000-1500 $/kW and installation cost is about 3500 $/kW and maintenance cost is 0.015-0.025 $/kWh and the stack life time is 40000hours. For MCFC, the investment cost changes between 350-1000 $/kW [5].

Recently, Roll Royce has declared the investment cost for a hybrid SOFC-gas turbine to be 300 $/kW. Most of the estimates are in range of 300-2000 $/kW, but important estimates are in range of 700-1300$/kW [3].

Investment costs comparisons in variant fuels are shown in fig5




## V. RELIABILITY

Fuel cells are an emerging technology with currently few manufacturers offering commercial units. As such, most of the research and development issues for fuel cells are centered on demonstrating units compatible with real-world conditions. However, research is needed for improved fuel reformers to efficiently provide necessary hydrogen fuel from hydrogen rich sources such as natural gas or gasoline. Additionally, fuel cells themselves have a high degree of reliability and availability due to their lack of moving parts, but are limited by the reliability of support systems such as pumps and fans needed for operation. Improvements in these areas would increase the attractiveness of fuel cells. Future research and development into fuel cell-turbine hybrids is also experienced.

Fuel cells are expected to have higher availability and reliability than reciprocating engines. The commercially available 200kW PAFC has been operated continuously for more than 5,500 hours, which is comparable to other power plants. Limited test data for this unit show 96% availability and 2500 hours between forced outages. In demonstration projects at different US, several pre-commercial PEMFC units suitable for residential/commercial application have been operational. Then 5 kW PEMFCs developed by Plug Power operated from 15-21 January 2002 in three of the US. Since August 31, 2002, these units to be operated for total of 51,967 hours with an average individual availability of 95.8%.

## VI. COCLUSIONS

Fuel cell is efficient energy converter and has more advantages in compare with DER equipments. This technology is suitable for cogeneration and electric power generation. Of course, fuel cells have high costs and some disadvantages too, but while using this technology in distributed generation and CHP and micro-CHP, future advantages will be achieved at least for environmental concerns that are why developing countries tend to do more researches to commercialize this technology.

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