

Cost Benefit Analysis for Polymer Electrolyte Fuel Cell Cogeneration

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ABSTRACT

Polymer electrolyte fuel cell (PEFC) cogeneration, which supplies whole space/water heating demand and 70% of electricity demand in a household in Japan, is considered to be a very attractive product for natural gas facilities to sell, because it is expected to double the natural gas sales to a household while letting the homeowner save electricity costs. On the other hand, the initial cost of fuel cell cogeneration equipment and installation is considered to be the main obstacles to its popularization. In this article, life cycle costs of both a conventional water heater and PEFC cogeneration was estimated, and it is concluded that a PEFC cogeneration system benefits homeowners, with a payback period of less than 4 years and system life cycle savings between \$1000 and \$1500 compared to a conventional water heating system.

INTRODUCTION

Fuel-cell technologies hold the promise of producing cleaner energy, but the big question has been whether they'll ever be commercially viable for the mass market. In this article, we use a case study of a Japanese residential customer, and then expand that to predict its benefit to small manufacturing customers in the US market.

In Japan, fuel cell application for residential cogeneration is expected to become popular in the near future, as well as for automobiles. Because around 60% of energy consumption in a household in Tokyo is for space/water heating, fuel cell cogeneration is considered to be a solution to supply the whole space/water heating use and cover 70% of total household electricity demand. Japanese Prime Minister Junichiro Koizumi mentioned in the policy speech on Feb. 4, 2002 that Japan will aim to achieve practical use as a power source for automobiles and a source of electric power for households within three years [1].

The most developed type of fuel cell, phosphoric acid fuel cell (PAFC) has been commercially available for more than five years and is already used at more than 200 sites all over the world—in hospitals, nursing homes, hotels, office buildings, schools utility power plants, an airport terminal, landfills and waste water treatment plants [2]. Also in the United States, through organizational linkages with the Gas Research Institute (GRI), electric utilities, energy service companies, and user groups, the U.S. Department of Energy (DOE) helped in bringing about the commercialization of a PAFC, produced by ONSI (now UTC Fuel Cells).

Although PAFC is the most developed and mature fuel cell technology, it is unlikely to be considered as a power source for residential cogeneration or automobiles, which have attracted great attention, because of its disadvantages; it generates low current and power compared to other types of fuel cells, it generally has a large size and weight, and it is not suited for applications where quick startup is required.

Instead, polymer electrolyte fuel cell (PEFC), or sometimes called proton exchange membrane fuel cell (PEMFC), is regarded as the most prominent candidate for “quick and small” applications, because it operates at relatively low temperatures (about 80°C or 175°F), has high power density, and can vary its output quickly to meet shifts in power demand. According to the U.S. DOE, “they are the primary candidates for light-duty vehicles, for buildings, and potentially for much smaller applications such as replacements for rechargeable batteries in video cameras.” [3]

The history of equipment costs has shown significant price reduction as the commercial market grows and the technology matures. Because research and development activities for a broad range of applications are being actively pursued, a drastic reduction in the production cost of PEFC system is expected in the near future once high volume

production and full commercialization is underway.

In this article, the energy-saving mechanism of fuel cell cogeneration is first exhibited. Next, conditions and assumptions for energy-saving calculations, including the expected cost of installing a PEFC cogeneration system are discussed. Finally, savings potential and life cycle cost are estimated, followed by conclusions.

ENERGY-SAVING MECHANISM OF FUEL CELLS

A fuel cell is very much like a battery. It contains electrodes (anodes and cathodes) separated by an electrolyte. But unlike a battery, a fuel cell consumes fuel and does not require recharging. Also, fuel cells are exothermic, producing heat as a byproduct of the chemical reaction, and this heat is available for cogeneration applications. Also, fuel cells have the following advantages:

- They can be sized to accommodate different capacity needs by connecting the same cell designs in series and/or parallel, referred to as “stacking” cells.
- Their high conversion efficiency is relatively independent of system capacity.
- They are environmentally benign because of their low emission.

Fuel cell systems are categorized by the type of electrolyte. Four major categories are currently being employed: PAFC (phosphoric acid fuel cell), MCFC (molten carbonate fuel cell), SOFC (solid oxide fuel cell) and PEFC (polymer electrolyte membrane fuel cell). The basic fuel cell characteristics are presented in Table 1.

The PEFC, whose application is mainly discussed in this article, is a thin plastic sheet that allows hydrogen ions to pass through it. The membrane is coated on both sides with highly dispersed metal alloy particles (mostly platinum) that are active catalysts. The electrolyte used is a solid organic polymer poly-perflourosulfonic acid. The solid electrolyte is an advantage because it reduces corrosion and management problems. Hydrogen is fed to the anode side of the fuel cell, where the catalyst encourages the hydrogen atoms to release electrons and become

Table 1. Type of Fuel Cells

	PAFC	MCFC	SOFC	PEFC
Fuel	H ₂	H ₂ , CO, CH ₄	H ₂ , CO, CH ₄	H ₂
Electrolyte	Liquid phosphoric acid	Liquid solution of lithium, sodium and/or potassium carbonates	Hard ceramic material of solid zirconium oxide	Solid organic polymer poly-perfluorosulfonic acid
Operating temperatures	200°C/390°F	650-700°C/ 1200-1300°F	700-1000°C/ 1300-1800°F	Up to 90°C/ 195°F
Achieved Efficiency (HHV)	36-38 %	40-50 %	40-50 %	30-35 %, when using reformed H ₂ gas
Development Stage	Commercially Available	R&D, for large-scale power gen.	R&D, for large-scale power gen.	Commercially available in 2004

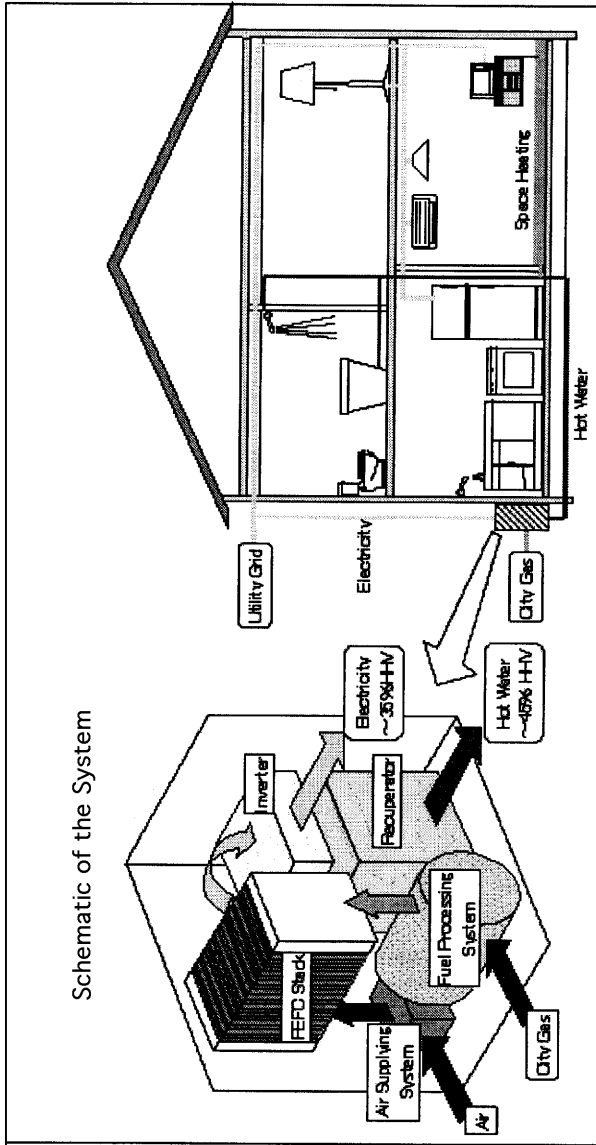


Figure 1. Residential PEFC Cogeneration System

hydrogen ions (protons). The electrons travel in the form of an electric current that can be utilized before it returns to the cathode side of the fuel cell where oxygen has been fed. At the same time, the protons diffuse through the membrane (electrolyte) to the cathode, where the hydrogen atom is recombined and reacted with oxygen to produce water, thus completing the overall process [2].

However, this type of fuel cell is sensitive to fuel impurities, so that one of the largest technical challenges to make PEFC commercially available has been in the fuel processing mechanism, which reforms CH_4 to H_2 before it is used in the fuel cell system. A solution was given in the fall of 2000, when Tokyo Gas, a utility company in Japan successfully developed the world's most efficient fuel processing device. A 1-kW PEFC cogeneration system developed by Ebara Ballard using this technology achieved the world's highest level of electrical efficiency [4]. Recently, Ballard Power Systems Inc.'s Ballard Generation Systems subsidiary entered into a three-year collaboration agreement with Tokyo Gas Co., Ebara Ballard and Ebara Corp. to commercialize fuel cell cogeneration units that will lead to the development of a natural gas-fueled, 1-kW cogeneration fuel cell power generator for use in the Japanese residential market.

The 1-kW generator is designed to meet the hot water and space heating needs of a typical Japanese household while providing electricity as well. The generator is designed to be operated in conjunction with the existing grid, allowing consumers to draw power from the grid when their power consumption at a given moment exceeds 1 kW [5].

CONDITIONS AND ASSUMPTIONS FOR THE ANALYSIS

Currently, the first commercialized PEFC cogeneration system is expected to be introduced into the market in 2004. The initial cost of a 1-kW PEFC system is estimated around \$1500, excluding installation. Once high volume production begins, the price is expected to drop to \$1000 per 1 kW [6]. Installation costs vary and are site specific. According to Federal Technology Alerts, it is estimated that the base system can be installed between \$250 to \$500/kW [7]. In this article, the total initial cost including installation is set a little higher to be \$2300 (300,000 JPY)* to

*JPY = Japanese Yen

avoid being a too optimistic. Therefore, compared to conventional water heaters, whose market price is around \$1500 (200,000 JPY) with installation costs of about \$150 (20,000 JPY), the surplus of initial cost accompanied with installing a PEFC cogeneration system is estimated to be \$600 (80,000 JPY). The life of the system is set to be 10 years in the following calculations, for both the PEFC cogeneration and conventional water heater.

The average electricity demand in the Tokyo area per household is 6500 kWh, while the average heat demand is 5200 kWh. The local utility companies in this region are Tokyo Electric Power Company and Tokyo Gas Company. The electric power and gas costs for residential use are shown in Tables 2 and 3. In Table 3, 1 m³ of natural gas provided by Tokyo Gas to residential customers is equivalent to 46.05 MJ (11,000 kcal).

In our calculations, operation and maintenance cost is ignored because manufacturers are planning to produce PEFCs for residential cogeneration with 60,000 to 100,000 hours of guaranteed maintenance-free life with 2-3,000 times of restarting [8].

SAVINGS AND POTENTIAL LIFE-CYCLE COST

To determine the overall savings potential for this application, annual cost/savings listed below, as well as initial cost must be estimated.

- a) The fuel cell energy consumption,
- b) The fuel cell electricity generated,
- c) The water heater fuel consumption avoided, and
- d) The operation and maintenance (O&M) costs associated with operating fuel cells (in this article, this factor is ignored).

First, the fuel cell energy consumption is determined by:

$$\text{NaturalGasInput [J/yr]} = \frac{\text{Space/WaterHeatingDemand [J/yr]}}{\text{HeatRate [J/J]} \times \text{PartLoadFactor [J/J]}}$$

The average space/water heating demand per household in Tokyo area is 18.7 TJ/year (= 5,200 kWh/year). The heat recovery rate in this equation is the ratio of heat generated [J] to natural gas input energy [J],

Table 2, Summary of Electricity Rate Schedules

<i>Demand Size [kVA]</i>	<i>Basic Service Fees [JPY/month]</i>
1.0	260
1.5	390
2.0	520
3.0	780
4.0	1,040
5.0	1,300
6.0	1,560
<i>Monthly Consumption [kWh]</i>	<i>Energy Charges [JPY/kWh]</i>
0 ~ 120	15.58
120~ 300	20.67
300	22.43

Table 3. Summary of Natural Gas Rate Schedules

<i>Monthly Consumption (V) [m3]</i>	<i>Utility Charge [JPY]</i>
0 ~ 20	690 + 127.25 V
20 ~ 80	1,040 + 109.75 V
80 ~ 200	1,460 + 104.50 V
200 ~ 500	2,000 + 101.80 V
500 ~ 800	5,050 + 95.70 V
800 ~	9,610 + 90.00 V

which is set to be 0.45 in this example. Also, the part load factor in this equation is the percentage of recoverable thermal energy that is actually utilized, 0.95 in this example.* Therefore, the fuel cell will consume 43.8 TJ of energy (natural gas) annually.

Next, the fuel cell electricity generated is calculated by:

$$\text{ElectricityGenerated [J/yr]} = \frac{\text{NaturalGasInput [J/yr]}}{\text{ElectricEfficiency [J/J]}}$$

According to Bungler and Kraus [9], the electric efficiency of PAFC to natural gas input (LHV* base) is set to be 0.31, so that annual electricity generated will be 13.6 TJ/year.

Also, natural gas consumption avoided, by replacing conventional water heater, is determined by:

$$\text{FuelAvoided [J/yr]} = \frac{\text{Space/WaterHeatingDemand [J/yr]}}{\text{PartLoadFactor [J/J]}}$$

The energy cost impacts can be determined by using the electric and natural gas rate schedules noted earlier and the energy consumption estimates calculated above. The value of the electric energy generated is 89,382 [JPY/year]. The value of the natural gas consumption avoided by replacing water heater is 59,443 [JPY/year], and the cost of the natural gas to run the fuel cell is 116,843 [JPY/year].

Finally, net present value (NPV) of life-cycle cost is calculated using MS Excel. The life cycle cost for the PEFC cogeneration system is calculated to be 534,247 JPY, compared with the conventional system with a life-cycle cost of 707,062 JPY, for a surplus net-present value of 172,815 JPY (\$1,330 USD). Also, a pay back period is calculated to be 3.3 years.

CONCLUSION

It is confirmed that installing a PEFC cogeneration system benefits Japanese homeowners. The estimated pay back period of 3.3 years is consistent to the estimate by Fuel Cell Technologies Ltd., which concludes the expected pay back period on a residential fuel cell for a typical

*Lower heating value (LHV)

homeowner to be four years [10]. It is recommended that natural gas utility companies should vigorously promote the product once it becomes available in the market, where heat demand is relatively high and natural gas price is relatively lower compared to electricity.

In the U.S., expansion of this technology through the small to medium facility owner, as well as the residential customer is dependent on the same factors, such as favorable energy policy, the relative cost of natural gas to electricity, and the availability of hardware and support. If, however, a relatively quick payback of 4 years or less is realized, rapid proliferation throughout the U.S. market should be expected.

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