FY 2008 Interim Annual Report

Progress Report on
The Large-scale Stationary Fuel Cell
Demonstration Project in Japan

April 2009

New Energy Foundation (NEF)

Funded and administrated by
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1 Project Overview

1.1 Objectives

The Kyoto Protocol, voted for in COP3, which was held in 1997 to examine the issue of global warming, requires Japan to reduce its CO\textsubscript{2} emissions by 6% from the 1990 level during the primary commitment period (2008–2012). However, by FY 2007 energy-derived CO\textsubscript{2} emissions had risen by 14.0% over the level in 1990, while household emissions showed a huge increase of 41.2%. There is thus strong pressure on the residential sector to reduce emissions in order to meet the target of a 6% reduction during the primary commitment period.

The fuel cell offers high generation efficiency that can be raised further if the exhaust heat is recovered in a cogeneration system. For this reason, Japan’s national energy policy sets out ambitious goals for the deployment of fuel cells.

Residential polymer electrolyte fuel cell (PEFC) systems installed in houses to meet the demand for electricity and heat are positioned as a cogeneration power (combined heat and power; CHP) system that achieves energy savings and reduces CO\textsubscript{2} emissions in the residential sector. Japan has been developing the technology as well as the pre-market infrastructure for commercialization and market creation.

With this background, “the Large-scale Stationary Fuel Cell Demonstration Project” has since FY 2005 installed a large number of residential PEFC systems in households nationwide to collect operation data on actual use. These PEFC systems are operated in a variety of residential settings and utilization patterns. The operation data collected has been fed back to manufacturers to facilitate further improvements in reliability and durability, with the ultimate goal of commercialization and setting the stage for mass production and cost reduction. The project aims to pave the way for a residential market for PEFC systems by using the data to determine the level of technological maturity required for commercialization and to identify the issues for further R&D efforts. It is also expected that the project will bring public recognition to residential PEFC systems by introducing and exposing them as well as presenting their operating records to the general public.

Note: The founding organizer NEDO (New Energy and Industrial Technology Development Organization) formally calls this project as “the Demonstration of Residential PEFC System for Market Creation”.

1.2 Project organization

The Large-scale Stationary Fuel Cell Demonstration Project was started in FY 2005, and FY 2008 was its fourth year.
As shown in Figure 1.2.1 – Project Organization, the New Energy Foundation (NEF) provides funding to project operators (energy suppliers such as city gas and oil companies) who will use the funds to purchase residential PEFC systems from fuel cell manufacturers and install and operate them at regular detached houses. At participating homes (hereinafter called the "site"), the PEFC system produces electricity and heat (hot water) for daily consumption. Any data obtained from the operation of the system (such as electric power supply, heat supply, fuel consumption, etc.) are collected by NEF via the project operators for analysis and evaluation. This data will assist in the determination of the technological maturity and identification of R&D challenges.

Figure 1.2.1 also shows that the project allows project operators a number of options, such as installing and operating PEFC systems from more than one manufacturer or partnering with another operator (collaborating operator) in the installation and operation.

Figure 1.2.1  Project organization

The funding is made available for PEFC systems with an electric power rating of approximately 1 kW that are designed for installation in regular residential houses. To be eligible, the systems must meet the following criteria:

a. Performance requirements
   Electric power generation efficiency of 30 % or more (at rated operation; based on HHV) and 27 % or more (at 50 % load);
   gross efficiency of 65 % or more (at rated; HHV) and 54 % or more (at 50 % load)

b. Manufacturer qualification
   Capable of providing 30 or more systems during the
c. Operator qualification  Capable of installing 10 or more systems during the project term.

d. Reporting requirements  To operate the systems for two years or more (one year for systems installed in FY 2008) and report monthly data every quarter.

The required period of data acquisition is, as described in the above requirements, two years for those systems installed up to and including FY 2007, and one year for those installed in FY 2008. As such, in addition to the operation data collected from sites that were installed in FY 2007 and have been in operation since, the project has obtained partial data from the sites placed in FY 2006 and in FY 2008. These data of systems installed over a period of three years are available for inter-system comparison and evaluation of performance improvements in areas such as electrical efficiency as well as reliability, such as failure incidents.

Figure 1.2.2 shows the schematics of PEFC system installation and data collection; the data points are shown with a ◎ mark. The fuel cell system is connected to a commercial grid, and the electricity and heat generated by the system are consumed by the household. The fuel flow, power output and power input, recovered heat, and electricity and heat consumptions of the site are measured.

As shown in Figure 1.2.3, the number of residential systems installed each year has been increasing greatly: 480 units in FY 2005 (175 in the first half and 305 in the second); 777 units in FY 2006; 930 in FY 2007; and 1,120 in FY 2008. The total number of systems installed is 3,307 units.
The 1,120 units that qualified for funding in FY 2008 were fully installed on site and had started operation by March 2009. They have been providing operation data since then.

The funding program for installation was for a period of four years from FY 2005 to FY 2008, in which year the financial assistance itself was ended. The operators are, however, still subject to the data reporting obligation described in (d) of the above requirements. As such, the data acquisition and analysis and evaluation will be ongoing until the end of FY 2009 (March 2010).

The project's financial contribution per system has declined year after year from ¥6 million in FY 2005, to ¥4.5 million in FY 2006, ¥3.5 million in FY 2007, and finally ¥2.2 million in FY 2008; this reflects decreases in the manufacturing cost on the part of manufacturers of residential PEFC systems. In other words, cost reductions have been successfully made as a part of this demonstration project.

Figure 1.2.3 states that "the world's first full market launch" will occur in FY 2009. This simply reflects the scheduled market launch of residential PEFC systems in FY 2009. It will be discussed in detail later.

1.3 Results of FY 2008 (Apr. 2008 – Mar. 2009)

The 16 project operators (energy suppliers) who were engaged in the installation and operation of residential PEFC systems in FY 2008 are as follows:


Note: Kyushu Oil was amalgamated into Nippon Oil as of October 1, 2008.
The five manufacturers that provided PEFC systems in FY 2008 were as follows:

ENEOS Celltech, Ebara, Toshiba Fuel Cell Power Systems, Panasonic (since October 2008; formerly Matsushita Electric Industrial), and Toyota Motor.

Note: ENEOS Celltech is a fuel cell manufacturer and distributor created by Nippon Oil and Sanyo Electric in April 2008. Sanyo Electric supplied fuel cell systems up to FY 2007.

The PEFC systems use city gas, LPG, or kerosene. Systems using city gas were supplied by all of the five manufacturers; those using LPG by ENEOS Celltech (Sanyo) and Toshiba Fuel Cell Power Systems; and those using kerosene by Ebara alone. By fuel type, by FY 2008 there were a total of 1,375 units installed that use city gas, 1,618 for LPG, and 314 for kerosene.

Tables 1.3.1, 1.3.2, and 1.3.3 show the number of units installed and operated by operator (energy supplier), by manufacturer, and by fuel type, respectively. (The figures for FY 2005 through FY 2007 are also shown for reference.)

### Table 1.3.1  Number of systems installed and operated by energy supplier

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tokyo Gas</td>
<td>City Gas</td>
<td>150</td>
<td>160</td>
<td>210</td>
<td>276</td>
<td>796</td>
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<tr>
<td>Osaka Gas</td>
<td>City Gas</td>
<td>63</td>
<td>80</td>
<td>81</td>
<td>141</td>
<td>365</td>
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<tr>
<td>Toho Gas</td>
<td>City Gas</td>
<td>12</td>
<td>40</td>
<td>38</td>
<td>34</td>
<td>124</td>
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<tr>
<td>Saibu Gas</td>
<td>City Gas</td>
<td>10</td>
<td>10</td>
<td>13</td>
<td>10</td>
<td>43</td>
</tr>
<tr>
<td>Hokkaido Gas</td>
<td>City Gas</td>
<td>-</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Nihon Gas</td>
<td>LPG/City Gas</td>
<td>-</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Nippon Oil</td>
<td>LPG/Kerosene/City Gas</td>
<td>134</td>
<td>301</td>
<td>396</td>
<td>497</td>
<td>1328</td>
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<tr>
<td>Idemitsu Kosan</td>
<td>LPG</td>
<td>33</td>
<td>40</td>
<td>50</td>
<td>28</td>
<td>151</td>
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<td>Japan Energy</td>
<td>LPG</td>
<td>30</td>
<td>40</td>
<td>34</td>
<td>40</td>
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<tr>
<td>Iwatani</td>
<td>LPG</td>
<td>10</td>
<td>34</td>
<td>29</td>
<td>10</td>
<td>83</td>
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<tr>
<td>Cosmo Oil</td>
<td>LPG/Kerosene</td>
<td>10</td>
<td>19</td>
<td>19</td>
<td>18</td>
<td>66</td>
</tr>
<tr>
<td>Taiyo Oil</td>
<td>LPG/City Gas</td>
<td>8</td>
<td>13</td>
<td>18</td>
<td>11</td>
<td>50</td>
</tr>
<tr>
<td>Kyusyu Oil*</td>
<td>LPG</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Showa Shell Sekiyu</td>
<td>LPG</td>
<td>6</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>36</td>
</tr>
<tr>
<td>Lemon Gas</td>
<td>LPG</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Eneurge</td>
<td>LPG</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Saisan</td>
<td>LPG/City Gas</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>480</td>
<td>777</td>
<td>930</td>
<td>1120</td>
<td>3307</td>
</tr>
</tbody>
</table>

* Kyusyu Oil merged Nippon Oil in October, 2008
Table 1.3.2  Number of systems installed and operated by manufacturer

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>LPG</th>
<th>City Gas</th>
<th>Kerosene</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENEOS Celltech</td>
<td>1062</td>
<td>191</td>
<td>0</td>
<td>1253</td>
</tr>
<tr>
<td>Ebara</td>
<td>0</td>
<td>396</td>
<td>314</td>
<td>710</td>
</tr>
<tr>
<td>Toshiba FCP</td>
<td>552</td>
<td>196</td>
<td>0</td>
<td>748</td>
</tr>
<tr>
<td>Panasonic</td>
<td>0</td>
<td>520</td>
<td>0</td>
<td>520</td>
</tr>
<tr>
<td>Toyota</td>
<td>0</td>
<td>76</td>
<td>0</td>
<td>76</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1614</td>
<td>1379</td>
<td>314</td>
<td>3307</td>
</tr>
</tbody>
</table>

Table 1.3.3  Number of systems installed and operated by fuel type

<table>
<thead>
<tr>
<th>Type of Fuel</th>
<th>FY2005</th>
<th>FY2006</th>
<th>FY2007</th>
<th>FY2008</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>City gas</td>
<td>235</td>
<td>303</td>
<td>355</td>
<td>482</td>
<td>1375</td>
</tr>
<tr>
<td>LPG</td>
<td>245</td>
<td>399</td>
<td>424</td>
<td>550</td>
<td>1618</td>
</tr>
<tr>
<td>Kerosene</td>
<td>75</td>
<td>151</td>
<td>88</td>
<td>314</td>
<td>314</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>480</td>
<td>777</td>
<td>930</td>
<td>1120</td>
<td>3307</td>
</tr>
</tbody>
</table>

Figure 1.3.1 shows the regional distribution of 3,307 sites where installation occurred between FY 2005 and FY 2008. The project successfully installed and is operating systems in all of Japan’s 47 prefectures. This broad distribution from Hokkaido in the north to Okinawa in the south allows the acquisition of operating data under a wide range of climatic conditions, both warm and cold.

Figure 1.3.2 shows the breakdown of participating households by family size and floor area. This information came from a survey of the 777 sites installed in FY 2006, to which 440 sites responded.

The family size varies from one to seven or more, with three- to five-person households dominating at 72.3 %. The floor area also ranges widely, from 50 m² or less to 300 m² or more; houses of 100 m² to 200 m² account for 66.7 %.

The sites installed in FY 2006 are, as mentioned earlier, distributed across Japan from Hokkaido in the north to Okinawa in the south. Houses in rural and suburban areas appear to be larger than those in urban areas. (Installations in FY 2007 and FY 2008 show a similar profile.)
Figure 1.3.1  Regional distribution of installation sites (3,307 sites installed between FY 2005 and FY 2008)

Figure 1.3.2  Households by family size and by floor area
Note: Based on a survey of FY 2006 installation sites. FY 2007 and 2008 sites show similar profiles.
2 Operating Performance

2.1 Electricity and hot water demand on site

Figure 2.1.1 shows electricity and heat demand at 456 sites using city gas (NG) or LPG systems that provided monthly data from January 2008 through December 2008, out of a total of 930 sites installed in FY 2007. The figure represents the distribution of electricity and heat demand by plotting the average electricity and heat (hot water) demand at each site for the year.

As this figure shows, demand for electricity and heat varies widely. Electricity demand ranges between 200 kWh and 2200 kWh per month, and heat demand from 400 MJ to 4000 MJ per month; both show a difference of one order or more. Average electricity demand is 652 kWh per month, and average heat (hot water) demand is 1,570 MJ per month. Compared to FY 2006, the electricity demand is down by 3 %, while the heat demand is up by 3 %, but both distribution and average values can be described as essentially the same.

The red dot and dash combination lines represent the amount of electricity and heat generated by a 1-kW system in 24-hour continuous operation, respectively. Compared to the region segmented by these red lines, the distribution of plotted data points indicates that the demand for heat is somewhat smaller than the heat generated and that the FC operation is, overall, driven by heat demand. In other words, smart fuel cell operation requires a higher ratio of heat supply to the demand and some kind of operational control that will allow the extraction of the maximum electric power output from the same heat generation base.

![Figure 2.1.1](image)

**Figure 2.1.1** Distribution of electricity and heat demand among FY 2007 installation sites

Note: Data from 456 sites, January–December 2008 (NG and LPG).
2.2 Electricity and hot water supplied by PEFC systems

Figure 2.2.1 shows the PEFC system performance in supplying electric power and hot water by month from January through December of 2008 at FY 2007 installation sites.

![Graph showing electricity and heat supply distribution.](image)

Figure 2.2.1 Operating performance: distribution of electricity and heat supplies

Note: Data from 456 sites, January–December 2008 (NG and LPG).

Both electricity and heat (hot water) supplied by the PEFC system vary in quantity depending on the demand of the site, and the average electricity supply was 238 kWh per month, while the average hot water supply was 1,143 MJ per month.

Both distributions and average values are very similar to those of FY 2006, except that the electricity supply grew by 5% while the hot water supply grew by only 0.6%. Taking into consideration that the electricity demand at the sites decreased by 3% compared to FY 2006, as shown in Figure 2.1.1, these figures are likely a reflection of the improved generation efficiency of PEFC systems.

Figure 2.2.2 shows monthly changes in the electricity demand and FC power supply as well as heat demand (hot water) and hot water supply.

As shown, the electricity demand curve has two distinctive peaks (W-shaped), one in summer for air-conditioning and the other in winter for heating. Heat demand, on the other hand, tends to increase in winter and decrease in summer (V-shaped curve), following the seasonal temperature changes.
Figure 2.2.2  Operation performance: monthly changes in demands and supplies of electricity and heat

Note: Data from 456 sites, January–December 2008 (NG and LPG).

In order to supply both electric power and heat efficiently, many residential PEFC systems are operated in the so-called DSS (Daily Start and Stop) mode: they are started in the morning, operated during the day, and shut down sometime in the evening as the hot water tank becomes full. Thus the FC power generation is largely dependent on the heat demand. In summer, the power generating time and power output decrease as the heat demand goes down, making the FC power supply ratio generally decline in summer even though the electricity demand goes up seasonally.

Please note that Figure 2.2.2 shows the average values of all the sites throughout the year, and thus represents the changes under the average climatic conditions in Japan. Different trends are observed under different climatic conditions. For instance, air-conditioning is not used very much in a cold climate, resulting in an electricity demand curve shaped more like a V than a W. At the same time, the summer drop in heat demand is not so pronounced as that in Figure 2.2.2 in a cold climate.

This type of correlation between electricity demand and heat demand is also observed in the reductions of primary energy and CO₂ emissions, as shown in Figure 2.2.3: they decrease in summer when the heat demand is lower. Having said that, it is also confirmed that PEFC systems are operating with a certain level of energy savings and CO₂ emissions reduction even in August when the heat demand is the smallest.
Figure 2.2.3 Operating performance: monthly changes in reduction of primary energy and CO$_2$ emission

Note: Data from 456 sites, January–December 2008 (NG and LPG).

Figure 2.2.4 shows monthly supply ratios obtained by dividing the electricity supply and the heat supply presented in Figure 2.2.2 by the electricity demand and the heat demand, respectively.

The electricity supply ratio remains at 35 % or more for nine months from November to May, and drops as low as 17.7 % in August. The heat (hot water) supply ratio, on the other hand, remains high at 80 to 85 % during summer (June to August), while it is lower at 66 to 70 % in winter (January and February). Averaged for the year, the supply ratios are 36 % for electricity and 73 % for heat (hot water). PEFC systems provided approximately one-third of the electricity demand and approximately three-quarters of the heat (hot water) demand of the sites. Compared to FY 2006, the electricity supply ratio improved by three points; this is attributed mainly to the improved generation efficiency of the PEFC systems.

Since the PEFC systems generate electricity based on heat demand, the heat supply ratio tends to go up when the heat demand is lower in summer. Yet it is still substantially less than 100 % at best, and the main reason lies in the fact that there are many sites with a large heat demand that is beyond the heat supply capacity of the PEFC system.
2.3 System power generation efficiency and heat recovery efficiency

Figure 2.3.1 shows the distribution of system electric power generation efficiencies for FY 2007 installation sites (NG and LPG) from January through December 2008. The average value is 31.0%, an increase of 0.9 point compared to that recorded in FY 2006.

![Graph showing electric power output vs. generation efficiency](image)

**Figure 2.3.1 Operating performance: distribution of electric power generation efficiencies**

Note: Data from 456 sites, January–December 2008 (NG and LPG).
The electrical efficiencies shown in Figure 2.3.1 are average values of the on-demand operation pegged to the chronological change of electric power consumption of the household. They do not represent the efficiency under steady-state operation at rated output. In other words, the longer the duration of partial load operation, the lower the efficiency becomes, especially against that achievable under rated operation. However, the site with the poorest system generation efficiency still recorded 26 %, establishing that the residential PEFC systems in the Large-scale Demonstration Project maintain high efficiencies at partial load relative to those at rated load.

The high variability observed in the system efficiency data is likely attributable to the site difference in the ratio of low load operation, rather than the performance difference among systems.

2.4 Utilization rates of electricity and heat

Figure 2.4.1 shows the distributions of utilization rates of electricity and heat (data from FY 2007 installation sites (NG and LPG) between January and December 2008).

The utilization rate of electricity is calculated as follows: subtract the standby power to be consumed by the PEFC system in shutdown, the start-up power to be consumed at the time of start-up, the reverse power from the system to the grid as well as the electricity consumption of the anti-reverse flow heater from the PEFC system's generated power (a cumulative value including partial load operation), and divided by the integrated value of the fuel flow rate. The result can be taken as the effective efficiency based on the ultimate electricity consumption of the household.

The utilization rate of recovered heat is also based on the actual heat consumption of the household in the form of hot water supply from the hot water tank to the bathroom and the kitchen. It is calculated by subtracting heat losses, such as heat released from the hot water tank, from the heat recovered from the fuel cell and stored in the hot water tank.

It is therefore common to see utilization rates of electricity and heat (based on the actual and effective energy consumption of the household) that are by three to five points lower than the system power generation efficiency and the heat recovery efficiency, which indicate the efficiencies of the PEFC system itself. (Compared to the 31.0 % of the system power generation efficiency shown in Figure 2.3.1, the utilization rate of electricity of 27.7 % in Figure 2.4.1 represents a decrease of 3.3 points.)

This utilization rate of electricity of 27.7 % is 1.3 points higher than that of FY 2006. In addition to the improvement in the power generation efficiency (+0.9 point) thanks to improved cell stack performance, it is believed that many factors contributed to this progress, among them reductions in the start-up and standby electricity consumption as well as better operation
protocol (software using AI control sequences). The utilization rate of heat recovery grew by 0.3%.

Figure 2.4.1 also shows changes in the primary energy reduction rate. In the region where utilization rate electricity and/or utilization rate of heat are low, there are sites that failed to reduce their primary energy requirement, but most sites produced savings in the primary energy demand, resulting in an 18.5% reduction on average.

![Figure 2.4.1 Operating performance: utilization rates of electricity and heat](image)

Note: Data from 456 sites, January–December 2008 (NG and LPG).

2.5 Energy-saving effect of PEFC systems

Figure 2.5.1 shows primary energy reductions by NG and LPG PEFC systems (FY 2007 installation sites for January through December 2008). As the figure indicates, energy savings are largely influenced by heat demand. The less heat demand the site had, the smaller the primary energy reduction it produced. For those households with heat demand of 500 MJ or less per month, it is difficult to obtain any gains in energy savings.
The red dot-dash combined line represents the approximation of the best-performing models. The best-performing models are those demonstrating the best performance in both equipment properties and operation among all the models participating in the project. In some performance parameters, such as primary energy reduction, the difference between the best performers and the others has been steadily shrinking as new models are introduced year after year. Compared to the data for FY 2006 sites, for instance, the best-performing group of FY 2007 sites gained 5% in primary energy reduction, whereas the overall average improved by 20%. It is therefore likely that the other models will soon reach the level of the best group.

Based on the average heat demand of 1,570 MJ per month, the average reduction in primary energy per fuel cell system is 1,015 MJ per month for the best performers, equivalent to eighteen 18-liter cans of kerosene oil per year (12,180 MJ per year). The average of all the sites is 693 MJ per month, equivalent to 12.6 cans of kerosene oil per year.

### 2.6 CO₂ emissions reduction effect

Figure 2.6.1 shows the CO₂ emissions reduction achieved by installing PEFC systems (data from January to December 2008 for FY 2007 installations of NG and LPG systems). The chart clearly depicts the significant influence heat demand has on reducing CO₂ emissions, an effect similar to the primary energy reduction.
The average reduction of CO₂ emissions was 75.1 kg per month, the equivalent of the CO₂ absorbed by 1,670 m² of forest. Top-performing systems had a reduction of 100.1 kg per month on average, the same level of CO₂ absorbed by 2,200 m² of forest. "Team Minus 6 %," a campaign by Japan’s Ministry of Environment, calls for "every person to reduce CO₂ by 1 kg per day," or a reduction of approximately 90 kg of CO₂ emissions per month for a family of three. It was demonstrated that the goal could be virtually achieved by installing a residential PEFC system.

Compared to the performance of FY 2006 systems, a majority of FY 2007 systems are coming closer to the top-performing systems, as attested by a performance gain of 14 % on average for all sites, compared to just 4 % for the best systems.

Please note that the CO₂ reduction effect shown in the figure is benchmarked against the emissions by fossil fuel generation plant, which uses a conversion factor of 0.69 kg of CO₂ per kWh (Interim Report of the Subcommittee for Goal-achieving Scenario, Global Environment Committee, the Central Environment Council of Japan, July 2001). There are different opinions on this CO₂ reduction comparison, but the above value has been consistently used in this project, and this document follows that convention.

2.7 System performance improvements by year

Manufacturers of residential PEFC systems have been improving their equipment as well as reducing costs year after year, with their operation performance improvement accordingly.
Figure 2.7.1 shows the operating characteristics of the PEFC systems installed from FY 2005 through FY 2008 by year.

As the figure shows, operating performance has improved year after year, with system power generation efficiency increasing from 29.4 % to 32.2 % (provisional data for FY 2008). Although heat recovery efficiency remained the same or increased only slightly (not shown in the figure), theoretically speaking, these systems are designed such that an increased generation efficiency means a smaller heat recovery efficiency. It is assumed, therefore, that effective heat recovery efficiency has been improving.

Both rates of primary energy reduction and CO₂ emissions reduction were substantially improved, from 13.6 % to 19.9 % and from 25.8 % to 32.5 %, respectively. This increase in system generation efficiency is attributable to improvements in fuel-processor and cell-stack hardware. In addition, progress in operation control technology is believed to have contributed to producing synergistic effects on the reduction of primary energy and CO₂ emissions.

### 2.8 Comparison by fuel type

The Large-scale Demonstration Project involves residential PEFC systems that use three types of raw fuel: city gas (NG; methane), LPG (propane), and kerosene.

Figure 2.8.1 compares the system power generation efficiency of LPG systems and city gas
systems installed in FY 2007. Virtually no difference was observed. (The yearly evaluation data such as efficiencies presented up to the foregoing subsection were reorganized to illustrate the behaviors of the city gas and LPG systems together.)

![Graph showing comparison between LPG PEFC systems and NG systems](image)

**Figure 2.8.1 Comparison between LPG PEFC systems and NG systems**

Note: Actual operating performance for sites installed in FY 2007, averaged over January to December 2008.

Figures 2.8.2 and 2.8.3 present comparisons between gaseous fuel systems (city gas and LPG) and kerosene systems. The kerosene systems show generation efficiencies that are a few points lower than those of city gas and LPG systems, but they are superior in heat recovery efficiency by a few points.

There are two likely reasons for the kerosene systems’ lower generation efficiency: a fundamental difference in the chemical process in that kerosene, with its heavy hydrocarbons, is more difficult to reform than city gas and LPG, which have light hydrocarbons; and a difference in the system design in that kerosene systems require a vaporizer and a liquid pump due to the fact that kerosene is liquid, while gaseous fuels such as city gas and LPG do not.

As far as the total efficiency and primary energy reduction are concerned, the kerosene systems demonstrated that they are equivalent to the city gas and LPG systems. Please note, however, that the CO₂ emissions reduction data are not included in this report because kerosene systems can't be compared to the other systems due to the fact that kerosene's heavy hydrocarbons render them poor in CO₂ emissions reduction performance relative to the other
systems.

Figure 2.8.2  Comparison between kerosene PEFC systems and city gas/LPG systems (1)
Note: Actual operating performance for FY 2007 installation sites, averaged over January to December 2008.

Figure 2.8.3  Comparison between kerosene PEFC systems and city gas/LPG systems (2)
Note: Actual operating performance for FY 2007 installation sites, averaged over January to December 2008.
2.9 Durability

The systems that were installed in FY 2006 completed their required two-year period of operating data acquisition in FY 2008.

Figure 2.9.1 shows the changes in system generation efficiencies of city gas systems over the two-year operation period. The PEFC systems of both manufacturers A and B had virtually the same distributions of generation efficiencies at the start of operation, over one year, and over two years, with little decrease in efficiency.

Figure 2.9.2 shows the changes in generation efficiency of LPG systems by manufacturer C and of kerosene systems by manufacturer D over the two-year operation period. Again, almost no decrease is found in efficiency.

Both figures essentially demonstrate that neither the fuel processors nor the cell stacks showed much performance degradation over the period. Thus the validation of system durability is deemed successful under the operating conditions of the project.

Figure 2.9.1  Changes in system efficiency (city gas systems over a two-year period)

Note: FY 2006 installation sites.
Figure 2.9.2 Changes in system efficiency (LPG and kerosene systems over the two-year period)

Note: FY 2006 installation sites.

2.10 Discussion of site conditions

Our discussion to this point has focused on the analyses and evaluations conducted on the average values of all participating sites. Looking closer at individual sites, it is observed that some sites are superior to others in energy savings (primary energy reduction) or CO₂ emissions reduction. The variability is significant as well.

Figure 2.10.1 shows electricity demand on the x axis and heat demand on the y axis, and each site is plotted. At the same time, each data point represents the primary energy reduction of the site by color and shape. The data source is the averaged operation record of FY 2007 installation sites over the one-year period from January to December 2008.

Figure 2.10.1 illustrates a strong correlation between the sizes of electricity demand and heat demand and the primary energy reduction of the sites, though there is a certain level of variability. This indicates that it may be possible to estimate to some degree the benefits (primary energy reduction, CO₂ emissions reduction, and/or cost merit) of installing a residential PEFC system at a particular site if we understand the electricity and heat demands of the household. This is a topic worth pursuing.

The relationship between primary energy reduction and energy demand shown in Figure 2.1.1 is mapped in Figure 2.10.2. The x axis shows household electricity consumption per month, while the y axis shows household heat energy (hot water) consumption per month expressed as the city gas equivalent. The projected primary energy reduction is shown by color; the warmer the color, the larger the reduction effect is.
Figure 2.10.1  Relationship between primary energy reduction and energy demand
Note: Actual operating performance for FY 2007 installation sites, averaged over January to December 2008.

Figure 2.10.2  Actual data for projection of benefits to be gained by FC installation
Note: Actual from January to December 2008 for FY 2007 installation sites.
Generally speaking, the larger the electricity and heat demands the family has, the greater the energy savings. A household with an average number of members and average house size (which typically consumes 400 to 800 kWh of electricity and 25 to 60 m³ of city gas or 11 to 26 m³ of LPG per month) can expect to save approximately 500 to 1,500 MJ of primary energy per month.

It also shows that for households in which either electricity demand or heat demand is below a certain level, the energy-saving effect tends to stagnate even if the other demand increases. In particular, houses that consume less than 20 m³ of city gas per month (9 m³ per month for LPG) do not realize meaningful energy savings with a residential PEFC system.

3 System Reliability

3.1 Fault occurrence

Figure 3.1.1 shows the chronological trends of failure occurrences for city gas and LPG systems by the year of installation and by the number of months of operation.

The general trend indicates that fault conditions tend to occur in the initial period after operation start-up; they then decrease in number after trouble-shooting, and flatten after one year or so of operation. Manufacturers have been incorporating feedback from the field operation into their designs and specifications every year with the aim of reducing costs ahead of commercialization. It is believed that such changes have been the cause of failures during initial operation.

The FY 2007 systems represent substantial improvements over those installed in FY 2006, with a lower frequency of unexpected shutdowns. Interim statistics for FY 2008 systems (failure information from October to December 2008 from 193 sites by three manufacturers; data available at the end of December 2008) indicate that unexpected shutdowns had dropped further to approximately 0.29 per system per year. It can be said that the improvements made to the fault measures based on past experiences have started to take effect.

An unexpected shutdown frequency of 1 per system per year means that any residential PEFC system at any site might shut down due to a fault once a year; this is a long way from the quality generally expected of commercial products. It is anticipated that a fault occurrence rate of less than roughly 0.3 per system per year, the level of the systems installed in FY 2008, will be the upper limit required for future commercialization.
3.2 Changes in the causes of failures

Figures 3.2.1 shows the changes in failure-causing components in PEFC systems installed in FY 2006 and FY 2007 by the number of months of operation.

The figure shows that systems installed in FY 2007 recorded a smaller number of failures (unexpected shutdowns) than did FY 2006 systems.

Cell stacks and inverters caused few troubles in both FY 2006 and FY 2007 systems, but the other components such as fuel processors, air supply devices, water supply devices, controllers (parameter changes), and others did not improve much. The reduction of faults in these components apparently remains a challenge.

For the water-supplying components, more than one manufacturer experienced frequent troubles caused by silica-based materials or slime (sludge generated by the proliferation of microbes) clogging up the pump or piping. The importance of water management in the PEFC system has been recognized anew.

Figure 3.1.1 Failure occurrences (unexpected shutdowns)
Note: City gas and LPG systems.
Table 3.2.1 shows the particulars of the unexpected shutdowns of systems installed in FY 2008.

The controllers had some failures of control parameters due to design changes, as did fuel processors and water supply components, but the overall failure rate was low.

The FY 2008 systems underwent design changes and/or manufacturing process changes geared toward mass production and reducing costs in preparation for commercialization, and this led to some maladjustments; however, the causes are clear and should be resolved quickly.

Table 3.2.1  Particulars of unexpected shutdowns of FY 2008 installation systems

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Unexpected shutdown</th>
<th>Freq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel processing</td>
<td>Fuel flow meter &amp; sensor malfunction</td>
<td>3</td>
</tr>
<tr>
<td>Water treatment</td>
<td>Reforming water pomp trouble</td>
<td>4</td>
</tr>
<tr>
<td>Heat recovery</td>
<td>Heat exchanger heater malfunction</td>
<td>1</td>
</tr>
<tr>
<td>Inverter</td>
<td>Inverter malfunction</td>
<td>1</td>
</tr>
<tr>
<td>Controller</td>
<td>Cathode air blower parameter change, Shut-off valve parameter change, Hot well tank</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>input/output temperature arrangement</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total 14</strong></td>
<td></td>
</tr>
</tbody>
</table>
3.3 Efforts for higher reliability

This Large-scale Demonstration Project has an evaluation committee of external experts that reviews the participating projects in their entirety. The committee has a working group dedicated to performance. The Performance Review Working Group is composed of representatives from five manufacturers in the Large-scale Demonstration Project and six major operating companies that install and operate systems from these manufacturers. The main activity of the working group is to exchange information on the system failures they experience in order to improve the reliability of residential PEFC systems.

![Diagram showing the process of information exchange between operators, manufacturers, and the Performance Review Working Group.]

Figure 3.3.1 Efforts for higher reliability

As shown in Figure 3.3.1, NEF collects and sorts failure information from the operators and refers it to the respective manufacturers for clarification. The manufacturers study the fundamental causes of such failures and possible remedial actions and report back to the Performance Review Working Group. The working group identifies the challenges to be shared among the members and gathers the expertise of the manufacturers and the operators for information sharing and collaboration toward solutions.

Any information that may be beneficial to the balance-of-plant (BOP) development is provided to BOP manufacturers to facilitate their work.
4 Public Relations

4.1 Exhibitions

The Large-scale Demonstration Project aims to build the foundation for market introduction of PEFC systems by identifying the technological issues to be addressed for commercialization in the market creation stage. Naturally, information dissemination and promotion of proper understanding of what residential fuel cells are and what benefits they offer are a part of the project’s activities, in addition to its main objective of advancing residential PEFC system hardware in areas such as durability, reliability, cost reduction, and mass-production readiness.

In FY 2008, the project participated in ten conferences and exhibitions across Japan in order to explore new sites of operation. Table 4.1.1 shows the particulars of these exhibitions.

<table>
<thead>
<tr>
<th>Name</th>
<th>Period</th>
<th>Venue</th>
<th>Outline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Fair in Kobe (Environment Ministers' Meeting)</td>
<td>23 - 26 May, 2008</td>
<td>Kobe City Central Gymnasium (Kobe City)</td>
<td>Held in conjunction with the G8 Environment Ministers' Meeting, the Lake Toya Summit</td>
</tr>
<tr>
<td>Energy Ministers' Meeting</td>
<td>7 - 8 June, 2008</td>
<td>Hotel Aomori (Aomori City)</td>
<td>Exhibit set up in the venue of the Energy Ministers' Meeting, the Lake Toya Summit</td>
</tr>
<tr>
<td>Integrated Exhibition of the Environment in Celebration of the Hokkaido Lake Toya Summit 2008</td>
<td>10 - 21 June, 2008</td>
<td>Sapporo Dome (Sapporo City)</td>
<td>Trade show held in Sapporo, near Lake Toya, to celebrate the hosting of the G8 Lake Toya Summit.</td>
</tr>
<tr>
<td>Fuel cell demonstration at the G8 Hokkaido Lake Toya Summit</td>
<td>5 - 10 July, 2008</td>
<td>Rusutsu Resort (Rusutsu-mura, Hokkaido)</td>
<td>Demonstration of the Zero-emissions House, a showcase of environmental technologies</td>
</tr>
<tr>
<td>Renewable Energy 2008 International Exhibition</td>
<td>30 July 30 to 1 August, 2008</td>
<td>Tokyo Big Sight (Koto-ku, Tokyo)</td>
<td>International forum and trade show focusing on new and renewable energies</td>
</tr>
<tr>
<td>Ishikawa</td>
<td>23 - 24 August, 2008</td>
<td>Ishikawa Industrial</td>
<td>Showcase of environmental</td>
</tr>
</tbody>
</table>
The advantages of residential PEFC systems and the objectives of the Large-scale Demonstration Project were presented at these venues through video streaming introducing the project, posters describing the project, models showing the mechanism and use of residential PEFC systems, and mockups of the actual systems used in the project by different manufacturers. Brochures on the project were distributed and a survey was conducted of exhibition visitors’ perceptions of residential PEFC systems.

As shown in Figure 4.1.1, there were a number of special exhibitions organized in conjunction with the G8 Summit, held in July 2008 at Lake Toya, in addition to the regularly held exhibitions. Since the Summit represented an excellent opportunity to showcase Japan's advanced environmental and new energy technologies, the exhibits were organized to introduce the project and residential PEFC systems at the direct request of the Resources and Energy Agency of METI.

For the actual G8 Summit meeting in Lake Toya, a Zero-emissions House was constructed next to the International Media Centre, also built especially for the occasion as the press center. The house was designed under the leadership of NEDO to showcase advanced technologies that are to contribute to Japan’s reductions of CO₂ emissions. The house also featured a footbath facility in which three residential PEFC systems were installed and operated.
3 residential PEFC systems were operated during the period of the Lake Toya Summit in July, 2008. Foreign mass medias and governmental officers realized the excellence and progress of residential PEFC system. The electricity generated by the installed FC systems was used to light the footbath facility, while the hot water produced by the recovered heat was supplied to the footbath. The footbath was well received by Japanese and international media people. In addition, the bath was honored by Prime Minister Fukuda and his wife (then) also having a dip. It is believed to have successfully accomplished its mission of promoting residential PEFC systems. In addition, in the month before the Summit, the adoption of “ENE-FARM” as the standard product name for residential PEFC systems was announced to the public, and the Summit provided an ideal opportunity and timing to promote this new name. The Large-scale Demonstration Project played a significant role in the popularization of the name.

4.2 Website

The project received a lot of attention in FY 2008, since it had many exhibits in conjunction with the Lake Toya Summit and commercialization under the name “ENE-FARM” was made official. That is why the brochures were revised. Public recognition and understanding of the project were sought by uploading the analysis of operation data to the website every quarter.

NEF created a page dedicated to the Large-scale Demonstration within its website. Figure 4.2.1 shows its top page, Figure 4.2.2 shows the page for the project brochure, and Figure 4.2.3 shows the page for data such as figures and charts of operation data and reporting materials.
Figure 4.2.1 Top page

News, etc.

Figure 4.2.2 Brochure page

The latest brochure is available for download.

Figure 4.2.3 Operation data page

PDF files are available for download; these include quarterly statistics, articles for annual report, and the results of surveys of the residents of homes with FC systems installed.
5 Results and Challenges

5.1 Achievements

The Large-scale Demonstration Project was started in FY 2005 for the purpose of creating the foundation for the commercialization of residential PEFC systems, and four years have passed as of FY 2008. During this time, improvements have been steadily made not only in performance but also in durability and reliability, thanks to the feedback of on-site operation data by the operators as well as to the system manufacturers’ own efforts.

With this background, residential PEFC systems were to be launched onto the market under the standard name of “ENE-FARM” in May 2009. On this basis alone, it would not be an overstatement to say that the Large-scale Demonstration Project has fulfilled its objectives.

The project will continue to acquire data from system operations through FY 2009, but now is an opportune time to summarize its achievements that have led to commercialization (market launch). These are as follows:

Note: The systems installed in FY 2007 have an obligation to operate and collect data for two years, and those installed in FY 2008, for one year. Although the project continues on until the end of FY 2009 (end of March 2010), the installation of new systems with funding ceased as of the end of FY 2008.

(1) Accumulation of operating experience

The Large-scale Demonstration Project had installed and operated a total of 3,307 residential PEFC systems across Japan by the end of FY 2008. Japan is the only country that has deployed so many residential PEFC systems simultaneously to demonstrate their operation; it would be fair to say that Japan is leading the world in this area.

As shown in Figure 5.1.1, the installation and operation consistently increased from the project commencement in FY 2005 to the end of FY 2008. All of the 3,307 systems budgeted were fully installed by the end of March 2009. As of the end of March 2009, the accumulated total duration of generation reached 21.59 million hours, with the aggregated total electric power output at 12.2 million kWh. Both cumulative generation hours and cumulative generated power show clean curves going upward to the right, illustrating that there were no major troubles in operation, which, in turn, attests to the systems having reached a certain level of durability and reliability.

Note: The generation hours is simply averaged out to approximately 6,350 hours per system (21.59 million hours divided by 3,307 systems). Attention is called to the fact that approximately one-third of the systems were installed in FY 2008 and thus have
not operated for very many hours, but those installed in FY 2007
and earlier recorded more than one year of operation on average.

There was absolutely no incidence of fire caused to the surrounding houses or bodily injury
due to ignition or explosion of fuel cell systems during these four years of operation. The systems are deemed validated for safety. The demonstration of safety is the fundamental
requirement for any product to be introduced into the market, and that is why it is extremely
significant that safety was firmly established in this project.

Figure 5.1.1  Changes in the cumulative operating hours and generated power

(2) Demonstration of benefits to society

As subsections 2.5 and 2.6 described the effects of residential PEFC systems on the primary
energy savings and CO\textsubscript{2} emissions reduction, it was demonstrated that by installing a 1 kW-class
PEFC system a typical-size household can save the equivalent of 12,180 MJ (eighteen 18-liter
cans of kerosene) per annum in energy and reduce CO\textsubscript{2} emissions by 1,200 kg per year
(equivalent to 2,200 m\textsuperscript{2} of forest).

The reduction ratios of primary energy and CO\textsubscript{2} emissions are 25 \% and 39 \%, respectively,
based on the energy provided by the PEFC system. Thus the PEFC systems demonstrated that they are effective in energy savings and CO₂ reductions. The deployment and popularization of residential PEFC systems are shown to be truly beneficial to society.

January to December 2008 data of top models of FY 2007

- Primary energy reduction: 12,18 MJ/year (25% less)
- CO₂ reduction: 1,200 kg-CO₂/year (39% less)

Projected household reduction per month
- 1,000 MJ in primary energy
- 100 kg in CO₂ emission

Less primary energy → Conserve resources/ less utility cost
Less CO₂ → Mitigation of global warming

Demonstrate the benefits of PEFC system energy savings and conservation effects

Figure 5.1.2 Social benefits of residential PEFC systems

(3) Improvements in system performance and operability

As mentioned in 2.7, the operation of new installations improved every fiscal year, with system generation efficiency rising by approximately three points over three years, from 29.4% in FY 2005 to 32.2% in FY 2008. The primary energy savings rose by approximately six points and CO₂ emissions dropped by approximately seven points, representing a notable improvement in performance.

This is a result of the PEFC system manufacturers working together with the operators in the improvement of performance and operation control. One of the contributing factors is NEF’s efforts such as hosting technology review forums and the Performance Review Working Group. At these forum meetings, manufacturers and energy suppliers exchange information and jointly discuss issues. These exchanges likely facilitated improvements through comparisons of data that identified issues and problems not necessarily evident in a single organization’s own data.
Figure 5.1.3  Improved system and operability performance

(4) Improved durability and reliability

As discussed in 3.1, the occurrence of failure (unexpected shutdown) decreased with each new fiscal year’s installation. Again, this likely reflects the fact that the PEFC system manufacturers and operators worked together and shared information on their failure occurrence and fault analysis and incorporated such feedback into their own products. As well, development has as much as possible been based on horizontal deployment.

Figure 5.1.4  Improved reliability
(5) Reduction of system cost

Over the three years from FY 2005 to FY 2008, a reduction of approximately 57% was achieved in the procurement price of residential PEFC systems (the price reported by the installer/operator as the cost of a system consisting of a fuel cell unit and a hot water tank unit from a system manufacturer qualified for funding).

![Figure 5.1.5 Reduction of system offering price](image)

(6) Clarification of the effects of site conditions (electricity and heat demand) on energy savings

As reported in 2.10, the averaging of results from all sites shows that there is a substantial level of benefit derived from the deployment of a residential PEFC system. On an individual basis, however, some sites showed an excellent CO₂ reduction benefit, while others did not, with the differences being significant. In addition, energy savings and CO₂ emissions reduction were impacted by the electricity and heat demands of the site household.

That led to a discussion of approaches for projecting the benefits (primary energy savings, CO₂ emissions reduction, cost benefit, etc.) to be gained by installing a PEFC system tailored to some degree to the electricity and heat demand of the receiving household. One example of such is included in this report. At the same time, it was demonstrated that families that consume less
than a certain volume of city gas (or LPG) are less likely to reap energy-saving benefits from the installation of a fuel cell system.

5.2 Future challenges

As mentioned already, residential PEFC systems are to be launched under the product name “ENE-FARM” from FY 2009 (http://www.ene-farm.info/en/). List prices range between approximately ¥3.2 million and ¥3.45 million, making the cost to general purchasers around ¥2 million even after the new financial assistance that will become available in FY 2009 (Financial Assistance for the Deployment of Household Fuel Cells). If the residential PEFC system market is to be developed, further cost-reduction efforts will be needed to achieve a target shipment price of ¥500,000 to ¥700,000 around 2015.

Regarding reliability and durability, although the unexpected shutdown incidents came down as low as 0.29 per unit per year for FY 2008 installations, it is desirable to continue the improvement efforts even further to ensure that average families can enjoy the benefits of PEFC systems.

To expand the market, manufacturers are expected to continue their work to improve residential PEFC systems, now being commercialized under the trade name “ENE-FARM.” It is believed that the fact that the market launch became possible in the spring of 2009 can be counted as one of the major successes of the Large-scale Demonstration Project.

6 Conclusion

The Large-scale Demonstration Project allowed the performance of residential PEFC systems to advance steadily during the four-year period from FY 2005 to FY 2008, culminating in the milestone of a market launch in FY 2009. NEF was engaged in the analysis and evaluation of the operation data, feeding back the results to the operators and the technological issues identified in the reported failures to the manufacturers. Thus the strategy of the project for commercialization worked very well, allowing both cooperation and competition to function effectively among the operators and the manufacturers. The project can be credited with having made a significant contribution to the market launch.

The funding assistance for new installations under the project was ended in FY 2008, but the analysis and evaluation of the operation data are ongoing until the end of FY 2009.

In FY 2009, the project activities are focused on feeding back analysis and evaluation data to the manufacturers and the operators as before and disseminating the information on the success of the project to a wider public. These activities will contribute to the future development and popularization of residential PEFC systems.
Presentations, speeches, and other public recognition of the demonstration project were executed at “2008 Fuel Cell Seminar & Exposition” (held on 28 Oct, 2008 at Phoenix, USA) and several seminars in Japan.

7 Contact Information

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## Definitions of indices

### FC electrical generation efficiency [\%]
\[
\text{FC electrical generation efficiency} = \frac{\text{FC power output (kWh) x 3.6}}{\text{fuel energy supplied to FC (MJ/HHV)}} \times 100
\]

### Heat recovery efficiency [\%]
\[
\text{Heat recovery efficiency} = \frac{\text{thermal energy of hot water recovered from FC (MJ) / fuel energy supplied to FC (MJ/HHV)}}{100}
\]

### Total system efficiency [\%]
\[
\text{Total system efficiency} = \frac{\text{FC electrical generation efficiency} + \text{Heat recovery efficiency}}{\text{fuel energy supplied to FC (MJ/HHV)}} \times 100
\]

### Electricity Utilization Efficiency [\%]
\[
\text{Electricity Utilization Efficiency} = \frac{\text{electric power supplied from FC (kWh) x 3.6}}{\text{fuel energy supplied to FC (MJ/HHV)}} \times 100
\]

### Heat Utilization Efficiency [\%]
\[
\text{Heat Utilization Efficiency} = \frac{\text{thermal energy of hot water recovered from FC (MJ) / fuel energy supplied to FC (MJ/HHV)}}{100}
\]

### Total utilization efficiency [\%]
\[
\text{Total utilization efficiency} = \frac{\text{Electricity Utilization Efficiency} + \text{Heat Utilization Efficiency}}{\text{fuel energy supplied to FC (MJ/HHV)}} \times 100
\]

### Reduction rate of primary energy [%]
\[
\frac{1 - \frac{\text{fuel energy supplied to FC (MJ/HHV)}}{\text{thermal energy of hot water recovered from FC (MJ) / fuel energy supplied to FC (MJ/HHV)}}}{\text{exchange rate of electric power (0.369)}} \times 100
\]

### Reduced primary energy [MJ]
\[
\text{Reduced primary energy} = \frac{\text{thermal energy of hot water recovered from FC (MJ) / fuel energy supplied to FC (MJ/HHV)}}{\text{exchange rate of electric power (0.369)}} - \text{fuel energy supplied to FC (MJ/HHV)}
\]

### Reduction rate of CO₂ [%]
\[
\frac{1 - \frac{\text{fuel energy supplied to FC (MJ/HHV) x exchange rate of fuel to CO₂}}{\text{thermal energy of hot water recovered from FC (MJ) / fuel energy supplied to FC (MJ/HHV) x exchange rate of fuel to CO₂ + electric power supplied from FC x exchange rate of fossil fuel plant to CO₂}}}{100}
\]

### Reduced amount of CO₂ [kg-CO₂]
\[
\text{Reduced amount of CO₂} = \frac{\text{thermal energy of hot water recovered from FC (MJ) / fuel energy supplied to FC (MJ/HHV)}}{\text{exchange rate of fuel to CO₂ + electric power supplied from FC x exchange rate of fossil fuel plant to CO₂}} - \text{fuel energy supplied to FC (MJ/HHV) x exchange rate of fuel to CO₂}
\]

---

1) Exchange rate from kWh to MJ  
2) From "Better Living standard of Japan" (Hot water system, Dec. 2005)  
3) From "The law of the efficient use of energy conservation of Japan", kWh = 9700kU  
4) Natural gas: 0.05125 [kg-CO₂ / MJ], LPG: 0.0387 [kg-CO₂ / MJ], Kerosene: 0.0679 [kg-CO₂ / MJ]  
5) 0.089 [kg-CO₂ / kWh]