PROGRESS OF HOME ENERGY STATION IV SYSTEM

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1. Introduction

At present, global warming is becoming increasingly apparent, and has become a major social issue. The increasing concentration of CO_2 in the atmosphere is considered to be one cause of global warming. According to the results of a survey, exhaust gas from automobiles accounts for about 20% of all CO_2 emissions[1]. Honda, as an automobile company, considers the solution to this issue to be a matter of urgent necessity, and is putting its efforts into the development of a fuel cell vehicle that emits only water as the exhaust gas, aiming at reducing CO_2 emissions, which are emitted while an automobile is being driven.

The fuel for a fuel cell vehicle is compressed hydrogen. In recent years, preparation of an infrastructure for supplying compressed hydrogen has gradually proceeded, however it cannot be said to be adequate. For this reason, Honda is carrying out research into the manufacture of compressed hydrogen. The company is promoting two manufacturing methods, one called gas reforming, which involves the reformation of natural gas, and the other, called water electrolysis, in which water is electrolyzed using electricity generated by solar cells. The reasons for using natural gas in the gas reforming method are that the infrastructure for supplying natural gas to homes, factories, and so on, already exists, and that compared to other fossil fuels the amount of CO_2 emitted during the manufacture of hydrogen is small.

This report describes the configuration of a 4th generation system (HES IV: Figure 1.1) of domestic hydrogen manufacturing and feeding equipment employing a gas reforming method, called a home energy station (HES), together with the contents of the proving test of the system.

Figure1.1 Home Energy Station IV

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In addition to a function for feeding hydrogen to fuel cell vehicles, this system also has a generating function for supplying electric power to homes, and a hot water supply function that utilizes the heat exhausted when the equipment is operating.

2. Design Concept

Under the HES development concept, which is shown in Figure 2.1, a single system uses natural gas taken into the home as raw material for manufacturing hydrogen to be supplied to fuel cell vehicles, and for supplying electricity and heat for domestic use.

One concern is that when fuel cell vehicles become popular, the infrastructure for supplying hydrogen for fuel will still be inadequate. Consequently, Honda is carrying out research and development on the HES to help overcome the insufficiency in the infrastructure, and to contribute to reduce energy costs and CO_2 emissions. Up to now, Honda has developed four generations of HES from I to IV, and has provided each of them with different characteristics. Table 2.1 shows a comparison of the main specifications of each type.

The systems up to HES III were developed with the focus mainly on technological evolution of performance, efficiency, and size. In contrast, the HES IV system was developed with an emphasis on practicality, and with home installation in mind. Its main points of difference from HES III are higher system efficiency and compactness, and the fact that the hydrogen feeding method is exclusively overnight fill. Overnight fill is a method in which manufactured hydrogen is pressurized by means of a compressor and then

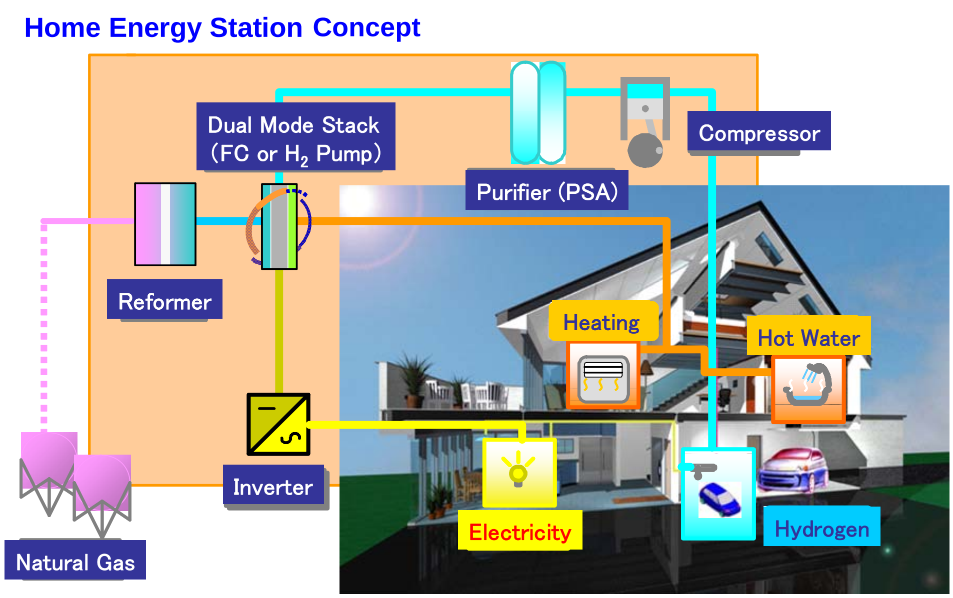


Figure 2.1 HES Design Concept

Table 2.1 HES Series

	HES I	HES II	HES III	HES IV
				
Power Output [kW max]	5.0	4.0	5.0	4.0
H_2 Production [SLM]	34	34	52	50
H_2 Storage [kg-H_2]	11.9	3.3	5.2	–
H_2 Purity [%]	>99.99	>99.99	>99.99	>99.99
Max Pressure [MPaG]	42	35	50	35
System Size [Liter]	4500	2000	1400	1200
Test Site	Torrance, CA	Latham, NY	Torrance, CA	Torrance, CA
Operation	'03/10～'05/6	'04/11～'06/3	'05/11～'07/6	'07/10～

fed directly to the tank of the fuel cell vehicle. In contrast to this, there is fast fill in which the supply side has a storage tank, and the tank on the vehicle side is rapidly filled by the pressure difference between it and the storage tank. In order to perform fast fill, the supply side must also have a storage tank, and in addition, the pressure of the storage tank must be higher than that of the tank on the vehicle side. To this end, HES III, which is capable of fast fill, has a storage tank of 160-liter capacity and maximum pressure of 50 MPaG. In contrast, the HES IV is intended exclusively for overnight fill, so the storage tank is eliminated, and the maximum filling pressure of the product hydrogen is set to 35 MPaG, which is the same as the maximum filling pressure for a fuel cell vehicle. As a result, the costly high pressure tank and high pressure piping could be eliminated.

3. Specifications

Figure 3.1 shows the size of the main unit of HES IV, and Table 3.1 shows the main specifications. Hydrogen is manufactured at the rate of 50 SLM, and when the tank if fed with this manufacturing rate for 6hours, the vehicle will be able to run for at least 100 miles. The maximum generated output is 4 kW.

The exhaust heat generated during hydrogen manufacture and power generating operation is recovered by a heat exchanger, enabling it to be used to meet heat demands such as hot water supply, heating, and so on. In this way, the energy efficiency of the overall system is further enhanced.

Figure 3.1　Dimension of HES IV

Table3.1　HES IV Specifications

Fuel Processor		ATR + WGS + PROX
Purifier		DMS + PSA
Electricity		120V/240V AC 60Hz
Natural Gas		13 kW
Noise		54 dB
H_2 Flow Rate		50 SLM
H_2 Purity		SAE J2719 Eq.
Start up time		10 min
Filling Pressure		35 MPaG
Max Power Output		4 kW-AC
Efficiency	H_2 mode	40%
	Power mode	30%

The equipment configuration of HES IV is shown in Figure 3.2. Details of each device are described in section 5. The system consists mainly of a reformer, dual mode stack (DMS), purifier, pressure swing adsorption (PSA) unit, hydrogen compressor, and a control and electrical section. Of these components, the DMS is newly adopted in HES IV. DMS is a device which functions as both fuel cell and hydrogen membrane pump. By switching over between these functions, the DMS can operate either as a fuel cell or as a hydrogen membrane pump. The systems up to now has a fuel cell for generating electricity, and a pressure boosting device (compressor, hydrogen membrane pump, etc.) as separate components. Because HES IV employs a DMS, the single device can be made to have both an electrical generating function and pressure boosting pump, thus greatly contributing to the compactness of the equipment. In addition, the reformer, inverter, and PSA have been modified for greater reliability.

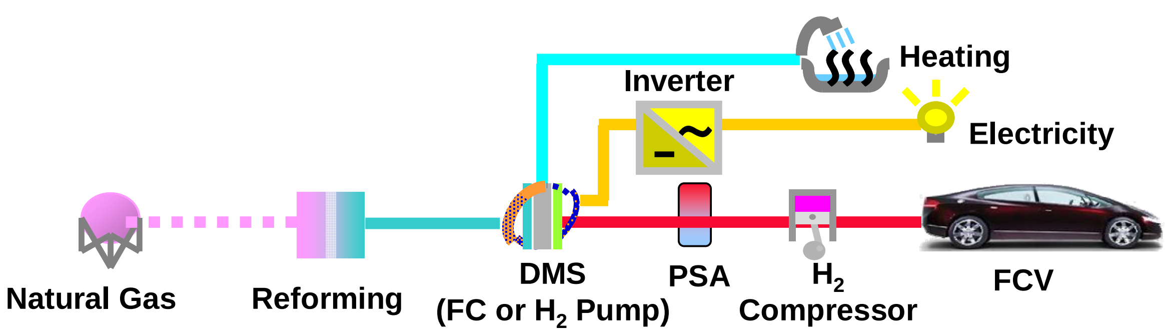


Figure 3.2　The Equipment Configuration of HES IV

Regarding the system design, by taking into account home installation, it was decided to make the system slim and tall. As a result, the system occupies minimal space when installed against the wall of a house, for example. The dispenser was installed separately from the main unit. This allows an installation method in which the main unit can be installed outdoors and the dispenser installed in a garage, for example.

4. Operation Mode

HES IV has two modes: One is a Hydrogen Mode that manufactures hydrogen and supplies it to a fuel cell vehicle, and the other is a Power Mode, which generates electricity and returns it to the power grid. The operation of each device shown in Figure 3.2 is controlled according to the particular mode.

The process of the Hydrogen Mode takes place in the following sequence.

1. A mixed gas consisting of natural gas, air, and water is fed to the reformer where they are caused to react by the catalyst, resulting in reformed gas containing approximately 40 – 50% hydrogen.
2. Hydrogen alone is extracted from the reformed gas using the hydrogen membrane pump function of the DMS.
3. The PSA removes moisture and the small amount of remaining impurities, resulting in hydrogen of at least 99.99% purity.
4. The hydrogen obtained is compressed by the compressor, and supplied to the fuel cell vehicle.

Here, the necessary electric power for manufacturing hydrogen is supplied from the power grid, via the inverter, to the system.

The process of electricity generation occurs as follows.

1. A mixed gas consisting of natural gas, air, and water is fed to the reformer where they are caused to react by the catalyst, resulting in reformed gas containing approximately 40 – 50% hydrogen.
2. The manufactured reformed gas is supplied directly to the DMS, causing electricity to be generated by the fuel cell function of the DMS.
3. The electric power obtained is converted to AC by the inverter, and then returned to the power grid (reverse power flow).

Figure 4.1 shows the standard utilization pattern throughout one day.

The user can start the Hydrogen Mode at any desired time by issuing an instruction from the operation panel on the disperser side. For example, in the standard utilization pattern of Figure 4.1, it is assumed that the vehicle is charged with hydrogen from evening until midnight when it is at the user’s home.

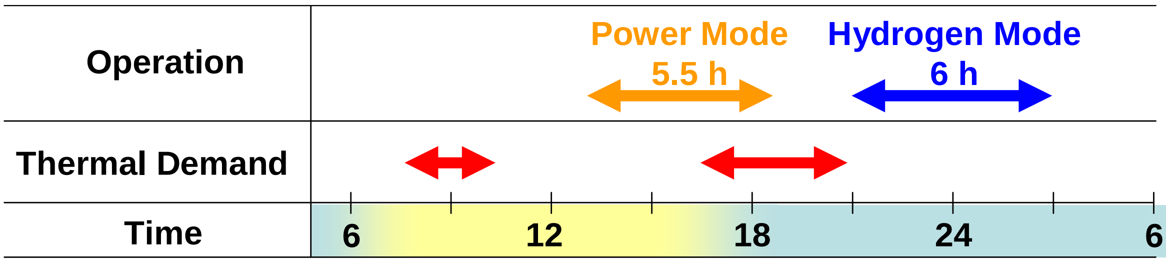


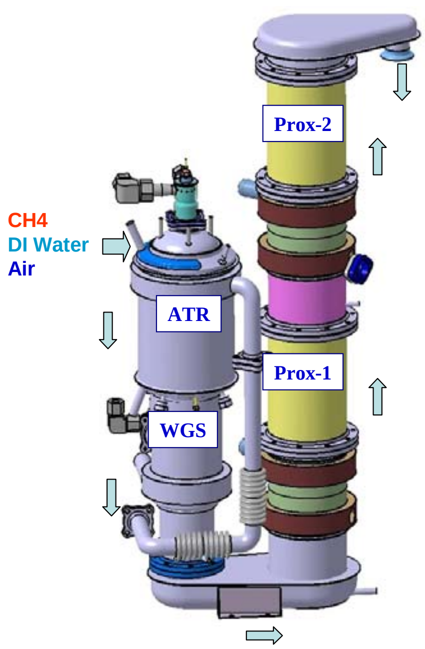
Figure 4.1 Standard Utilization Pattern of HES IV

5. Equipment Configuration

As shown in Figure 3.2, HES IV consists mainly of a reformer, DMS, PSA, hydrogen compressor, and a control and electrical section. The overall system is of compact design. The features of each component of the system are described below.

5.1 Reformer Unit

Figure 5.1 shows the configuration of the reformer unit. The reformer unit consists of an autothermal reactor (ATR), a water gas shift (WGS) catalyst, and a 2-stage preferential oxidation (PROX) catalyst. It also contains a combustion catalyst that burns the reformed gas (off-gas) extracted from the hydrogen and uses the resulting heat to heat the evaporator,



	Reaction
ATR	$CH_4+2O_2 \rightarrow CO_2+2H_2O$ $CH_4+H_2O \rightarrow CO+3H_2$
WGS	$CO+H_2O \rightarrow CO_2+H_2$
PROX-1	$CO+1/2O_2 \rightarrow CO_2$
PROX-2	$CO+1/2O_2 \rightarrow CO_2$

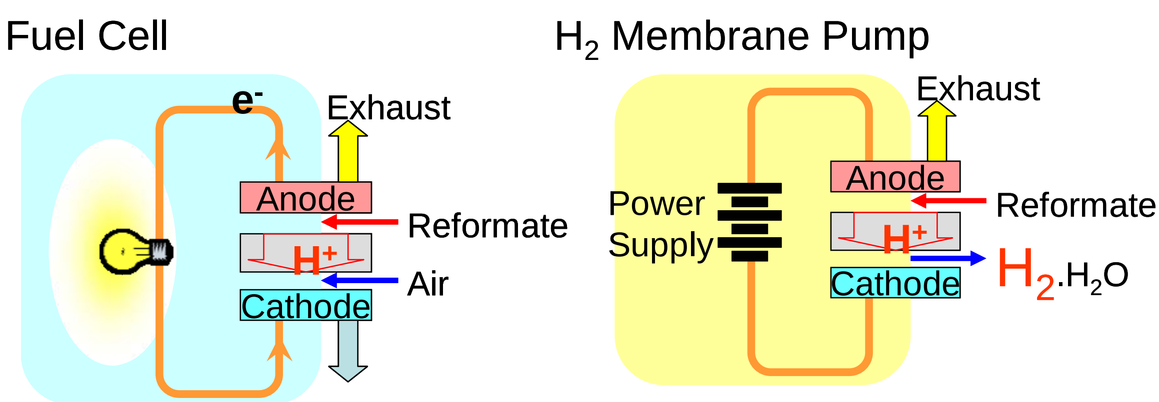
Figure 5.1 Reformer Unit

a heat exchanger for heat management, and a mixer that supplies air to the PROX catalyst. These elements are integrally designed, and heat management of the overall reformer is performed, enabling reformed gas to be manufactured efficiently. Also, Honda used its experience in the development of vehicle-mounted reformers to develop a compact reformer unit that can be started in a short time.

5.2 Dual Mode Stack (DMS)

The dual mode stack (DMS) is a stack that functions both as a fuel cell and a hydrogen membrane pump. In Power Mode, the stack operates as a fuel cell shown in Fig. 5.2 (a), and in Hydrogen Mode, it operates as a hydrogen membrane pump shown in Fig. 5.2 (b).

A hydrogen membrane pump is a stack that functions to move hydrogen alone from the reformed gas supplied to the anode (negative electrode) side, to the cathode (positive electrode) side, by means of a voltage applied to the electrodes. The gas pressure can be boosted by converging the pathway on the cathode side. As a result, the reformed gas is refined and its pressure is boosted. The gas that remains after hydrogen is extracted from the reformed gas is fed to the combustion catalyst of the reformer as off-gas, and used as heating fuel for the evaporator.



(a) DMS – Fuel Cell Mode (b) DMS – Hydrogen Membrane Pump Mode

Figure 5.2 Dual Mode Stack

5.3 Pressure Swing Adsorption (PSA)

PSA is a gas refining method that utilizes the fact that impurities contained in a gas are adsorbed to/separate from adsorbent material under pressure. The hydrogen obtained from the DMS contains moisture and minute amounts of other gases, so in HES IV the hydrogen gas is dehumidified and the other gases are removed from it by means of a 2-stage PSA. Pressure is required to drive the PSA process, and is obtained from the DMS.

In HES IV, the off-gas output from the PSA unit is returned to the entrance of the DMS and passes through the refining process once again, enabling as much of the hydrogen contained in the off-gas as possible to be acquired as product hydrogen. Also, a process that uses the pressure of the gas that remains in the adsorption tower to purge the adsorption tower when the system is stopped has been introduced, thus increasing the purity of the gas that is produced immediately after the system is started next.

Figure 5.3 PSA

Table 5.1 PSA Specifications

Operating Temp.	45℃
Cycle Time	90 sec
Adsorption Pressure	0.8 MPaG
Desorption Pressure	Atmosphere pressure
Sorbent	Activated Carbon

5.4 Hydrogen Compressor

The HES IV system has a reciprocating gas compressor, which boosts the pressure of the manufactured product hydrogen to a maximum of 35 MPaG. Figure 5.4 shows the exterior of the compressor, and Table 5.2 shows its main specifications. This compressor is an oil-free type that employs 4-stage compression to prevent oil and other contaminants from becoming mixed with the product hydrogen. The rated processing rate is 55 SLM, and the processing rate can be raised or lowered by adjusting the motor speed. This function is used to reduce the processing rate to cope with situations in which the amount of hydrogen produced is less than the rated amount during system operation, such as immediately after the system is started.

Table5.2　H_2 Compressor Specifications

Type	Air-Cooled 4 Stages Oil Free Compressor	
Motor Speed	1450	rpm
Flow Rate	55	SLM
Suction Press.	0.8	MPaG
Suction Temp.	50	℃
Discharge Press.	35	MPaG
Discharge Temp.	70	℃
Power Consumption	1.2	kW
Weight	76	kg
Drive	Direct Drive by Motor	
Size	436 × 296 × 332	

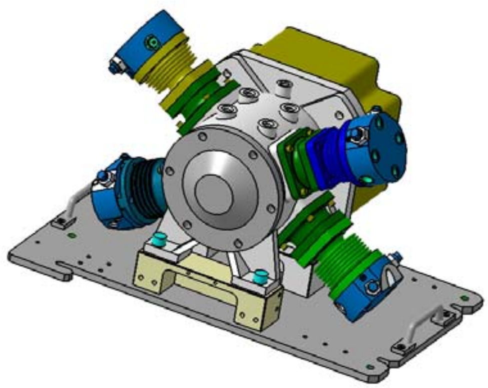


Figure 5.4　H_2 Compressor

5.5 Dispenser and User Interface

The dispenser consists of a filling nozzle and a user interface monitor, which also functions as an operation panel. It is separated from the main unit in consideration of the convenience of the user and freedom of installation (Figure 5.5). The user interface allows operation status to be checked and the settings for the filling operation and automatic operation to be changed by means of intuitive operations.

Figure 5.5　Dispenser & User Interface

6. System Efficiency, Energy Cost and CO_2 Emissions

Figure 6.1 shows the operation pattern diagram for rated operation in each mode of the HES IV system, as well as the efficiency of each component and of the overall system.

Regarding Hydrogen Mode, the electric power that is required to drive the system is supplied from the power grid, and 9 kW (50 SLM) of hydrogen is generated from 13 kW of natural gas. Here, in the efficiency calculation, it was assumed that the power generating efficiency of the necessary power grid was 38%. The efficiency target for Hydrogen Mode is 40%.

Regarding Power Mode, 13 kW of natural gas is reformed and electricity is generated directly by the DMS. The electric power that is required to operate the system is obtained from part of the electricity that the system generates itself. The remainder of this generated electricity is converted to AC by the inverter and returned to the power grid. The maximum power that can be returned to the power grid is 4 kW, and the efficiency target for Power Mode is 30%. By using the exhaust heat generated in each mode for making hot water, heating, and so on, the overall total energy efficiency can be increased further.

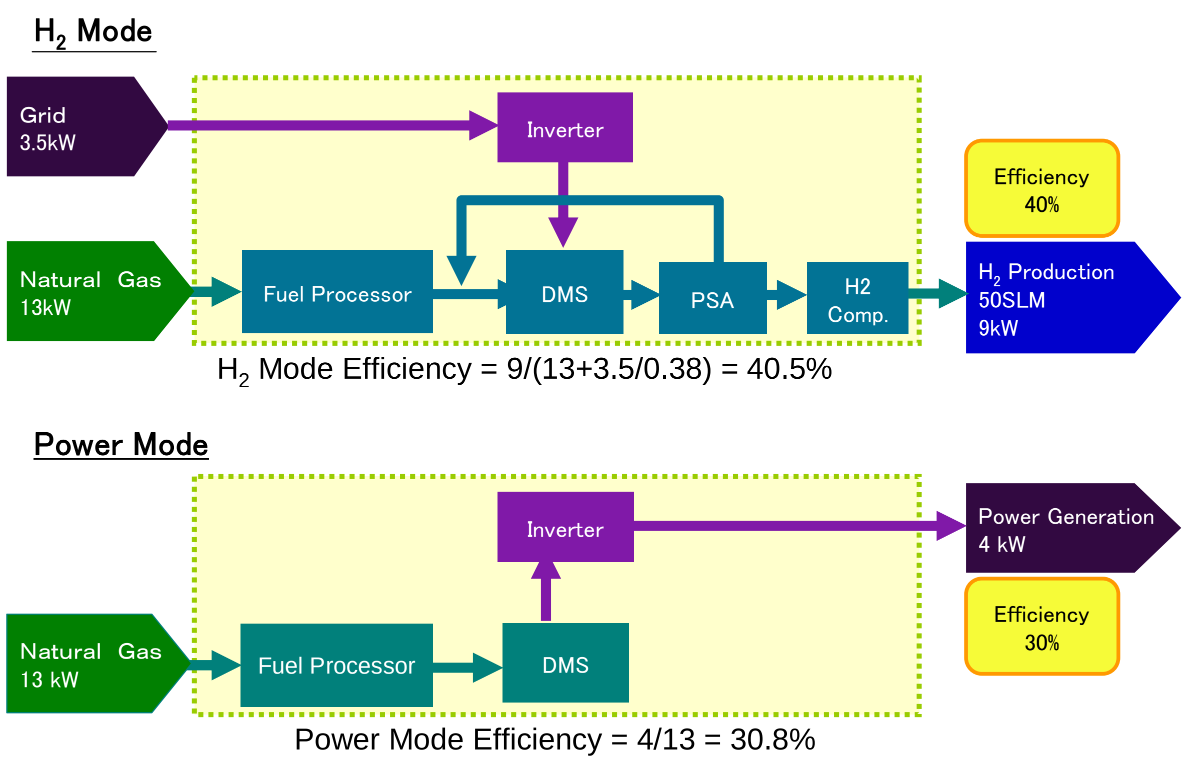


Figure 6.1 System Efficiency of Each Mode

Calculations that assume two kinds of households were performed, and the results of a comparison of the energy cost and CO_2 emissions are set out below. One household uses a conventional gasoline-fueled internal combustion engine vehicle, and uses the power grid for obtaining electric power and supplying the necessary heat loads. The other household uses a fuel cell vehicle, and uses HES for obtaining electric power and supplying the necessary heat loads. Figure 6.2 shows a comparison of the energy cost and CO_2 emissions for these households over a period of 1 year. As the calculation conditions, the average energy consumption profile for the Los Angeles area was used, and it was assumed that both vehicles traveled 10,000 miles in 1 year.

From Figure 6.2, it can be seen that by using the HES, roughly the entire demand for hot water can be met by utilizing exhaust heat from the HES, thus enabling the energy required for making hot water to be greatly reduced. It can also be seen that by using hydrogen manufactured by an HES and a fuel cell vehicle, CO_2 emissions can be reduced to about one half of those from a gasoline-fueled internal combustion engine vehicle. In total, the annual energy cost can be reduced by $1608 (approx. 50%), and CO_2 emissions reduced by 3.8 tons (approx. 30%), compared to the use of a gasoline-fueled internal combustion engine vehicle and the power grid.

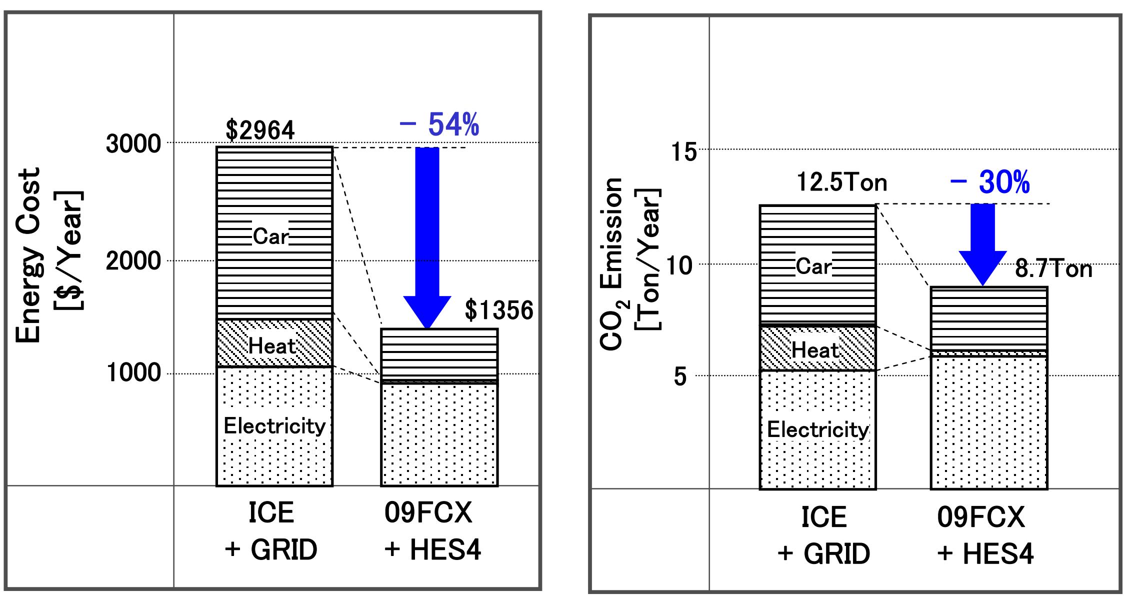


Figure 6.2 Energy Cost and CO_2 Emission

7. Future Development

On October 2007, HES IV was installed at the test site on the premises of Honda R & D America Inc. in Los Angeles, and proving tests were started. The efficiency of the HES, which has the three functions of hydrogen supply, electrical power generation, and hot water supply, is greatly affected by the balance between supply and demand for each load. Consequently, it is extremely important to know the actual operating data and the way in which the system is used in the real world. The proving tests on HES IV are to be continued for several years, with the elucidation and validation of resultant issues to also be carried out.

Figure 7.1　HES IV and FCX Clarity

8. References

1. Ministry of the Environment Government of Japan : Annual Report on the Environment and the Sound Material-Cycle Society in Japan 2007