

Introduction of Solar Hydrogen Station Installed in Japan

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ABSTRACT

A high differential pressure water electrolysis-type solar hydrogen station has been installed on the campus of the Saitama Prefectural Office in Japan. This is Japan's first demonstration with this type of system, and the first such system in the world to be installed in a public location. A station of the same type, conforming to U.S. standards, had previously been installed at Honda R&D Americas, Inc. Los Angeles Center in Torrance, California, but it was necessary to make modifications in introducing the system to Japan in order to conform to Japanese laws and regulations. Thus, a fire-protection wall was put in place, the system ventilation airflow was increased and pressure proof tests were conducted on the high differential pressure water electrolysis stack. In the course of accommodating the Japanese laws and regulations, it was realized that under the present laws, the same configurations would be necessary when considering the household installation of such hydrogen stations. The study has also shown that this hydrogen station is capable of stably producing hydrogen in a verification test conducted in coordination with a fuel cell electric vehicle being used as an official vehicle by Saitama Prefecture.

1. Introduction

Viewing hydrogen fuel cells as the ultimate next-generation automotive powerplant, providing an alternative to fossil fuels and functioning to reduce exhaust emissions and assist in mitigating global warming, Honda has been engaged for some time in development efforts related to fuel cell electric vehicles.

Honda also takes research on technologies for the supply of hydrogen to fuel cell electric vehicles with minimal carbon emissions very seriously, and, looking towards the realization of a future hydrogen energy-based society, is conducting R&D in the area of solar hydrogen stations that use solar cells as their power source. As the first stage in this process, Honda commenced experimental tests on a solar hydrogen station produced using commercially available components at Honda R&D Americas, Inc. Los Angeles Center in Torrance, California, from July 2001. In October 2003, the company introduced a uniquely developed normal pressure water electrolysis-type solar hydrogen station (Solar Hydrogen Station 1, or SHS1)⁽¹⁾, and in January 2010 replaced the SHS1 with a high differential pressure water electrolysis-

type solar hydrogen station (Solar Hydrogen Station 2, or SHS2)^{(2), (3)}. This paper will introduce a version of the SHS2 established to domestic specifications on the campus of the Saitama Prefectural Office (termed "domestic SHS2" below). This station is Japan's first demonstration of high differential pressure water electrolysis system, and the first such system in the world to be situated in a public location. The system was jointly established by the Saitama prefectural government, Iwatani Corporation, Honda Motor Company, Ltd., and Honda R&D Co., Ltd, as part of the project "CO₂ emission reduction system which combined small scale solar hydrogen station and fuel cell electric vehicles," itself part of the Ministry of the Environment's FY2011 Low Carbon Technology Research and Development Program. On March 27, 2012, the station was delivered to the Saitama prefectural government, and the project was commenced for a projected period of two years. The domestic SHS2 has been modified in relation to the U.S. specifications ("U.S. SHS2" below), chiefly in order to conform to laws and regulations related to domestic facilities. This paper will discuss the design of the domestic SHS2, responses to laws and regulations, and the operating status of the station.

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2. Design

2.1. Concept

Figure 1 shows the design concept of the SHS2.

The concept for the station was FLUID FUNCTION, as in the case of the U.S. SHS2. The flow of energy production by the system is expressed by symmetrical curved surfaces that offer a sense of stability. The finishing of the area around the station, the color choice, and the positioning of the station were designed to help ensure that it would blend in with the surrounding environment in the grounds of the prefectural office with no sense of incongruity, and the exterior of the station overall sought to offer a feeling of advanced technology. Figure 2 shows the exterior of the domestic SHS2 that embodies these design concepts.

2.2. Layout

Looking towards the widespread diffusion of small hydrogen stations in the near future, the domestic SHS2 is a facility that conforms to Japanese laws and regulations concerning the design of high-pressure gas refueling stations, and that is being used in tests and evaluations of equipment for the supply of hydrogen fuel

for fuel cell electric vehicles. Because the station is used to supply fuel for the fuel cell electric vehicle that serves as the Saitama Governor's official vehicle every working day, the station was designed to be able to be used safely and effectively by any user. The layout of the station is compact but offers a sense of openness, while also taking into consideration a variety of design features considered necessary for the future use of similar equipment in ordinary households. Figure 3 shows a CG layout of the domestic SHS2.

The vehicle to be fueled backs up to the filling position within the guide lines, and stops at the optimum position as indicated by a guide bump positioned at the rear of the vehicle. The curb around the island on which the refueling dispenser is located is elevated 150 mm above ground level, and the distance of the refueling dispenser from the curb was determined with consideration of preventing impact with the dispenser even in the event of mis-steering. In consideration of rainy climates, a roof has been added to the area where the vehicles park, to help protect them from rain during the refueling process. To help ensure that there is no interference between the roof and the doors of vehicles being fueled when occupants get out, and in addition to maintain the harmony of the overall design, the roof uses cantilevered pillars, creating a comfortable refueling area with a sense of openness.

2.3. User Interface

The U.S. SHS2 employs a user interface (UI) screen offering simple and intuitive operations; the UI screen was modified for the Japanese station. Figure 4 shows the UI screen. First, the display language was changed entirely to Japanese. Instructions for fueling operations are presented in an animated form, making them more intuitively understandable. In addition, while the U.S. SHS2 provides a numerical display of the status of hydrogen fueling, the domestic version offers a graphic display in which a gauge fluctuates depending on the state of fueling, and also indicates the remaining fueling time, increasing convenience for users.

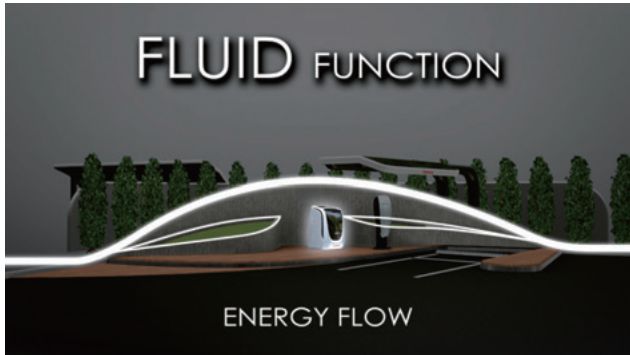


Fig. 1 Design concept of SHS2



Fig. 2 External view of SHS2 installed on Saitama prefecture property

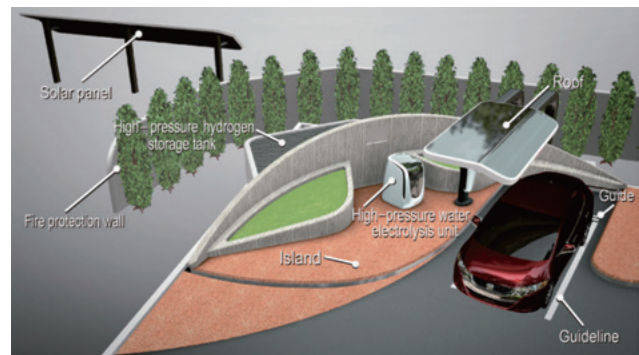


Fig. 3 System layout of SHS2



(a) Connecting nozzle



(b) Refueling

Fig. 4 UI screens of SHS2

3. System Specifications

Like the U.S. SHS2 (as previously reported⁽²⁾), the domestic SHS2 combines a high differential pressure water electrolysis system with solar cells, making it possible to generate hydrogen without any associated CO₂ emissions. Table 1 shows the specifications of the U.S. and the domestic SHS2 stations. In terms of basic specifications, the two stations are identical. The specifications differ in the hydrogen storage amount, the area of the solar cells, and the ventilation flow rate. Because the U.S. SHS2 was developed in order to conduct proving trials of hydrogen home refueling appliances, the hydrogen storage amount was set at a low 4 kg (35 MPa, 167 L). At this hydrogen storage amount, final refueled pressure is too low to complete the hydrogen refueling process exclusively by means of fast fill, which uses the pressure differential between the hydrogen storage tank and the fuel cell electric vehicle tank. Because of this, after hydrogen has been fueled using fast fill, the U.S. SHS2 employs slow fill, a method in which hydrogen is supplied directly to the vehicle's tank from the high differential pressure water electrolysis stack. In Japan, however, the law stipulates that a person must be present while the vehicle is being fueled with hydrogen, and slow fill, which would take several hours at the hydrogen

Table 1 Specifications of SHS2

		United States	Japan
Hydrogen production	Flow rate	0.7 Nm ³ /h	
	Filling pressure	35 MPa	
	Purity	>99.99%	
	Storage	4 kg	20 kg
Component	Photovoltaic module	CIGS 6 kW	CIGS 10.5 kW
	Electrolysis unit	High differential pressure electrolyzer	
Utility	Electricity	240 VAC / 60 Hz	200 VAC / 50 Hz
	Water	Tap water	
	Ventilation	3.5 Nm ³ /min	7 Nm ³ /min
Unit volume		Approx 0.33 m ³	

production rate of the SHS2, is therefore impracticable. The domestic SHS2 therefore does not employ slow fill. A high pressure is necessary in order to complete hydrogen fueling using fast fill, and it was also necessary to take into consideration the fact that the station would be situated in a public area, and therefore might be used to fuel multiple vehicles. Given this, the hydrogen storage amount for the domestic SHS2 was set at approximately 20 kg (35 MPa, 828 L). Like the U.S. SHS2, the domestic SHS2 employs CIGS thin-film solar cells⁽⁴⁾ manufactured by Honda Soltec in its solar cell panels; the increase in the hydrogen storage amount necessitated a higher hydrogen production, and the output of the cells was therefore increased from 6 to 10.5 kW. In addition, the system is also able to utilize commercial power in order to produce hydrogen when power output from the solar cells declines at night, due to rainy weather, or simply when necessary.

4. Responses to Laws and Regulations

4.1. Overview of Laws and Regulations

Table 2 shows the applicable laws, regulations and standards in Japan and the U.S. Laws, regulations and standards concerning the installation of hydrogen stations differ between the two countries. ISO 22734-2⁽⁵⁾, for residential applications of hydrogen generators using a water electrolysis process, has already been established as an international standard for this type of hydrogen generator, and this was the main standard applied to the U.S. SHS2. Other than ISO 22734-2, the U.S. NFPA55⁽⁶⁾ standard for the handling of high-pressure gas and NFPA497⁽⁷⁾ standard for the classification of hazardous locations were also applicable, and the system received approval for operation as a hydrogen station as a result of satisfying these standards. The SHS2 had therefore already been designed to satisfy U.S. standards, but because domestic standards based on the High Pressure Gas Safety Act and the Building Standards Act were more stringent, it was necessary to introduce new responses in order to comply with these regulations.

Table 2 Codes and standards for US and Japan

	United States	Japan
Water electrolysis applications	ISO22734-2	None
High-pressure gas applications	NFPA55	High Pressure Gas Safety Act Building Standards Act
Classification	NFPA497	JIS60079-10

4.2. Differences in Responses in U.S. and Japan

4.2.1. Responses to Japanese laws and regulations

The High Pressure Gas Safety Act classifies high-pressure gas production equipment into Class 1 Producers, the operation of which must be approved, and Class 2 Producers, on which there are comparatively few restrictions, and that can be installed after the relevant authorities are notified of the fact. Based on its specifications and volume of hydrogen production, the SHS2 corresponds to a Class 2 Producer. Nevertheless, because the Saitama Prefectural Office, where the domestic SHS2 would be installed, is located in a commercial district, the restrictions on areas able to be used stipulated by Article 48 of the Building Standards Act would, in principle, prohibit the production of flammable and compressed gases. However, in accordance with the government's measures to stimulate more widespread use of fuel cell electric vehicles, hydrogen stations are able to be installed if they are Specific Compressed Hydrogen Stations, which have received approval as Class 1 Producers. It was therefore necessary to design the domestic SHS2 to conform to the technical standards related to Specific Compressed Hydrogen Stations as stipulated in Article 7, Part 3(2) of the Security Regulation for General High-Pressure Gas. The main points of the Security Regulation to which it was necessary to respond in the domestic SHS2 as a high differential pressure water electrolysis system were as follows:

- (1) Installation of a fire-protection wall around the area in which the system is installed
- (2) Installation of a firefighting sprinkler system in order to control temperature increase in the tank
- (3) Positioning of the system at least 6 m from any equipment or facility in which fire is employed
- (4) Demonstration by calculation that the components have sufficient strength; otherwise, in pressure proof tests that the components would not rupture at more than four times normal operating pressure
- (5) Guarantee of explosion-proof performance in the unit

4.2.2. Area of installation of system

In selecting the area for installation of the unit, it was necessary to consider items (1) Installation of a fire-protection wall, (2) Installation of a sprinkler system, and (3) Distance from equipment of facilities using fire in Section 4.2.1 above. A fire-protection wall that wraps around the back of the island on which the system is positioned was therefore installed, as shown in Fig. 3. A

sprinkler system was installed at the tank section in order to help prevent fires and control temperature increase. In addition, as will be discussed below, the SHS2 maintains explosion-proof performance by means of ventilation, but the system contains relays and other sources of potential ignition, and these can be regarded as fires. Given the necessity of satisfying item (3) in Section 4.2.1, the air inlet for system ventilation was positioned more than 6 m from the system. By contrast, in the case of the U.S. SHS2 it was not necessary to install a fire-prevention wall or a sprinkler system, and requirements regarding distance from equipment or facilities that use fire did not apply to the system. However, NFPA55 regards vent pipes for the release of hydrogen as a source of hazard, and stipulates a distance of at least 15 ft (approx. 4.6 m) from the vent pipe to the system. Response to this stipulation was the only response necessitated for the U.S. SHS2.

4.2.3. Stack

The High Pressure Gas Safety Act stipulates that the Security Regulation for General High-Pressure Gas is applicable to any container for which the product of the designed pressure expressed in MPa and the internal volume expressed in m³ is 0.004 or less. This is expressed in equation form as Eq. (1). The Designated Equipment Inspection Regulations apply to all other high-pressure containers, and these regulations place major restrictions on the structure of the container and the materials used in comparison to the Security Regulation for General High-Pressure Gas.

$$P \times V \leq 0.004 \quad (1)$$

P : Designed pressure (MPa)

V : Interior volume (m³)

Because the designed pressure of the high differential pressure water electrolysis stack used in the SHS2 is 38.5 MPa, if the internal volume was 103.9 cm³ or less, the Security Regulation for General High-Pressure Gas would apply. The internal volume of the water electrolysis stack is 100.8 cm³, meaning that it was the Security Regulation for General High-Pressure Gas for which compliance was necessary.

As indicated in item (4) in Section 4.2.1, it is necessary for a high-pressure vessel to have sufficient strength corresponding to the normal operating pressure. An illustration of the Security Regulation for General High-

Pressure Gas specifies calculation methods for pressure resistance when a container is manufactured from metal, and it is also possible to use calculations to indicate the ability of components such as pipes, relief valves, check valves, and solenoid valves that possess pressure-resistant structures made exclusively of metal to have sufficient strength. However, because a part of the pressure-resistant structures in the high differential pressure water electrolysis stack is composed of non-metallic proton exchange membranes, the formulas specified by the illustration of the Security Regulation for General High-Pressure Gas cannot be applied. The ability of the stack to resist rupture was therefore verified in pressure resistance tests at 160 MPa, which is more than four times normal operating pressure.

4.2.4. Pressure resistance design for components

Like the high differential pressure water electrolysis stack, it was also necessary to demonstrate that the components used in high-pressure sections were able to resist four times normal operating pressure. By contrast, the U.S. regulations stipulated that pressure-resistant containers in high-pressure sections should resist 2.4 times normal operating pressure, and plumbing should resist three times normal operating pressure. The components employed in the SHS2 had been selected on the assumption of being used in a U.S. system, and it was therefore necessary to verify that each device was able to resist four times design normal operating pressure. The performance of each component used in the SHS2 was investigated and the results showed that components including the filters and various fittings did not satisfy pressure resistance demands. These components were therefore redesigned to give them sufficient thickness to resist four times normal operating pressure.

In addition, to help ensure space, the high-pressure hydrogen separator and the absorber vessel were coupled by square flanges. However, the Security Regulation for General High-Pressure Gas does not specify any formulas for square flanges, and these were therefore redesigned as cylindrical flanges, for which the Security Regulation does specify formulas.

4.2.5. Ventilation flow rate

As indicated by item (5) in Section 4.2.1, because the system contains non-explosion-proof components, the Security Regulation for General High-Pressure Gas specifies that the system unit should have a structure in which ventilation helps to ensure explosion proofness. A continuous ventilation system has been employed to help ensure explosion proofness in the SHS2, and this system is also used in the U.S. SHS2. The concept behind this use of ventilation for explosion proofness is to employ sufficient ventilation such that even if a hydrogen leak occurs in the system, the hydrogen content concentration in the air will be less than 1%, or less than one-quarter of the lower

flammable limit.

In the case of the U.S. NFPA497 regulations and ISO 22734-2, it is not necessary to consider ruptures, disconnection, or similar phenomena in parts that have been designed for pressure resistance. The Japanese High Pressure Safety Act, however, does demand consideration of sudden escape of hydrogen due to the rupture of a pipe. The scenario to be assumed is that a pipe ruptures when the system is operating at full pressure, and all of the hydrogen produced by the system leaks into the system. At this time it is necessary to maintain a high degree of ventilation by means of a formula stipulated by JIS C 60079-10⁽⁸⁾. The conditions for this maintenance of ventilation are shown in Eq. (2). Here, a high degree of ventilation is a degree of ventilation helping to ensure that the gas concentration in the source of the gas release is instantaneously reduced. Satisfying Eq. (2) makes it possible to avoid the danger associated with a release of gas. Given that the system's hydrogen production rate is 0.7 Nm³/h and its interior volume is 0.17 m³, from Eq. (2), it is necessary to maintain a ventilation flow rate of 5.6 Nm³/min. A ventilation fan capable of realizing a ventilation flow rate of 5.6 Nm³/min or higher was therefore installed in the domestic SHS2.

$$\frac{f \times (dG/dt)_{\max} \times T}{C \times k \times LFLm \times 293} < 0.1 \quad (2)$$

f	: Ventilation efficiency
$(dG/dt)_{\max}$	: Maximum hydrogen production rate
T	: Surrounding temperature
C	: Ventilation flow rate / Volume to be ventilated (Interior volume)
k	: Safety rate in relation to $LFLm$
$LFLm$	: Lower flammable limit

4.3. Issues Related to Household Installation

By making modifications in order to conform to Japanese laws and regulations, as described above, it was possible to establish a domestic version of the SHS2 in Japan. However, under the terms of the Building Safety Act, in Japan at present the installation of hydrogen stations and other equipment that produce flammable gas is restricted in principle to industrial districts. It is possible to obtain a special ruling from the relevant authorities to locate a facility outside an industrial district, as in the case of the domestic SHS2, but in such cases the technical standards relating to the large facilities classified as Class 1 Producers are applied. Therefore, for household installation of a system of this type, it would be necessary to install a fire-prevention wall and a sprinkler system, and to position the system 6 m or more from any flames, as discussed above. It would be challenging to satisfy these conditions in an ordinary household. In addition, by contrast with the U.S., where components are expected to display resistance to 2.4 times and three

times normal operating pressure, Japanese laws stipulate that components should be able to resist four times normal operating pressure, resulting in increased cost. Given this, while it would be possible to install the domestic SHS2 in households under existing Japanese law, it would be costly and necessitate the use of a large amount of space. It is clear that the introduction of further legislation will be necessary in order to promote widespread use of the system.

The goal of the present research is ultimately to promote the installation of small, inexpensive hydrogen supply systems in households, and in future it will be necessary for Honda to influence the authorities to make legal changes to enable domestic installation of the systems.

5. Operating Status

Despite the fact that a number of modifications were made to the domestic SHS2, for example to increase pressure resistance and the ventilation flow rate, as indicated in Chapter 3, the basic makeup of the system is identical to that of the U.S. SHS2, and the system therefore displays identical levels of system efficiency and hydrogen quality to the U.S. system. Table 3 shows the quality of the hydrogen produced by the SHS2. While some components of the gas cannot be adequately measured due to limit values for detection, overall, the figures are identical to figures for the U.S. SHS2⁽³⁾.

The proving trial discussed here is being conducted in order to study patterns of use when fuel cell electric vehicles are used as the official vehicles of a local administration, and the consequent demands on a hydrogen station. Figure 5 shows a profile of hydrogen production over a typical month. The current domestic SHS2 is being used to fuel a single fuel cell electric vehicle used as an official vehicle by Saitama Prefecture, and is demonstrating the ability to stably produce hydrogen in response to the distance driven by the vehicle. The findings produced by the proving trial will be compiled at the completion of its two-year period.

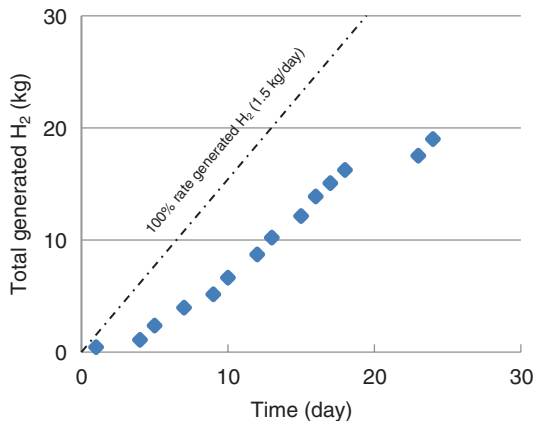


Fig. 5 Typical H₂ production at Saitama

Table 3 Hydrogen quality of SHS2

	ISO14687-2	SHS2 US	SHS2 JP
H ₂ (%)	>99.99	>99.99	>99.99
H ₂ O (ppm)	<5	<1	<5
Hydrocarbon (ppm)	<2	<0.1	<0.3
O ₂ (ppm)	<5	1	<0.1
He, Ar, N ₂ (ppm)	<100	<16	<0.1
CO ₂ (ppm)	<1	<0.1	<0.1
CO (ppm)	<0.2	<0.001	<0.1
Sulfur (ppm)	<0.004	<0.0008	<0.8*
HCHO (ppm)	<0.01	<0.001	<0.01
HCOOH (ppm)	<0.2	<0.001	<5*
NH ₃ (ppm)	<0.1	<0.02	<0.01
Halogenates (ppm)	<0.05	<0.004	<0.5*

* below detectable limit

6. Conclusion

A high differential pressure water electrolysis-type solar hydrogen station has been established in Japan. The following are the salient points of this study.

- (1) Modifications were made to the system in order to respond to Japan's current laws and regulations relating to the installation of hydrogen stations; this is Japan's first demonstration with this type of system, and the first to be installed in a public location anywhere in the world.
- (2) A survey of relevant laws and regulations indicates that Japanese laws do not make adequate provision for domestic installation of systems of this type. It will be necessary to identify the issues related to future domestic installation of the systems, and to work towards the modification of existing laws.
- (3) The results of the initial operation of the domestic SHS2 indicate that its system efficiency and hydrogen quality are identical to those of the U.S. system. In addition, the system is able to be operated in coordination with a single fuel cell electric vehicle with no particular issues.

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