Hybrid Vehicles, Electric Vehicles, Fuel Cell Electric Vehicles

1 Hybrid Vehicles

1. 1. Introduction

Demand for vehicles with better fuel efficiency and cleaner exhaust emissions is growing in light of rising fossil fuel prices and environmental problems such as air pollution and global warming. Automakers have been working to expand the number of vehicle models equipped with hybrid systems as one way of addressing this demand. Japanese manufacturers have focused on fuel-efficient hybrid electric vehicles (HEVs), which combine an internal combustion engine with an electric motor. Section 1 of this article describes the trends in HEVs that occurred in 2014.

1. 2. Popularization of HEVs in Japan

Figure 1 shows that the number of HEVs on the roads in Japan is increasing year after year. The number of hybrid passenger vehicles has significantly exceeded the 3 million vehicle mark and is quickly approaching 4 million vehicles. In 2013, the number of HEVs on the road in Japan increased by nearly 1 million vehicles compared to the previous year. The number of trucks and other non-passenger hybrid vehicles is also expanding steadily. The number of plug-in HEVs (PHEVs) is also increasing and there are approximately 30,000 on the road. This number should continue to expand in the future as automakers continue to increase the availability of PHEVs.

1. 3. New HEVs that launched in Japan in 2014

Table 1 lists the hybrid passenger vehicles that launched in Japan in 2014 according to the month of release. The main trends were as follows.

In January, Toyota Motor Corporation released hybrid versions of the Noah and Voxy minivans. These are the first minivans with a height of 1.8 meters or more, seating for 7 to 8 people, and in the 1.8-liter to 2.0-liter class that are equipped with a full hybrid system. The hybrid system is almost the same as the one in the Prius. These vehicles are equipped with a 1.8-liter inline four-cylinder engine and the total system output is 100 kW. The fuel economy is 23.8 km/L (under the JC08 test cycle).

In July, Toyota Motor Corporation added a four-wheel drive version of the Crown Majesta. This is the first full-time four-wheel drive HEV from Toyota. The original hybrid system in the two-wheel drive vehicle was equipped with a 3.5-liter V6 engine and the total system output was 252 kW. In this new four-wheel drive version, a 2.5-liter inline four-cylinder engine was added, creating a total system output of 162 kW. The fuel economy is 19.0 km/L (under the JC08 test cycle).

On the same day in July, Toyota Motor Corporation also added a four-wheel drive version to its hybrid Crown model. The hybrid system is the same as the one in the Crown Majesta. It is equipped with a 2.5-liter inline four-cylinder engine with a total system output of 162 kW. The fuel economy is 21.0 km/L (under the JC08 test cycle).

Also in July, Lexus launched the NX300h. The hybrid system in the four-wheel drive version is almost the same as that in the Toyota Harrier. It is equipped with a 2.5-liter inline four-cylinder engine, a 105 kW motor on the front axle and a 50 kW motor on the rear axle. This

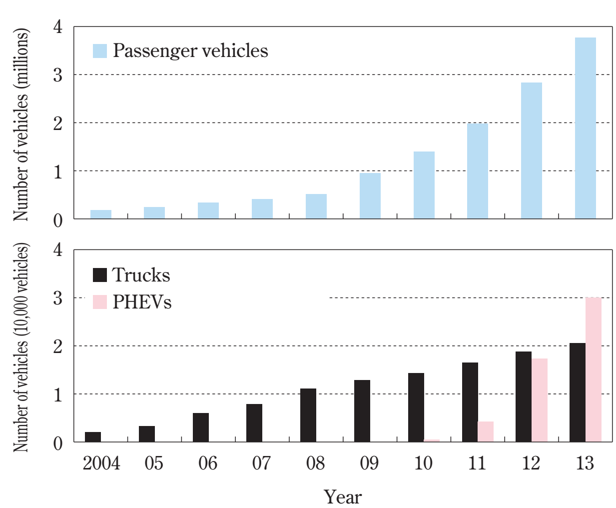

Fig. 1 Trends in the number of HEVs on the road in Japan (1)

Table 1 Main hybrid passenger vehicles launched in Japan in 2014[(2)–(6)]

							
Date announced/went on sale		2014/1/20	2014/7/9	2014/7/9	2014/7/29	2014/7/29	2014/8/25
Name of company		Toyota Motor Corporation			Lexus		Suzuki
Name of vehicle		Noah/Voxy hybrid	Crown Majesta Four	Crown Hybrid Four	NX300h	NX300h	Wagon R FZ
Type of hybrid system		Series-parallel	Series-parallel	Series-parallel	Series-parallel	Series-parallel	Parallel
Drivetrain		Front-wheel drive	Four-wheel drive	Four-wheel drive	Four-wheel drive	Front-wheel drive	Front-wheel drive
Fuel economy (JC08 test cycle, km/L)		23.8	19.0	21.0	19.8	21.0	32.4
Engine	Model	2ZR-FXE	2AR-FSE	2AR-FSE	2AR-FXE	2AR-FXE	R06A
	Displacement (cc)	1 797	2 493	2 493	2 493	2 493	658
	Output (kW)	73	131	131	112	112	38
Motor	Type	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor	DC synchronous motor
	Output (kW)	60	105	105	Front 105 + Rear 50	105	1.6
Battery	Type	Nickel-metal hydride	Nickel-metal hydride	Nickel-metal hydride	Nickel-metal hydride	Nickel-metal hydride	Lithium-ion
	Capacity (kWh)	1.3	1.5	1.5	1.6	1.6	0.04

							
Date announced/went on sale		2014/9/9	2014/10/23	2014/10/29	2014/11/10	2014/12/1	2014/11/25
Name of company		Toyota Motor Corporation	Lexus	Toyota Motor Corporation	Honda Motor Company		Mercedes-Benz
Name of vehicle		Camry Hybrid	RC300h	Esquire Hybrid	Legend	Grace	S550 plug-in hybrid with long wheelbase
Type of hybrid system		Series-parallel	Series-parallel	Series-parallel	Series-parallel	Parallel	Parallel
Drivetrain		Front-wheel drive	Rear-wheel drive	Front-wheel drive	Four-wheel drive	Front-wheel drive	Rear-wheel drive
Fuel economy (JC08 test cycle, km/L)		25.4	23.2	23.8	16.8	34.4	13.4
Engine	Model	2AR-FXE	2AR-FSE	2ZR-FXE	JNB	LEB	276M30
	Displacement (cc)	2 493	2 493	1 797	3 471	1 496	2 996
	Output (kW)	118	131	73	231	81	245
Motor	Type	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor
	Output (kW)	105	105	60	35 + 27× 2	22	85
Battery	Type	Nickel-metal hydride	Nickel-metal hydride	Nickel-metal hydride	Lithium-ion	Lithium-ion	Lithium-ion
	Capacity (kWh)	1.6	1.5	1.3	1.3	0.9	8.7

makes the total system output 145 kW. In the two-wheel drive version, the hybrid system consists of a 2.5-liter inline four-cylinder engine and a 105 kW motor on the front axle, creating a total system output of 145 kW. The fuel economy is 19.8 km/L for the four-wheel drive version and 21.0 km/L for the two-wheel drive version (under the JC08 test cycle).

In August, Suzuki Motor Corporation launched the hybrid Wagon R. This is the first time that a hybrid system has been equipped on a mini vehicle with the "tall wagon" design (i.e., a mini-vehicle with a height of 1.55 meters or more). The hybrid system is a so-called mild hybrid that is equipped with an integrated starter generator (ISG). The ISG uses the energy from deceleration (braking) to charge the vehicle's lead and lithium-ion batteries and then this electrical power is used for

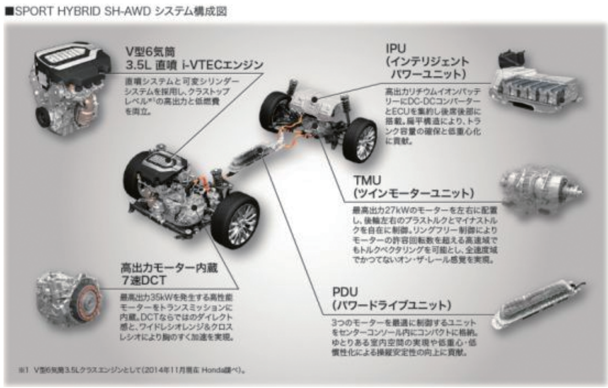

Fig. 2 Composition of the 3-Motor Hybrid System(3)

the engine assist during acceleration and also to restart the engine after an idling stop. The fuel economy is 32.4 km/L (under the JC08 test cycle).

In September, Toyota Motor Corporation added a version of its Camry hybrid with 16-inch wheels. There were no changes to the hybrid system and the fuel economy is 25.4 km/L (under the JC08 test cycle).

In October, Lexus launched the RC300h. It is equipped with a 2.5-liter inline four-cylinder engine and the total system output is 162 kW. The fuel economy is 23.2 km/L (under the JC08 test cycle).

In the same month Toyota Motor Corporation also launched the Esquire. The hybrid system is almost the same as that in the Noah and Voxy that were launched in January. The Esquire is equipped with a 1.8-liter inline four-cylinder engine and the total system output is 100 kW. The fuel economy is 23.8 km/L (under the JC08 test cycle).

In November, Honda Motor Company launched the hybrid Legend. This vehicle is equipped with the world's first three-motor hybrid system, as shown in Fig. 2. Positioned at the front of the vehicle are a newly developed V6 3.5-liter direct-injection engine and a 7-speed dual-clutch transmission (DCT) with an integrated electric motor. The rear-mounted twin motor unit (TMU) contains two motors that distribute torque to the rear wheels. This hybrid system features three distinct driving modes where the hybrid system automatically controls the engine and three motors for optimal performance. In EV drive, the two rear electric motors power the vehicle. In hybrid drive, the gasoline engine powers the front wheels while the two rear motors power the rear wheels. In engine drive, the gasoline engine provides power to the front wheels. The hybrid system automatically selects the most energy-efficient driving mode and the optimal choice of front-wheel drive, rear-wheel drive, or four-wheel drive by continuously responding to driver inputs and the driving conditions. The two motors on the rear axle are independently controlled and can supply advanced torque vectoring to the left and right rear wheels independently. This torque vectoring is not dependent on the engine torque so it is possible to provide either positive (drive) torque or negative (declaration) torque to each rear wheel. The total system output is 281 kW and the fuel economy is 16.8 km/L (under the JC08 test cycle).

In December, Honda Motor Company launched the hybrid Grace. The hybrid system is almost the same as that in the Fit Hybrid. The Grace is equipped with a 1.5-liter inline four-cylinder engine and the total system output is 101 kW. The fuel economy is 34.4 km/L (under the JC08 test cycle).

In the case of imported hybrid vehicles from non-Japanese manufacturers, Mercedes-Benz launched the S550 plug-in hybrid with a long wheelbase as an additional model to its S-Class in November. The vehicle is designed for normal charging only and it takes 4 hours to fully charge a depleted battery using a 200 V outlet. It is equipped with a 3-liter V6 engine and the total system output is 325 kW. The fuel economy is 13.4 km/L (under the JC08 test cycle).

1. 4. Trends in standardization

ISO/TC22/SC37 is carrying out standardization activities for general vehicles powered by electricity (i.e., electrically-propelled road vehicles), including HEVs, fuel cell vehicles (FCEVs), and battery electric vehicles (BEVs). (Up until 2014 this work was carried out by SC 21, but this changed to SC37 in 2015 due to a reorganization of the ISO/TC 22 parent committee). The main trend in these activities in 2014 has been the creation of ISO 6469-4 (a new standard) since January of 2012 in WG 1, which is the group that handles safety aspects and terminology. This new standard concerns the post-crash electrical safety specifications for electrically-propelled road vehicles. In the future it is planned for this standard to be formally issued after proceeding through the Final Draft International Standard (FDIS) voting. Furthermore, in 2014, revision work also began on ISO 6469-1 (Safety specifications for the on-board rechargeable energy storage system (RESS)), ISO 6469-2 (Vehicle operational safety means and protection against failures), and ISO 6469-3

(Protection of persons against electric shock). There are also plans to hold discussions on other electrical safety issues, such as the grades to apply to different levels of high voltage. In contrast, WG 2, which is the group that handles performance and energy consumption, has been working on the creation of fuel consumption testing methods for all HEVs (ISO 23274-1 and 23274-2). This includes both HEVs with and without external charging functions and both of these testing methods were proposed by Japan. ISO 23274-1 (revised), which is the standard for vehicles without an external charging function, was issued on January 13, 2013 and ISO 23274-2, which is the standard for vehicles with an external charging function, was issued on July 26, 2012. In addition, ISO/TR (Technical Report) 11955 (Guidelines for charge balance measurement) was also issued in October of 2008 as the guidelines for the fuel consumption testing methods.

2 Electric Vehicles

2. 1. Introduction

Electric vehicles (EVs) have been attracting attention in recent years as the next generation of environmentally friendly mobility with excellent environmental performance and energy efficiency. Despite this, the main issues holding back EVs, such as battery performance (cruising range, charging time), cost, and the available charging infrastructure, have yet to be resolved. However, technological developments to improve battery performance and reduce the cost of EVs have been making steady progress. Front-runners in the EV field such as Nissan and Mitsubishi Motors Co., Ltd. have expanded the number of EV models to meet a variety of different needs and uses, while also reducing price. In addition, the Japanese government has actively worked to further promote the introduction of EVs into the market by expanding the available charging infrastructure, as well as by encouraging technological development and launching budgetary and tax measures to improve performance and reduce cost. As a result, the popularization and adoption of EVs has started to gain more momentum. Section 2 of this article describes the current state of EV use in Japan, the initiatives taken in 2014 to further expand the usage of EVs, and the trends in standardization. Section 4 of this article will provide more details about the battery charging infrastructure in Japan.

2. 2. Popularization of EVs

2. 2. 1. Market introduction and sales

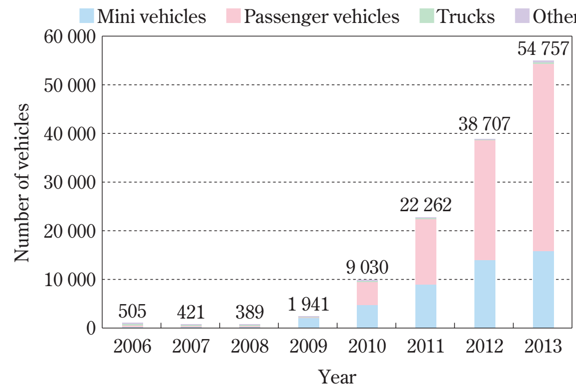

Fig. 3 Trends in number of EVs in use in Japan[7]

Figure 3 shows the number of EVs on the roads in Japan, excluding motor-driven cycles and mini-vehicles (7). The number of such vehicles in Japan has increased since 2009 when Mitsubishi Motors and Fuji Heavy Industries began sales of two small EVs, the i-MiEV and the Subaru plug-in Stella, respectively. By the end of 2013 the number of EVs had reached 54,757 vehicles (the great majority of these are mini-vehicles and passenger vehicles, the number of trucks and other EVs has hovered around several dozen vehicles). Table 2 shows the specifications of the main EVs launched in Japan from 2009 to 2013 (8)-(14). In the case of passenger EVs, the Nissan Motor Co., Ltd. began general sales of its Nissan Leaf in 2010, while Mercedes-Benz began selling its smart fortwo electric drive model in 2012. Also in 2012, Honda, Mazda Motor Corporation, and Toyota began leasing the Fit EV, Demio EV, and eQ, respectively. By 2013 Mitsubishi had established different grades for the i-MiEV depending on the cruising range on a single charge (the top model featured an extended range on a single charge). The lineup of i-MiEV mini-vehicles also featured commercial models such as the Minicab-MiEV Van (2011) and the Minicab-MiEV Truck (2013). Mitsubishi revised the prices of all of these EVs in an effort to help lower the prices of other EVs in Japan. Nissan also worked to extend the cruising range on a single charge of its Leaf EV and revised its pricing to help lower the sales prices of other EVs in Japan.

Table 3 shows the specifications of the main EVs launched in Japan in 2014 (10)(15)(16). In April, BMW began selling the i3. This same vehicle is also offered with the option of a range extender (an engine for generating electricity) that is expected to help extend the cruising range.

Table 2 Specifications of main EVs launched in Japan from 2009 to 2013 (8)-(14)

		i-MiEV	Subaru plug-in Stella	Nissan Leaf	MINICAB-MiEV VAN	smart fortwo electric drive
External appearance						
Manufacturer		Mitsubishi Motors Co., Ltd.	Fuji Heavy Industries Ltd.	Nissan Motor Co., Ltd.	Mitsubishi Motors Co., Ltd.	Mercedes-Benz
Sales format		General	Fleet	General	General	General
Occupant capacity		4	4	5	2 (4)	2
Cruising range on a single charge (km)		120 /180 *1, 3	90 *2	228 *1	100 /150 *1, 3	181 *1
AC power consumption rate (Wh/km)		110 *1		114 *1	125 *1	110 *1
Motor	Type	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor
	Max. output (kW)	30 /47 *3	47	80	30	55
Battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total power (kWh)	10.5 /16 *3	9	24	10.5 /16 *3	17.6
Charging time	Normal	4.5 h/7 h *3, 4 (AC 200 V)	8 h *5 (AC 200 V)	8 h *4 (AC 200 V)	4.5 h/7 h *3, 4 (AC 200 V)	8 h *4 (AC 200 V)
	Rapid *6	15 min/30 min	15 min	30 min	15 min/35 min	Not applicable

		Fit EV	Demio EV	eQ	Minicab-MiEV Truck
External appearance					
Manufacturer		Honda Motor Company	Mazda Motor Corporation	Toyota Motor Corporation	Mitsubishi Motors Co., Ltd.
Sales format		リース	リース	リース	一般
Occupant capacity		5	5	4	2
Cruising range on a single charge (km)		225 *1	200 *7	100 *1	110 *1
AC power consumption rate (Wh/km)		106 *1	100 *7	104 *1	120 *1
Motor	Type	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor
	Max. output (kW)	92	75 *7	47	30
Battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total power (kWh)	20	20 *7	12	10.5
Charging time	Normal	6 h *4 (AC 200 V)	8 h (AC 200 V)	3 h *4 (AC 200 V)	4.5 h *4 (AC 200 V)
	Rapid *6	20 min	40 min	15 min	15 min

＊1 : JC08 test cycle　＊2 : 10 -15 test cycle　＊3 : Different depending on grade
＊4 : Charging via AC 100 V also possible (recommended to charge with AC 200 V)
＊5 : Charging via AC 100 V also possible　＊6 : 50 kW output, charging up to 80
＊7 : Measurement value from manufacturer

In September, deliveries of the Model S from Tesla Motors finally began after reservations had opened back in the spring of 2011. The Model S can be charged using the CHAdeMO fast-charging standard that was developed in Japan, a 200 V outlet, or Tesla's own proprietary Supercharger rapid charging stand. The maximum output that the Supercharger can provide is 120 kW (16), which makes it possible to charge the Model S at twice the speed of the CHAdeMO standard.

In October the e-NV200 commercial vehicle from Nissan went on sale. This same vehicle is also available in a wagon version that can also be used as a passenger

Table 3 Specifications of main EVs launched in Japan in 2014 (10) (15) (16)

		BMW i3	Model S	e-NV200
External appearance				
Manufacturer		BMW	Tesla Motors	Nissan Motor Co., Ltd.
Sales format		General	General	General
Occupant capacity		4	5	Van: 2 or 5 Wagon: 5 or 7
Cruising range on a single charge (km)		229 *1	390/502 *2	185/188/190 *1, 3
AC power consumption rate (Wh/km)		98 *1	—	142
Motor	Type	AC synchronous motor	AC induction motor	AC synchronous motor
	Max. output (kW)	125	225/270/310 *3	80
Battery	Type	Lithium-ion	Lithium-ion	Lithium-ion
	Total power (kWh)	21.8	60/85 *3	24
Charging time	Normal	7 ~ 8 h (AC 200 V)	24.4 h/31.4 h *5 (AC 200 V)	8 h (AC 200 V)
	Rapid *4	30 min	3.1 h/4 h *5	30 min

*1 : JC08 test cycle *2 : NEDC *3 : Different depending on grade
*4 : 50 kW output, charging up to 80 % *5 : Source = JARI

vehicle.

Volkswagen has announced that it will be selling its e-up! and e-Golf EVs in Japan. Orders started in February 2015 (17).

Consequently, it is clear that the number of EV models that Japanese consumers can choose from has only been increasing since 2009 and that the variety vehicle models has been expanding steadily to meet different needs and uses.

2. 3. Initiatives to expand EV popularization

2. 3. 1. Adoption of EV buses, trucks, and taxis

The Japanese Ministry of Land, Infrastructure and Transport (MLIT) is looking to effectively accelerate the popularization and adoption of electric vehicles with particularly good environmental performance (including PHEVs). Electric buses, taxis, and trucks are being used to promote more environmentally friendly regions and transportation-related businesses and also to promote low-carbon urban development. To this end, MLIT is carrying out a project to make regional and transportation businesses more environmentally friendly as a way to induce the adoption of EVs by other regions and businesses (18). This project provides targeted support to specific automobile and transportation businesses (limited to bus, taxi, or truck businesses) that have been identified as pioneers to help encourage the rapid popularization of EVs. Every year numerous potential targets for support are selected and the creation of well-conceived initiatives is expected to help popularize the adoption of EVs all across Japan.

2. 3. 2. Adoption of ultra-compact vehicles

In recent years, ultra-compact vehicles that are even smaller than mini-vehicles have been attracting an increasing amount of attention. The guidelines developed by MLIT to help promote the use of these ultra-compact vehicles define these as vehicles that are more compact, maneuverable, and environmentally friendly than conventional automobiles, and that can carry one or two people on short local trips. MLIT has introduced relaxed standards based on the Safety Regulations for Road Vehicles under the Road Trucking Vehicle Law as a way of ensuring the safety of ultra-compact vehicles. These standards prohibit the driving of ultra-compact vehicles on expressways, restrict usage to locations capable of ensuring safe and smooth traffic flows, and apply conditions for size and performance. This relaxing of some regulations is allowed only in the cases where the safety and environmental performance of these vehicles is not adversely affected. These standards (the ultra-compact vehicle certification system) were established in January 2013 and allow ultra-compact vehicles to be driven on public roads in Japan (18).

Table 4 Specifications of main ultra-compact vehicles[(10)(12)(14)(20)]

		COMS	New Mobility Concept	MC-β	i-ROAD
External appearance					
Manufacturer		Toyota Auto Body Co., Ltd.	Nissan Motor Co., Ltd.	Honda Motor Company	Toyota Motor Corporation
Sales format		General	Not for sale	Not for sale	Not for sale
Occupant capacity		1	2	2	1[*1]
Cruising range (km)		50	100	50	50
Max. speed (km/h)		60	80	70 or more	60[*1]
Motor	Rated output (kW)	0.59	8	2 × 2	2 × 2
Battery	Type	Lead	Lithium-ion	Lithium-ion	Lithium-ion
	Total power (kWh)	5.2	6.1	—	—
Charging time		6 h (AC 100 V)	4 h (AC 200 V)	3 hours or less (AC 200 V) 7 hours or less (AC 100 V)	—

＊1：Japanese specifications

Since the definition of these ultra-compact vehicles clearly states that excellent environmental performance is required, most of these vehicles are EVs. This has raised expectations that vehicles such as these will be able to make a major contribution to a transportation system that uses significantly less energy and emits far less carbon. Combining these vehicles with urban planning may help to improve quality of life and mobility as a new form of urban and local transportation. These vehicles may even have many other positive social benefits, such as providing a boost to tourism and regional regeneration, as well as supporting the mobility of the elderly and child-raising families. Consequently, local governments are leading trial introductions of these ultra-compact vehicles and trial demonstrations are being carried out in conjunction with urban planning projects all across Japan. Table 4 shows the specifications of the main ultra-compact vehicles (10)(12)(14)(20).

2. 4. Trends in EV standardization

Section 1.4 explained how the international standardization of electric vehicles is being handled by ISO/TC 22/SC 37. The safety aspects of EVs are being addressed in ISO 6469-1 to ISO 6469-4 (see Section 1.4). The international standards that concern the performance aspects of EVs include ISO 8714 (Reference energy consumption and range for BEV), which was issued in 2002, and ISO 8715 (Road operating characteristics for BEV), which was issued in 2001.

3 Fuel Cell Electric Vehicles

3. 1. Introduction

Since fuel cell vehicles (FCVs) have zero tailpipe CO_2 emissions, the increased adoption and popularization of these vehicles is seen as an important way of helping to reduce greenhouse gas emissions (21). FCVs began to be leased to government agencies in Japan in December 2002 and, by 2014, the driving range of these vehicles had been extended due to the improved hydrogen storage efficiency of the on-board high-pressure hydrogen fuel tanks. In addition, the warm-up performance of these vehicles has also improved to allow use in sub-zero temperatures. As a result, the convenience of FCVs is now considered to be roughly on a par with gasoline engine vehicles. The Fuel Cell Commercialization Conference of Japan has proposed a scenario to help promote the popularization of FCVs, and 2015 is the target year to begin expanding the adoption of FCVs by the general public (22). In an effort to follow through on this scenario, on June 25, 2014 Toyota announced that it would begin selling a sedan-type FCV in Japan during fiscal year 2014 and that it would cost approximately 7 million yen (23). On December 15, 2014 Toyota put the Mirai FCV on sale in Japan for 7,236,000 yen (including consumption tax) (24) and Honda announced on November 17 that it too would start selling a new model FCV in Japan during the 2015 fiscal year (25). This section introduces the

Fig. 4 Toyota Mirai FCV[24]

research and development of FCVs, starting with the Mirai, and the trends surrounding the establishment of hydrogen fuel stations in Japan.

3. 2. Trends in FCV research and development

There were news releases about FCVs from two of Japan's largest automobile manufacturers, Toyota and Honda, in 2014.

On August 29, 2014 Toyota announced that it had obtained the approval of the Japanese Ministry of Economy, Trade and Industry (METI) as a "registered container manufacturer" for its high-pressure hydrogen fuel tanks (26). All containers and accessories for storing gas at 1 MPa (10 atm) or more of pressure, such as a high-pressure hydrogen fuel tank, must be type-certified by METI. In addition, the High Pressure Gas Safety Law in Japan requires that this manufacturing process be made available for official safety inspections by the High Pressure Gas Safety Institute of Japan. Now that Toyota has obtained this approval, it is allowed to self-inspect its own high-pressure hydrogen fuel tanks, which is expected increase manufacturing efficiency and productivity.

As mentioned above, Toyota also began selling its first FCV to the general public. Figure 4 shows the Toyota's Mirai FCV, which has the following distinguishing characteristics (24).

(1) Adoption of the Toyota Fuel Cell System (TFCS), which realizes excellent environmental performance and convenience
(2) Enhanced equipment and a vehicle design that ensures safety and security
(3) A design that is instantly recognizable as that of the Mirai
(4) Superior levels of quietness and excellent steering stability that instills the joy of driving
(5) A large-capacity, external, electric power supply system

Table 5 shows the main specifications of the TFCS and Table 6 shows the main specifications of the Mirai. The FC stack and high-pressure hydrogen fuel tank were both developed in-house by Toyota. These technologies deliver a power output density of 3.1 kW/L, 2.2 times greater than that achieved in Toyota's previous FCHV-adv model. Power generation efficiency has been improved by using 3D fine mesh flow channels that ensure uniform generation of electricity on the cell surfaces. The hydrogen storage capacity of the fuel tank has been increased by around 20% and the weight and size have been reduced to around 5.7 wt%, while also ensuring even higher performance. Toyota announced that the Mirai has a hydrogen refueling time of around three minutes and a driving range of approximately 650 km (24).

Table 5 Main specifications of the TFCS[24]

FC stack	Name	Toyota FC Stack
	Type	Solid polymer electrolyte
	Volume output density	3.1 kW/L
	Max. output	114 kW (155 PS)
	Humidification system	Internal circulation system (no humidifier)
High-pressure hydrogen fuel tanks	Number	2 tanks
	Nominal usage pressure	70 MPa (approximately 700 atm)
	Storage capacity	5.7 wt%
	Fuel tank volume	122.4 L (Front: 60.0 L. Back: 62.4 L)
	Amount of stored hydrogen	Approximately 5 .0 kg
Motor	Type	AC synchronous motor
	Max. output	113 kW (154 PS)
	Max. torque	335 N·m (34.2 kgf·m)
Drive battery	Type	Nickel-metal hydride

Table 6 Main specifications of the Mirai FCV[24]

Length	4 890 mm
Width	1 815 mm
Height	1 535 mm
Wheelbase	2 780 mm
Tread (front/rear)	1 535／1 545 mm
Min. ground clearance	130 mm
Interior length	2 040 mm
Interior width	1 465 mm
Interior height	1 185 mm
Vehicle weight	1 850 kg
Passenger capacity	4 people

On November 17, 2014 Honda unveiled both its new-model FCV concept car, called the Honda FCV CONCEPT (Fig. 5), and also the concept model of its portable inverter box, called the Honda Power Exporter CONCEPT (Fig. 6), which can provide an external supply of electricity from a FCV at a maximum output of 9 kW (25).

The Honda FCV CONCEPT is equipped with a new fuel cell stack that is 33% smaller than the original model, produces an output of 100 kW or more, and realizes

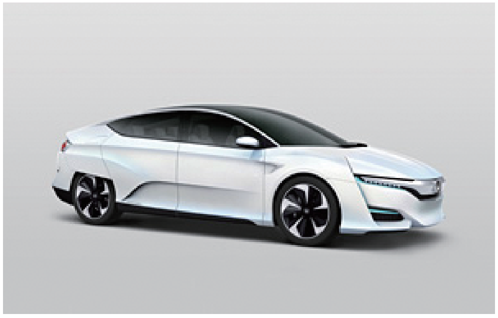

Fig. 5 Honda FCV CONCEPT(25)

Fig. 6 Honda Power Exporter CONCEPT(25)

a power output density of 3.1 kW/L, an improvement of approximately 60% compared to the original. According to the announcement from Honda, the hydrogen fuel is supplied from a high-pressure tank that stores the fuel at a pressure of 70 MPa and the driving range of the vehicle is 700 km or more. One of the merits of the vehicle's design is that the fuel cell stack is contained entirely under the hood and within the front of this sedan-type vehicle, which leaves room for 5 adult passengers. A new model FCV from Honda based on this concept vehicle is planned to go on sale in Japan sometime during the 2015 fiscal year (25).

3.3. Trends in establishing hydrogen refueling station infrastructure

The development of a hydrogen fuel infrastructure has become an urgent task as FCVs have begun to be commercially available to the general public. Hydrogen refueling stations must be located in areas that are close to FCV users and an environment must be established that allows hydrogen refueling at an appropriate price for FCVs to grow in popularity.

On July 14, 2014 Iwatani Corporation opened the first commercial hydrogen fuel station in Amagasaki City in Hyogo Prefecture (27). This station has adopted an off-site method to supply fuel to the FCVs and uses liquid hydrogen that is transported to the station on trucks from liquid hydrogen production bases. The hydrogen fuel supply capacity is 6 vehicles per hour (340 Nm^3/h), the pressure of the liquid hydrogen during refueling is 70 MPa, and it takes about 3 minutes per vehicle to finish refueling. On August 28, 2014 Iwatani also announced a plan to build hydrogen refueling stations in central Tokyo, the place where demand for a hydrogen fuel supply is most desired (28). In addition, Iwatani Corporation has committed itself to building 20 commercial hydrogen fuel stations in the four major metropolitan areas of Tokyo, Nagoya, Osaka, and Fukuoka by 2015. Clearly, progress is being made in preparations to establish a solid foundation for a hydrogen fuel supply infrastructure for FCVs.

On November 14, 2014 Iwatani announced that the price of hydrogen fuel would be 1,100 yen/kg (100 yen/ Nm^3) (29). This price is equivalent to the fuel cost for hybrid vehicles. According to the Hydrogen and Fuel Cell Strategy Roadmap (30) compiled by METI, the targets for the price of hydrogen fuel were "equal to or less than the fuel cost of gasoline engine vehicles" by 2015 and "equal to or less than the fuel cost of hybrid vehicles" by 2020. Consequently, the price of hydrogen fuel has been set at a level that realized these goals a full 5 years ahead of schedule.

On December 10, 2014 Iwatani Corporation signed a comprehensive agreement with Seven Eleven Japan Co. to build hydrogen stations and convenience stores in the same facilities. It was announced that the first two such facilities are scheduled to open in Tokyo and Aichi Prefecture in 2015 (31). It is thought that a single location where consumers can shop for daily necessities and also refuel FCVs will make a major contribution to improving the convenience and popularity of FCVs.

JX Nippon Oil and Energy Corporation announced on November 12, 2014 that it would be opening its first commercial hydrogen refueling station in December of the same year and a total of 11 such stations by the end of the 2014 fiscal year (32). The first station is the Dr. Drive Ebina Chuo Store that opened on December 25, 2014 in Ebina City, Kanagawa Prefecture (33). There are also plans to open two additional hydrogen refueling stations in the same prefecture in the Izumi Ward and Asahi Ward of Yokohama City. In addition, there are also plans to open one station in Chiba Prefecture, three stations in Saitama Prefecture, two stations in Tokyo, and two stations in Aichi Prefecture.

JX Nippon Oil and Energy Corporation also announced on December 25, 2014 that the price for hydrogen fuel would be 1,000 yen/kg (excluding consumption tax) (33). The company said that it set the price to be equivalent to the gasoline cost of a hybrid vehicle of the same class as the Toyota Mirai FCV. The hydrogen refueling stations are operated with an "off-site" method, where compressed hydrogen is transported from the manufacturing site using a hydrogen trailer, or other appropriate container. The hydrogen supply capacity of the stations is 300 Nm^3/h which makes it possible to fill five or six FCVs per hour. The filling pressure is 70 MPa, which is the same pressure used in the fuel storage tanks of the Toyota Mirai, and it takes about 3 minutes to completely fill the tanks.

As described in the preceding paragraphs, a hydrogen fuel infrastructure is being prepared and put into place following the pace of commercial sales of FCVs.

3. 4. Summary

In 2014 Toyota began selling an FCV. The spread and popularization of FCVs is being promoted by the Japanese government and local agencies through subsidies to help consumers purchase these vehicles. However, this subsidy system and the promotion policies have a time limit and will not continue for long. Therefore, reducing the use of expensive materials in the fuel cell stack and high-pressure hydrogen storage tanks, as well as improving durability will continue to be issues that need to be addressed to help bring down the cost of FCVs. It is also essential to enhance the hydrogen fuel infrastructure to help FCVs to become widely accepted by consumers. It is expected that the number of hydrogen fuel stations will continue to increase as Japan moves toward the full-fledge acceptance and adoption of FCVs.

4 Electric Power

4. 1. Introduction

The electrification of vehicles is continuing to advance both to reduce CO_2 emissions and to improve power performance. As this electrification advances, electric motors and batteries are being equipped on vehicles in various different categories. The motors and batteries with output characteristics that are the most suitable for the respective application and level of performance are being adopted. External battery charging is necessary for EVs and PHEVs. Consequently, new charging methods that offer even more convenience are being developed as the charging infrastructure continues to spread and become more widely available. This section introduces the main trends in electric motors and EV charging infrastructure in 2014.

4. 2. Electric motors

Table 7 shows the main electric motors used to provide drive power in passenger vehicles sold in Japan. Almost all of these motors, regardless of installation in an HV or EV, are AC synchronous motors using permanent magnets. The output of these motors varies from about 2 kW for the motors used in mild hybrid EVs to about 10 to 40 kW in the motors for parallel hybrid EVs, in which these motors mainly provide drive assist. The motor output rises to 20 to 150 kW in hybrid systems that enable fully electric driving. As a result, there is a great range in motor output depending on the size of the vehicle and the driving performance. In the case of motors used in EVs, the motor output is usually about 30 to 125 kW and, since the motor is the main source of power, this output is largely dependent on the vehicle weight. The speed of these motors during maximum output varies from roughly equivalent to the speed of a gasoline engine to motors with high speeds of 10,000 min^{-1} or higher. In most cases, the higher the output of the motor, the greater the chance that it is also a high speed motor.

One recent trend influencing the research and development of new electric motors is the aim to greatly reduce or eliminate the use of rare earth elements by actively seeking more efficient arrangements for the magnets and even adopting switched reluctance (SR) motors, which use no rare earth elements at all. Other new technological developments, such as adopting different winding wires, are also being pursued to help increase rotation speed and to reduce size and weight.

4. 3. Charging infrastructure

The Japanese government and automobile industry groups are implementing various policies to help promote the spread and popularization of the charging infrastructure for EVs and PHVs. The following paragraphs briefly describe the policies being implemented to promote the spread and popularization of this charging infrastructure and the recent trends in battery charging technologies.

4. 3. 1. Policies to promote popularization

4. 3. 1. 1. Next-generation vehicle battery charging infrastructure development and promotion

Table 7 Main motors installed in EVs[(35)-(44)]

Name of company	Designation	Type(*)	Max. output (kW/min^{-1})	Torque (Nm/min^{-1})	Use	Main vehicles equipped with this motor
Toyota Motor Corporation	1 LM	PM	45/—	169/—	HEV	Aqua, Corolla Hybrid
	2 JM	PM	105/4 500	270/0−1 500	HEV	Sai, Camry, Estima Hybrid (front), Harrier Hybrid (front), Alphard Hybrid (front), HS250 h, NX300 h (front)
	3 JM	PM	60/—	207/—	HEV	Prius, Prius PHV, CT200h
	4 JM	PM	123/—	335/—	HEV	RX450 h (front)
	5 JM	PM	60/—	207/—	HEV	Prius Alpha, Noah Hybrid, Voxy Hybrid, Esquire Hybrid
	1 KM	PM	147/5 615−13 000	275/0−3 840	HEV	Majesta 2WD, GS450h
			105/—	300/—	HEV	Crown Hybrid, Majesta 4WD, GS350h, IS300h, RC300h
			165/—	300/—	HEV	LS600h
	2 FM	PM	50/4 610−5 120	130/0−610	HEV	Estima Hybrid (rear), Harrier Hybrid (rear), Alphard Hybrid (rear)
			50/—	139/—	HEV	RX450 h (rear), NX300 h (rear)
Nissan Motor Co., Ltd.	HM34	PM	50/1 646−2 000	290/0−1 646	HEV	Fuga Hybrid, Cima, Skyline 350 GT Hybrid
	SM23	PM	1.8/—	53.6/—	HEV	Serena S-Hybrid
	EM57	PM	80/3 008−10 000	254/0−3 008	EV	Leaf, e-NV200
Honda Motor Company	MF6	PM	15/2 000	78/1 000	HEV	CR-Z
		PM	10/1 500	78/1 000	HEV	Freed Hybrid, Fit Shuttle Hybrid
	MF8	PM	124/3 857−8 000	307/0−3 857	HEV	Accord, Accord plug-in
	H1	PM	22/1 313−2 000	160/0−1 313	HEV	Fit Hybrid, Vezel Hybrid, Grace
	H2	PM	35/3 000	148/500−2 000	HEV	Legend (front)
	H3	PM	27/4 000	73/0−2 000	HEV	Legend (rear)
	MCF3	PM	92/3 695 -10 320	256/0−3 056	EV	Fit EV
Fuji Heavy Industries Ltd.	MA1	PM	10/ —	65/—	HEV	XV Hybrid
Suzuki	WA04A	IM	1.6/1 000	40/100	HEV	Wagon R
Mazda Motor Corporation	MG	PM	60/—	207/—	HEV	Axela Hybrid
Mitsubishi Motors Co., Ltd.	S61	PM	60/—	137/—	HEV	Outlander PHEV (front)
	Y61	PM	60/—	195/—	HEV	Outlander PHEV (rear)
	Y51	PM	30/—	160/—	EV	i-MiEV M
		PM	47/—	160/—	EV	i-MiEV G
		PM	30/—	196/—	EV	Minicab MiEV
Audi Japan	EAFA	PM	40/—	210/—	HEV	Q5 hybrid, A6 hybrid
BMW	—	PM	40/—	210/—	HEV	ActiveHybrid 3, ActiveHybrid 5, ActiveHybrid 7
	—	PM	125/5 200	250/100−4 800	EV	i3
Mercedes-Benz Japan	21227	PM	20/1 800	250/0−800	HEV	S400 Hybrid, E400 Hybrid
	EM0003	PM	55/4 000	130/0−4 800	EV	smart fortwo electric drive
	22227	PM	85/3 500	340/0−2 400	HEV	S550 Plug-in Hybrid Long

(*)

In the 2012 fiscal year supplementary budget, subsidies of 100.5 billion yen were enacted for the establishment of a charging infrastructure and another 30 billion yen was enacted as part of the 2014 fiscal year supplementary budget. The latter subsidies were enacted in an effort to help enhance the content, such as by adding the establishment of billing devices to the applicable targets for the subsidies, in order to make the applicable targets even easier to use.

4.3.1.2. Establishment of Nippon Charge Service, LLC (NCS)

NCS was established on May 26, 2014 by four major

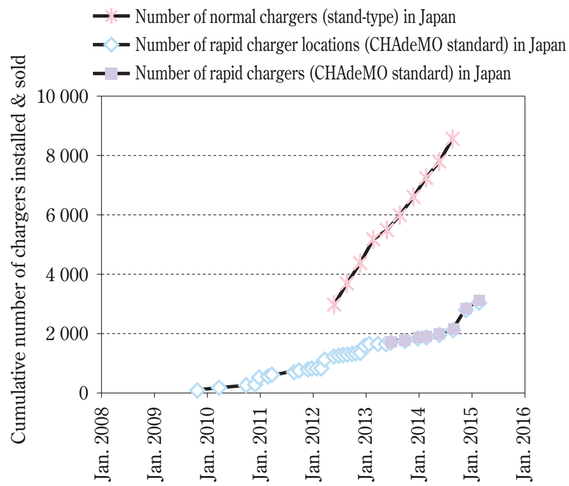

Fig. 7 Cumulative number of chargers for EVs in Japan[48][49]

Japanese automobile manufacturers (Toyota, Nissan, Honda, and Mitsubishi) to promote the installation of electric vehicle charging devices and to build up a charging infrastructure network with a high level of convenience (45). NCS is aiming to build a nationwide network of rapid chargers (in this article this means a charger with an output of 10 kW or more) that are connected to each other and that all use the same common card to gain access. This is being carried out to eliminate the inconvenience of needing a separate specific card to use each of the old charging networks. According to a press release on March 19, 2015, NCS is aiming to have around 11,000 chargers in its charging infrastructure network operational by the end of 2015 (46).

4. 3. 2. State of progress

Figure 7 shows the cumulative number of rapid and normal chargers (in this article, a charger with an output of less than 10 kW) that have been installed in Japan. However, the rapid chargers shown in the figure are limited to only those that received CHAdeMO certification (47). The following sections provide examples and details about the state of progress in installing both kinds of chargers.

4. 3. 2. 1. Rapid chargers

The number of these chargers that were installed increased significantly starting at the end of 2014 due to the subsidies that were enacted. The data is not shown in the graph in Fig. 7, but the number of fast chargers with the CHAdeMO charging standard that were installed outside Japan also increased significantly starting in 2013 and the cumulative number of overseas CHAdeMO locations is quickly approaching that of Japan (48).

Fig. 8 Tesla Motors, Inc. Supercharger (Port Island Golf Club in Kobe City, Hyogo Prefecture).

The Family Mart chain of convenience stores in Japan announced in April 2014 that it would install rapid chargers at 500 of its store locations starting in the summer of 2014. According to a website that allows you to search for Family Mart store locations, 680 stores have rapid chargers available as of April 17, 2015. This is one example of how the subsidies from the Japanese government and the efforts of the four major automobile manufacturers (Toyota, Nissan, Honda, and Mitsubishi) through the PHV, PHEV, and EV Charging Infrastructure Promotion Project have been utilized to maximum effect. By some calculations, the number of fast chargers in Japan increased by approximately 30% within one year.

One type of rapid charger that does not use the CHAdeMO standard is the Supercharger from Tesla Motors, Inc. (Fig. 8) and it too has begun making inroads into Japan. This charger is different from CHAdeMO in that it can currently only be used to charge the Model S luxury sedan EV from Tesla Motors. A major feature of the Tesla Supercharger is that it can provide a charge at a maximum of 120 kW, which is more than two times greater than the CHAdeMO standard (max. 50 kW). As of April 15, 2015, there were 6 locations in Japan with Tesla Superchargers and worldwide it is available in 419 locations (2,305 chargers) (52). Plans to set up additional Supercharger stations around the world through the year 2016 were released via the Tesla Motors website. The Model S is equipped with a CHAdeMO adapter so that it can be charged using a fast charger with the CHAdeMO standard, but currently there is no adapter that allows EVs designed for the CHAdeMO standard to make use of the Tesla Supercharger.

4. 3. 2. 2. Normal chargers

Figure 7 shows that the number of normal chargers has been increasing steadily. In recent years it is more

Fig. 9 Normal chargers for employees (Mitsubishi Motors Okazaki Plant Employee Parking Area)(56)

common to hear of single locations equipped with multiple normal chargers. In the Tokyo Midtown parking area, 125 normal chargers were installed in December 2014 (54). On February 27, 2015, Mitsubishi Motors Co., Ltd. announced the installation of a total of 1,154 normal chargers in its employee parking lots to enhance the convenience of workers who commute to work using EVs (Fig. 9). Autobacs Seven Co., Ltd. announced in its CSR and Governance Report the installation of charging stands at 102 stores by the end on March 2015 (normal chargers will be installed at 98 of those stores) (55). In all of these instances, the normal chargers are provided for users leaving a vehicle parked for an extended period of time, such as while shopping or working.

4. 3. 3. Technological trends

4. 3. 3. 1. Rapid chargers

The line-up of rapid charger models continues to increase to meet the various needs of the installers. The number of different models that can be chosen, starting with 10 kW models, is increasing to reduce the burden of the electric power contracts on the installers. Hybrid model fast chargers with an internal battery are now also available for this same purpose. Some models are also equipped with two connectors to help relieve the stress of EV users who must wait for others to finish before charging.

4. 3. 3. 2. Normal chargers

The establishment of billing functions on normal chargers has helped turn the provision of EV chargers into a viable business model. Initially, most normal chargers were quite simple and had no billing function, but now all of the charger manufacturers are selling charger models that come with an IC card authentication function for the purpose of billing.

4. 3. 3. 3. Vehicle-to-home (V2H)

In addition to an external charging function, some EVs are also equipped with a V2H function that supplies electricity to a home. The first system in the market with this function is the "LEAF to Home" that went on sale from Nissan in June of 2012. In July 2014, Mitsubishi began selling its SMART V2H system. This system makes it possible to use a mix of electric power from an EV, a solar power generation system, and the existing power grid of a home. In addition, it is also possible to switch between charging or discharging the EV battery at will without a power outage occurring. Functions such as these are helping to boost the added value provided by EVs.

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