HYBRID VEHICLES, ELECTRIC VEHICLES, FUEL CELL ELECTRIC VEHICLES, TRACTION MOTORS

1 Hybrid Vehicles

1. 1. Introduction

Demand for vehicles with better fuel efficiency and cleaner exhaust emissions is growing in light of environmental problems such as air pollution and global warming. Automakers have been selecting hybrid electric vehicles (HEVs), which combine an internal combustion engine and electric motors, as one way of improving fuel efficiency. There has also been an increase in the number of plug-in hybrid vehicles (PHEVs), which allow external charging of the on-board battery that powers the electric motors. This section describes the recent trends seen in HEVs and PHEVs.

1. 2. Popularization of HEVs in Japan

Fig. 1 shows that the number of HEVs and PHEVs on the roads in Japan is increasing year after year. In 2015 the number of HEVs (passenger vehicles) on the road in Japan, not including mini-vehicles, increased by nearly 860,000 vehicles compared to the previous year to reach approximately 5.5 million vehicles (14% of the total number of passenger vehicles (approximately 39.35 million)). The number of PHEV (passenger vehicles) on the road in Japan has also continued to increase since 2011, and had reached approximately 57,000 vehicles in 2015. In addition, the number of HEV (mini vehicles) on the road in Japan has increased significantly since 2014 and in 2015 the number reached approximately 2.39 million vehicles.

1. 3. New HEVs launched in Japan in 2016

Table 1 lists the HEVs and PHEVs launched in Japan in 2016 according to the date that they went on sale. The main trends were as follows.

In January, the 225xe Active Tourer and 330e iPerformance vehicles from BMW went on sale. In the 225xe Active Tourer the engine drives the front wheels, while the electric motor drives the rear wheels. Front-, rear-, or four-wheel drive are all available based on the driver's selection or on driving conditions. In comparison, the 330e iPerformance is simply a rear-wheel drive vehicle. The operating range (converted EV running distance) of these vehicles using only external electric power as their energy source and their hybrid fuel economy are 42.4 km (JC08) and 17.6 km/L (JC08) for the 225xe Active Tourer, and 36.8 km (JC08) and 17.7 km/L (JC08) for the 330e iPerformance, respectively[2]. The same month the XC90 T8 Twin Engine AWD Inscription from Volvo also went on sale. The front wheels are driven by the engine and an electric motor, while the rear wheels are driven by another motor, making this a four-wheel drive vehicle. However, in fully electric EV running mode the vehicle switches to just rear-wheel drive. It has a converted EV running distance is 35.4 km (JC08) and a hybrid fuel economy is 15.3 km/L (JC08)[3].

In February, Honda Motor Company launched the Odyssey Hybrid and Odyssey Hybrid Absolute. Both vehicles are equipped with the Intelligent Multi-Mode Drive (i-MMD) as their hybrid system[4]. Fig. 2 shows that the i-MMD system contains two electric motors, one for electric power generation and one for providing drive to the wheels. The vehicle can be run in three different driving modes: EV running mode, hybrid running mode (where the engine is used only to generate electricity), and engine running mode.

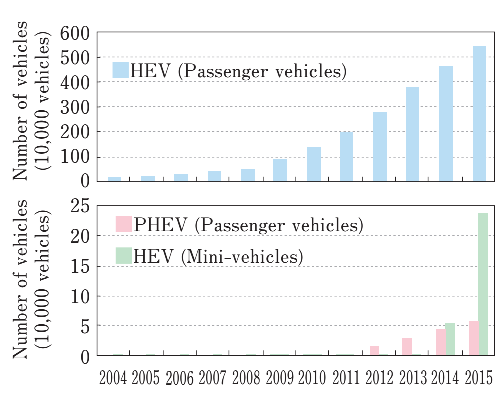

Fig. 1 Trends in the Number of HEVs and PHEVs on the Road in Japan[1]

Table 1 Main Hybrid Electric Vehicles Launched in Japan in 2016[(2)-(11)]

						
Release date		2016/1/26	2016/1/26	2016/1/27	2016/2/5	2016/2/18
Name of company		BMW	BMW	Volvo	Honda	Suzuki
Name		225xe Active Tourer	330e iPerformance	XC90 T8 Twin Engine AWD Inscription	ODYSSEY HYBRID/ ODYSSEY HYBRID ABSOLUTE	IGNIS HYBRID
Type of hybrid system		Series-parallel (PHEV)	Series-parallel (PHEV)	Series-parallel (PHEV)	Series-parallel (HEV)	parallel (HEV)
Drivetrain		Four-wheel drive	Rear-wheel drive	Four-wheel drive	Front-wheel drive	Front-wheel drive/Four-wheel drive
Fuel economy〔km/L〕		17.6	17.7	15.3	26.0	28.8
Engine	Designation	B38A15A-P160	B48B20A	B420	LFA	K12C
	Displacement〔cc〕	1 498	1 998	1 968	1 993	1 242
	Output〔kW〕	100	135	235	107	67
Motor	Type	AC synchronous motor	AC synchronous motor	—	AC synchronous motor	DC synchronous motor
	Output〔kW〕	65	65	22(front), 28(rear)	135	23
Battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Capacity〔kWh〕	7.7	7.7	9.36	—	—

						
Release date		2016/4/18	2016/5/26	2016/6/7	2016/7/14	2016/9/9
Name of company		Toyota	Honda	Volkswagen	Mazda	Mercedes-Benz
Name		Auris	ACCORD HYBRID	Passat GTE/Passat GTE Variant	AXELA HYBRID	GLC 350e 4MATIC Sports
Type of hybrid system		Series-parallel (HEV)	Series-parallel (HEV)	Series-parallel (PHEV)	Series-parallel (HEV)	Series-parallel (PHEV)
Drivetrain		Front-wheel drive	Front-wheel drive	Front-wheel drive	Front-wheel drive	Four-wheel drive
Fuel economy〔km/L〕		30.4	31.6	21.4	30.8	13.9
Engine	Designation	2ZR-FXE	LFA	CUK	PE-VPH	274
	Displacement〔cc〕	1 797	1 993	1 394	1 997	1 991
	Output〔kW〕	73	107	115	73	155
Motor	Type	AC synchronous motor	AC synchronous motor	—	AC synchronous motor	AC synchronous motor
	Output〔kW〕	60	135	55	60	85
Battery	Type	Nickel-metal hydride	Lithium-ion	Lithium-ion	Nickel-metal hydride	Lithium-ion
	Capacity〔kWh〕	—	—	9.9	—	8.31

The same month Suzuki Motor Corporation released its Ignis Hybrid vehicle. It is equipped with a mild-hybrid system in which an electric generator with a motor function (ISG) generates electric power from deceleration energy, and uses it to assist the engine during acceleration[(5)].

In April Toyota Motor Corporation released the Auris hybrid vehicle. The hybrid system in this vehicle combines a 1.8 L engine with the Toyota Hybrid System II (THS II) with a reduction gear[(6)].

In May Honda Motor Company released the Accord Hybrid. Compared to the conventional model, this model features various refinements, including an electric motor with higher torque and power output, as well as a smaller and lighter weight lithium-ion battery, improving fuel economy to 1.6 km/L[(4)].

In June the Passat GTE and Passat GTE Variant from Volkswagen both went on sale. The hybrid systems in these vehicles consist of an electric motor placed between the 1.4 L TSI engine and the six-speed direct shift

Table 1 Main Hybrid Electric Vehicles Launched in Japan in 2016[2-11] (Cont.)

						
Release date		2016/9/16	2016/10/11	2016/10/13	2016/11/2	2016/11/29
Name of company		Honda	Porsche	BMW	Nissan	Suzuki
Name		FREED/FREED+	Panamera 4 E-Hybrid	740e iPerformance	NOTE e-POWER	SOLIO HYBRID/ SOLIO BANDIT HYBRID
Type of hybrid system		Series-parallel (HEV)	Series-parallel (PHEV)	Series-parallel (PHEV)	Series (HEV)	parallel (HEV)
Drivetrain		Front-wheel drive/Four-wheel drive	Four-wheel drive	Rear-wheel drive	Front-wheel drive	Front-wheel drive
Fuel economy〔km/L〕		27.2	—	15.6	37.2	32.0
Engine	Designation	LEB	—	B48B20B	HR12DE	K12C
	Displacement〔cc〕	1 496	2 894	1 998	1 198	1 242
	Output〔kW〕	81	243	190	58	67
Motor	Type	AC synchronous motor	Permanent-magnet type AC synchronous motor	AC synchronous motor	AC synchronous motor	DC synchronous motor / AC synchronous motor
	Output〔kW〕	22	100	83	70	23/10
Battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Capacity〔kWh〕	—	14	9.2	—	—

Table 1 Main Hybrid Electric Vehicles Launched in Japan in 2016[2-11] (Cont.)

			
Release date		2016/12/14	2016/12/20
Name of company		Toyota	Suzuki
Name		C-HR	LANDY
Type of hybrid system		Series-parallel(HEV)	Parallel(HEV)
Drivetrain		Front-wheel drive	Front-wheel drive/Four-wheel drive
Fuel economy〔km/L〕		30.2	16.6
Engine	Designation	2ZR-FXE	MR20
	Displacement〔cc〕	1 797	1 997
	Output〔kW〕	72	110
Motor	Type	AC synchronous motor	AC synchronous motor
	Output〔kW〕	53	19
Battery	Type	Nickel-metal hydride	Lead
	Capacity〔kWh〕	—	—

gearbox (DSG). The DSG and the motor are integrated into a single unit. There are clutches between the engine and the motor as well as between the motor and the DSG, enabling the vehicle to run in three different driving modes: EV running mode, hybrid running mode, and engine running mode. The converted EV running distance is 51.7 km (JC08) and the hybrid fuel economy is 21.4 km/L (JC08)[7].

In July the Mazda Motor Corporation released the Axela Hybrid. This vehicle is equipped with a hybrid system composed of the SKYACTIV-G 2.0 gasoline engine developed exclusively for hybrid vehicles and two electric motors, one for electric power generation and one to provide drive to the wheels[8].

In September Mercedes-Benz released the GLC 350e 4MATIC Sports. This vehicle combines the first full-time four-wheel drive system (4MATIC) from Mercedes-Benz with a plug-in hybrid system. It has a converted EV running distance of 30.1 km (European reference value) and a hybrid fuel economy is 13.9 km/L (JC08)[9]. The same month saw the release of also released the Freed Hybrid and Freed+ Hybrid by Honda Motor Company. Both of these vehicles are equipped with the Sport Hybrid Intelligent Dual Clutch Drive (i-DCD) system, which combines a 1.5 L direct injection engine with a 7-speed dual clutch transmission (DCT) and an electric motor. The i-DCD drive motor is a dedicated hybrid vehicle motor containing a neodymium magnet, making it the world's first such motor to be completely free of heavy rare earth elements[4].

In October the Panamera 4 E-Hybrid from Porsche was released. The converted EV running distance is 50.0 km (European reference value) and the hybrid fuel economy is 2.5 L/100 km (European reference value)[10]. The same month BMW released the 740e iPerformance, fea-

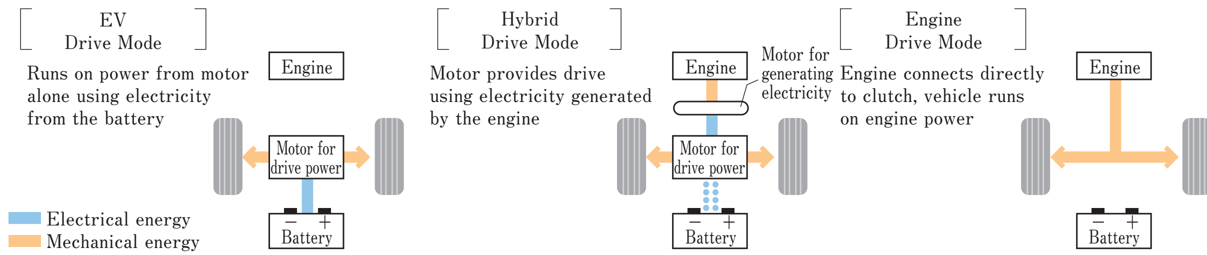

Fig. 2 Running Modes of i-MMD[4]

turing a hybrid system that combines the engine to an 8-speed automatic transmission integrated with an electric motor. It has a converted EV running distance of 42.0 km (JC08) and of hybrid fuel economy is 15.6 km/L (JC08)[2].

In November the Note e-Power from Nissan Motor Co., Ltd. went on sale. The hybrid system in this vehicle is a series hybrid that combines an engine dedicated to generating electrical power with a power generating motor and another motor to provide drive to the wheels. The motor that provides drive is the same as the one in the Nissan Leaf[11]. The same month Suzuki Motor Corporation also released the Solio Hybrid and Solio Bandit Hybrid, which use two different types of parallel hybrid systems. One vehicle is a mild hybrid equipped with an ISG, while the other uses a combination of a drive motor that can also generate electricity (MGU) with an auto gear shift transmission (AGS)[5].

In December Toyota Motor Corporation launched the C-HR. This is the second vehicle designed under the Toyota New Global Architecture, the automobile manufacturing structural reform currently pursued by Toyota. This means the C-HR shares a platform with the Prius, the first vehicle designed under that new architecture[6]. The same month Suzuki Motor Corporation also released the Landy, which is equipped with the smart and simple hybrid system (S-Hybrid) from Nissan Motor Co., Ltd.[5]

1. 4. Trends in standardization

ISO/TC22 (Road vehicles)/SC37 (Electrically-propelled vehicles) is the committee carrying out the standardization activities for general vehicles that are powered by electricity (electrically-propelled road vehicles), including HEVs, fuel cell vehicles (FCEVs), and battery electric vehicles (BEVs). The majority of the work is pursued in WG2, the group responsible for performance and energy consumption. This group is currently discussing the method for determining the power output of HEV systems (ISO/CD20762) to allow easy comparison with the power outputs of engines in internal combustion vehicles, which are measured with existing international standards and criteria. They aim to issue this standard as a formal IS sometime in 2018.

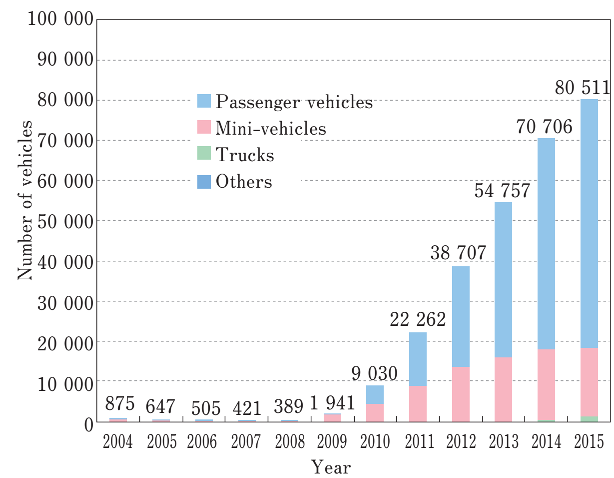

Fig. 3 Change in Number of EVs Owned (at end of each fiscal year)[13]

2 Electric Vehicles

2. 1. Introduction

Electric vehicles (EVs) are highly energy efficient in well-to-wheel analyses and also have low amounts of greenhouse gas emissions[12], so they have been garnering a lot of attention in recent years as the next generation of environmentally friendly vehicles. Starting in 2009 with the first mass-produced EV, the i-MiEV from Mitsubishi Motors equipped with a lithium-ion battery and mainly sold to corporate customers, the number of EVs owned in Japan has steadily increased. However, as of the end of 2015 the number of EVs owned in Japan had still not reached 100,000 vehicles[13]. Problems related to the performance of the EVs themselves, such as battery charging time, cruising range on one electrical charge, and the high cost of the vehicles, as well as infrastructure problems such as the lack of charging facilities at existing apartment complexes, have been cited as rea-

Table 2 Specifications of Main EVs Sold in Japan in 2016 [14)-(18]

Manufacturers		Nissan	Mitsubishi Motors Co., Ltd.	Mitsubishi Motors Co., Ltd.	Mitsubishi Motors Co., Ltd.
Name		Leaf	i-MiEV M/X	Minicab MiEV Van	Minicab MiEV Truck
External appearance					
Length × width × height〔mm〕		4 445 × 1 770 × 1 550	3 395 × 1 475 × 1 610	3 395 × 1 475 × 1 915 /1 810	3 395 × 1 475 × 1 820
Passenger capacity		5	4	2 (4)	2
AC power consumption rate〔Wh/km〕		114/117	110	125	120
Cruising range on a single charge〔km〕		228/280 *1, 3	120/180 *1, 3	100/150 *1, 3	110 *1, 3
Drive battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total voltage〔V〕	360	270/330 *3	270/330 *3	270
	Total amount of power〔kWh〕	24/30	10.5/16 *3	10.5/16 *3	10.5
Motor	Rated output〔kW〕	70	30	25	25
	Max. output〔kW〕	80	30/47	30	30
	Max. torque〔N·m〕	254	160	160	196
Charging time	Normal〔h〕	Approx. 8 / Approx. 11 (200 V) *3	Approx. 4.5 / Approx. 7 (200 V) *3	Approx. 4.5 / Approx. 7 (200 V) *3	Approx. 4.5 (200 V)
	Fast〔min〕	Approx. 30 (80 %)	Approx. 15 (80 %)/ Approx. 30 (80 %)	Approx. 15 (80 %)/ Approx. 35 (80 %)	Approx. 15 (80 %)

Manufacturers		Nissan	BMW	Tesla	Tesla
Name		e-NV200	i3	Model S	Model X
External appearance					
Length × width × height〔mm〕		4 560 × 1 755 × 1 855/1 850	4 010 × 1 775 × 1 550	4 979 × 1 950 × 1 453	5 037 × 2 070 × 1 680
Passenger capacity		Van : 2/5 Wagon : 5/7	4	5	5/7
AC power consumption rate〔Wh/km〕		142	98	—	—
Cruising range on a single charge〔km〕		Van : 190/188 *1, 3 Wagon : 188/185 *1, 3	229 /390 *1, 3	408/490/557/613 *2, 3	417/489/565 *2, 3
Drive battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total voltage〔V〕	360	393.6 /398.4	—	—
	Total amount of power〔kWh〕	24	21.8 /33.1	60/75/90/100 *3	75/90/100 *3
Motor	Rated output〔kW〕	70	75	—	—
	Max. output〔kW〕	80	125	235	245
	Max. torque〔N·m〕	254	250	440	525
Charging time	Normal〔h〕	Approx. 8 (200 V)	Approx. 8 (200 V)	—	—
	Fast〔min〕	Approx. 30 (80 %)	Approx. 45 (80 %)	—	—

*1 : JC08 test cycle *2 : NEDC test cycle *3 : Different depending on grade and specifications

sons for this state of affairs. However, along with improvements in cruising range, an increase in the number of charging stations, and revised vehicle prices, the Japanese government and some municipal governments are offering subsidies for the purchase of EVs and battery chargers as incentives. This section describes the current state of EV use in Japan, as well as recent trends in research and development, the EV infrastructure, and standardization.

2.2. Extent of EV Use and Efforts to Increase Popularization

2.2.1. Market introduction and sales

Figure 3 shows the change in the number of EVs on the roads in Japan[13]. The number of EVs on the roads in Japan continued to decrease until 2008 remaining at less than 1,000 vehicles. However, since the launch of the i-

MiEV by Mitsubishi Motors in 2009 and of the Leaf by Nissan Motor Co., Ltd. in 2010, EV ownership has increased each year, reaching 80,511 vehicles at the end of 2015. Table 2 shows the specifications of the main EVs sold by automobile manufacturers in Japan in 2016[14)-(18]. In 2016 the only new EV that went on sale in Japan was the Model X from Tesla, Inc. However, BMW gave the i3 EV a facelift, expanding battery capacity to achieve a cruising range of 390 km on a single charge.

2. 2. 2. Initiatives to promote EV popularization

In March 2016 the Japanese Ministry of Economy, Trade, and Industry (METI) announced the EV and PHV Roadmap[19]. This plan set targets such as up to 1 million EVs and PHVs on the road in Japan by 2020 (the total number of sales as of the end of 2016 was 140,000). It also calls for EVs and PHVs to account for 20% to 30% of all new vehicles sold, and 16% of all vehicles owned, in 2030. Proposals to promote greater adoption of EVs and PHVs included "the thorough consideration of optimal placement and methodical installation of vehicle charging stations for public use in logical, easy-to-access locations, such as roadside rest areas and highway service and parking areas, to alleviate motorists' concerns about running out of electric power and to increase their peace of mind while driving", and "with respect to basic charging at home, installing EV and PHV charging stations near apartment buildings where nearly 40% of Japanese citizens live as an extremely important measure to uncover the latent market for EVs and PHVs".

In addition, METI is allocating money to subsidize the cost of measures to promote the adoption of clean-energy vehicles (13.7 billion yen) as well as of measures to promote the development of next-generation vehicle charging infrastructure (2.5 billion yen) in an effort to support improvements in EV cruising range, the purchasing of EVs, and the installation of the charging infrastructure at housing complexes and lodging facilities[20][21]. The Japanese Ministry of Land, Infrastructure Transport and Tourism (MLIT) has also been allocating resources to accelerate the adoption of EVs (400 million yen) through the introduction of more environmentally friendly forms of local transportation by supporting pioneering efforts to provide EV-based transportation services tailored to the actual situations in local communities[22].

2. 3. Trends in EV Research and Development

Research and development to extend the cruising range of EVs is being complemented by activities to promote their popularization, such as exploring new ways of utilizing EVs. These efforts are introduced in more detail in the following sections.

2. 3. 1. Vehicles and Batteries

In April 2016, Tesla, Inc. unveiled its newest EV, the Model 3, for the first time[23]. The Model 3 was developed with ambitious performance targets, such as being able to accelerate to 100 km/h in less than 6 seconds and possessing a minimum cruising range of 345 km or more under the fuel consumption measurement method prescribed by the U.S. Environmental Protection Agency (EPA). Volkswagen announced their electric vehicle, the 2017 e-Golf at the Los Angeles Motor Show in November 2016. Battery capacity has been increased from the previous 24.2 kWh to 35.8 kWh, while the maximum output/maximum torque of the motor was increased from the previous 115 hp (86 kW)/27.5 kgm to 134 hp (100 kW)/29.5 kgm[24].

Nissan Motor Co., Ltd. displayed its new high-energy-density battery as a reference exhibit at the Automotive Engineering Exposition 2016 Yokohama held in May 2016. This battery has improved capacity per volume (60 kWh, prototype) compared to the current 30 kWh battery equipped on the Leaf[25]. In addition, both NEC and Hitachi, Ltd. are now developing high energy density lithium-ion batteries for EVs using next-generation cathode and anode materials[26][27].

2. 3. 2. Demonstration Projects

In September 2015, Nissan Motor Co., Ltd. announced that it would allow local authorities that developed examples of ways to use the e-NV200 EV van to borrow this vehicle for three years free of charge[28]. In 2016, this led to the lending of e-NV200 EV vans to local authorities such as Okinawa Prefecture and Yokohama City[29][30]. These local authorities are implementing uses of this EV as a potential source of emergency electrical power in the event of a disaster and as a means of transportation and a power source for work activities in situations where noise and exhaust emissions are problematic.

Toshiba Corporation, PUES Corporation, Hasetec Corporation, and Oriental Consultants Global Co., Ltd. are working with Malaysian bus operator Putrajaya Bus (PAPSB), to develop a heavy-duty double decker EV bus that achieves performance equivalent to that of diesel vehicle through optimal capacity storage batteries and high-power charging technologies that make ten-minute charging possible. The world's first demonstration proj-

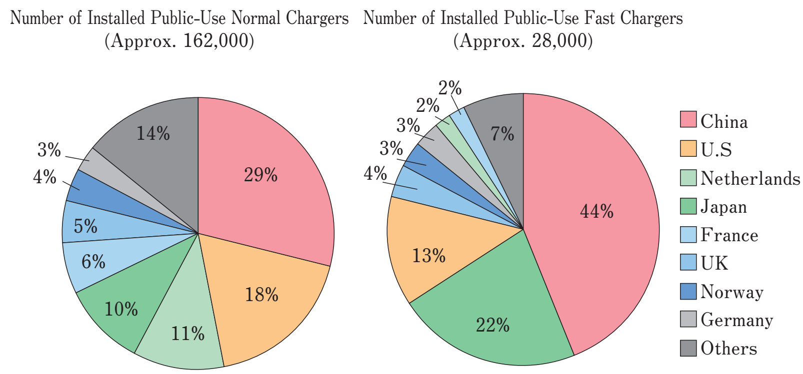

Fig. 4 Percentage of the Total Number of Normal and Fast Chargers in the World as of 2015 by Country (Aggregate values from IEA, where a normal charger is defined as AC 22 kW or less, and fast chargers include both AC 43 kW and DC chargers)[34]

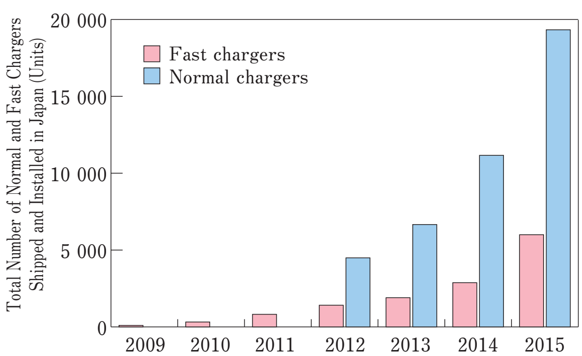

Fig. 5 Total Number of Normal and Fast Chargers Shipped and Installed in Japan[36][37] (Number of normal chargers is the number shipped, number of fast chargers is the estimated number installed based on the number of installation locations)

ect using two of these EV buses, to be carried out in the Malaysian city of Putrajaya, was announced in June 2016[31].

In September 2016, Toyota Motor Corporation began phase two of its Open Road Project in Tokyo in collaboration with both businesses and members of the general public with a focus on the eventual full-scale commercialization of its Toyota i-Road ultra-compact EV[32]. As part of the Open Road Project, Toyota will provide the i-Road to general consumers as test pilots for a fixed period to assess their mobility needs. Toyota also plans to validate the feasibility of satisfying a variety of i-Road-related needs by planning and providing associated services in cooperation with partner companies that possess a diverse range of technologies and knowledge.

In November 2016 Nissan Motor Co., Ltd. and Kanematsu Corporation announced that they had broken ground on a massive demonstration project commissioned by the New Energy and Industrial Technology Development Organization (NEDO) called Drive the ARC, which aims to increase the distance traveled by electric vehicles (EVs) in metropolitan areas of northern California in the United States[33]. This project will install direct current fast chargers along inter-city routes and provide EV users with real time navigation and other services for the purpose of increasing the distance traveled by EVs and expanding their usage to these inter-city routes. The aim of conducting this demonstration project in northern California is to collect data on various EV driver behavior patterns and to then use surveys, analysis, and research to further popularize EVs and establish models to promoting their increased use.

2. 4. Charging Infrastructure

This section first introduces trends concerning the installation of normal and fast chargers for EVs and PHEVs in and outside Japanese, and then presents the trends in the development of wireless charging system and higher power chargers.

2. 4. 1. Situation in the Installation

The total number of normal and fast chargers for public use installed around the world is estimated to have reached 190,000 units by 2015[34]. Fig. 4 shows the cumulative number of normal and fast chargers installed in various countries. A breakdown of the normal chargers by reveals that China has the most, followed by the U.S., the Netherlands, Japan, and France. Similarly, China also has the highest number of fast chargers installed, followed by Japan, the U.S., the U.K., Norway, and Germany. From a global point of view, China and Japan appear to have the largest percentages of installed fast chargers, while the Netherlands and France have the largest percentages of installed normal chargers. The large number of installed normal chargers is attributed to the very favorable treatment, including tax incentives and company car system offered in the Netherlands (and also offered in other EU nations) to individuals and employers who use EVs and PHEVs, and to the significant increase in the share of PHEV sales (which was in the 10% range in 2013)[35].

Next, Fig. 5 shows the total number of normal and fast chargers that were shipped and installed in Japan[36][37]. The number of installed fast chargers increased significantly in 2010 by 330%, and again in 2011 by 260% in comparison to the previous year, but in 2013 this increase slowed to just 140% compared to the previous year. However, this number has started to rise again, by 150% in 2014 and 210% in 2015, respectively, in comparison to the previous year. At the same time, the number of installed normal chargers has increased in the range of 150% to 170% compared to the previous year since 2012, the first year for which there is statistical data.

In December 2015 METI issued a press release stating that there would be an easing of regulations to allow electricity to be supplied to normal chargers attached to fast chargers[38]. This made it possible to use the same electric power receiving equipment and install normal chargers in locations such as roadside rest areas and highway service areas where fast chargers had already been installed. There were already instances of fast and normal charger installed together, this deregulation is expected to further promote the installation of normal chargers.

2. 4. 2. High Power Charger

Efforts to boost the output of the battery chargers and achieve the larger capacity that batteries will require to extend the cruising range of EVs are underway. In Japan, the CHAdeMO Association issued its CHAdeMO Specifications Version 1.2 and raised the maximum current of a fast charger from 125 A to 400 A[39]. This will eventually make chargers with up to the maximum of 150 kW under the CHAdeMO standard available in the market. Outside of Japan, the BMW Group, Daimler AG, Ford Motor Company, the Volkswagen Group, Audi, and Porsche announced that they had signed a memorandum of understanding to build a fast charging network in Europe that will be capable of charging up to a maximum of 350 kW[40]. Construction is planned to start in 2017, with an initial target of about 400 charging sites in Europe. A current of 350 A and a voltage of 1000 V is assumed for these fast charging stations with an output of 350 kW.

2. 4. 3. Wireless Charging System

Wireless charging system is a technology that is attracting more attention recently because it greatly improves convenience for users of EVs and PHEVs and also expands potential applications to charging vehicle batteries during driving. Several issues must be overcome before this technology can be put to practical use. In order of importance, they are: (1) unnecessary radiation, EMC countermeasures, protections for the human body, and safety measures, (2) compatibility, (3) installation of multiple wireless charging devices and efficient control technologies, (4) standardization, and (5) preparation and maintenance of legal systems and frameworks[41].

With respect to standardization, the SAE International published their industry guideline for wireless charging system of light-duty vehicles, J2954, in May 2016[42]. This guideline covers both the electromagnetic induction and electric field resonance methods, and also indicates the common frequency band to be used and the power output classes of the chargers. Outside Japan, standardization is also being discussed within the IEC and ISO. In Japan, the same discussions, centered around the Broadband Wireless Forum (BWF), are being conducted through coordination between the Japan Automobile Manufacturers Association (JAMA) and the Japan Automobile Research Institute (JARI)[43].

In 2018, Daimler AG plans to release a PHEV equipped with the world's first wireless charging system on a mass-production vehicle (produced by Qualcomm, maximum output of 3.6 kW)[44]. The roadmap created by the BWF presents a scenario that predicts wireless charging of electric vehicle batteries will be introduced in the Japanese market by 2020 and spread in the following years[45]. Wireless charging technology is fully expected to become available in Japan in the near future.

2. 5. Trends in Standardization

ISO/TC22 (Road vehicles)/SC37 (Electrically-propelled vehicles)/WG1 (Safety) is now deliberating potential revisions to 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). It was decided to integrate the content of ISO 12405-3 Safety performance requirements for lithium-ion battery packs as special notes and instructions in the third edition of ISO 6469-1 currently under discussion. In addition, separate discussions and examinations on adding the thermal chain test as an addendum to ISO 6469-1 were begun.

3 Fuel Cell Electric Vehicles

3. 1. Introduction

Instead of using a conventional internal combustion engine that relies on fossil fuels such as gasoline, fuel cell electric vehicles (FCVs) are equipped with a high-pressure hydrogen container that stores hydrogen fuel and a fuel cell stack that generates electric drive power. In FCVs the stored hydrogen combines with oxygen to form water in an electrochemical reaction that generates the electricity used to provide drive power to the vehicle. Consequently, like electric vehicles, FCVs are considered zero emissions vehicles (ZEVs) because they do not directly emit carbon dioxide, nitrogen oxides, or other pollutants, leading to calls for the wider adoption of these vehicles. The first FCVs were leased to Japanese government agencies in December 2002, and, following a series of refinements, the first mass-production FCV went on sale in Japan on December 15, 2014[46].

On March 22, 2016, METI released a revised version of its Strategic Roadmap for Hydrogen and Fuel Cells[47], which set targets for the dissemination and adoption of FCVs in Japan of about 40,000 vehicles by the year 2020, about 200,000 vehicles by 2025, and about 800,000 vehicles by 2030. In addition, the plan also included targets of about 160 stations by 2020 and 320 stations by the year 2025 for the number of hydrogen fueling stations to establish for FCVs.

3. 2. Trends in Research and Development

3. 2. 1. Trends in FCV Research and Development

Following in the footsteps of the Mirai FCV from Toyota Motor Corporation, Honda Motor Company released its FCV, the Clarity Fuel Cell, on March 10, 2016[48]. The fuel cell powertrain of the Clarity has been downsized and is contained entirely under the hood, making it the first sedan FCV in the world with room for five adult passengers. In addition, if it is used in combination with the Power Exporter 9000 portable external electric power supplier released by Honda at the same time as the Clarity, the vehicle can become a “drivable electric power source” and provide electrical power to an average household for approximately seven days. These vehicles are expected to serve as a supply of electrical power in the event of a natural disaster or other emergency.

Fig. 6 FC forklift

Fig. 7 FC bus

Fig. 8 FC motorcycle

The release of the Toyota Mirai led to keeping records on the number of FCV passenger vehicles owned in Japan, with the figures standing at 150 vehicles as of the end of March 2015 and 630 vehicles by the end of March 2016[49]. Given the target of 40,000 FCVs by 2020 set in the Strategic Roadmap for Hydrogen and Fuel Cells released by METI[47], providing grounds to expect greater FCV adoption in the coming years.

Outside the passenger vehicle category, Toyota L&F announced on July 26, 2016 that they would sell a fuel cell forklift (FC forklift, shown in Fig. 6) in the fall of 2016[50]. This forklift uses the same fuel cells as the Mirai and is equipped with a dedicated FC system for forklifts with high-efficiency electric power generation. It has a hydrogen fueling pressure of 35 MPa and an operating time of eight hours. Over 6,200 FC forklifts have been introduced into the U.S. market between 2003 and 2015[51], creating are expectations that they will become popular in Japan as well.

On October 21, 2016 Toyota Motor Corporation an-

Fig. 9 Opening Ceremony of the Tsukuba Kasuga Hydrogen Fueling Station

nounced that they would begin selling a fuel cell bus, as shown in Fig. 7, starting in early 2017[52]. These buses are equipped with the Toyota Fuel Cell System (TFCS) that was developed for the Mirai. On March 21, 2017 there was an announcement from Suzuki Motor Corporation concerning the start of public road driving of their fuel cell motorcycle (shown in Fig. 8)[53]. The hydrogen fuel tank holds 10 L of fuel and can be filled to 70 MPa, providing a cruising range of 120 km on a single tank of fuel.

Fuel cell-based drive systems are expected to spread to various vehicles outside the passenger car category.

3. 2. 2. Trends in the Establishment of Hydrogen Fueling Stations

The establishment of the commercial use hydrogen fueling stations essential to FCVs began in 2013. They have mainly been built in four major metropolitan areas (the Tokyo metropolitan, Chukyo, Kansai, and northern Kyushu areas) and along the major roadways that connect those areas. As of December 2016, there were 80 hydrogen fueling stations operating in Japan[54]. There are 35 stations in the Tokyo metropolitan area, 21 in the Chukyo area, 11 in the Kansai area, 10 in the northern Kyushu area, and 3 stations in other regions. On April 6, 2016 the first commercial hydrogen fueling station in the three prefectures of the north Kanto region opened in Tsukuba City. Fig. 9 shows the opening ceremony. This is a mobile hydrogen fueling station, and the background shows a heavy-duty trailer holding the set of equipment needed to supply hydrogen fuel to vehicles. Such mobile hydrogen fueling stations are seen as an effective approach during the early stages of FCV popularization, and therefore account for 29 of the 80 hydrogen fueling stations operating in Japan.

As of January 2017 there are plans to establish additional hydrogen fueling stations in 11 more locations[55]. These include the first such station in the Tohoku region in the city of Sendai, in Miyagi Prefecture. As mentioned previously, the Strategic Roadmap for Hydrogen and Fuel Cells released by METI[47] has set a target of around 160 established hydrogen fueling stations by 2020 and a push to both increase FCV adoption and build more stations around the country is expected.

3. 3. Trends in Standardization

On February 23, 2016 MLIT revised the announcements concerning the Safety Regulations for Road Vehicles and stipulated the world's first safety standards for FC motorcycles[56]. These standards take into consideration issues specific to motorcycles in an accident, such as the vehicles tipping over. Specifically, they stipulate that when the pressure relief device on the hydrogen fuel tank activates and there is an emergency release of hydrogen, the hydrogen is to be discharged perpendicularly outward from the bottom of the vehicle body.

On June 30, 2016 METI established a ministerial ordinance concerning the mutual recognition of type approvals for FCVs[57]. This measure introduces the UN Regulation concerning FCVs (UNR 134) to Japan, and is expected to make the importing and exporting of high-pressure hydrogen fuel tanks for FCVs more efficient. However, the discussions of materials (countermeasures for hydrogen embrittlement) in UNR 134 remain unfinished, leaving confirmation of the safety of the materials to be carried out by individual countries. Consequently, the existing Japanese material standards shall continue to apply. A global, unified test method is strongly desired for these material evaluations, and UN deliberations on this topic are scheduled to resume in 2017.

The development of international standards for FCVs is being handled by ISO/TC22 (Road vehicles)/SC37 (Electrically-propelled vehicles) and ISO/TC197 (Hydrogen technologies). Through the deliberations in these committees, issues such as FCV safety, the fuel tanks equipped on FCVs, hydrogen fueling station safety, and hydrogen fuel specifications are all being actively discussed at the international level in accordance with the deliberation phase of the ISO.

ISO 6469-4 (Post-crash electrical safety) was formally issued in September 2015 by ISO/TC22/SC37 in the context of its recent moves to issue international standards (IS) and continue to issue new ones in the near future. In that vein, this committee is currently revising two more IS on electric vehicle safety, ISO 6469-2 (Vehicle operational safety means and protection against failures) and

Table 3 Main Electric Motors Equipped on Electric Passenger Vehicles[58]-[66]

Manufacturers	Designation	Type	Max. output〔kW〕	Max. torque〔Nm〕	System	Main vehicles equipped with this motor
Toyota	3JM	AC synchronous motor	60	207	HEV	Auris
	1NM		53	163		C-HR
Nissan	EM57		80	254		Note
	SM24		1.9	48	Mild HEV	Serena
Honda	H4		135	315	HEV	Odyssey
	H1		22	160		Freed
	MCF4		130	300	FCV	Clarity
Suzuki	PB05A		10	30	HEV	Solio SZ, SX, SV
	WA05A	DC synchronous motor	2.3	50	Mild HEV	Ignis
Mitsuoka Motors	1LM	AC synchronous motor	45	169	HEV	Ryugi Wagon
Volvo Car Japan	T35		35	160	PHEV	XC90 T8 (Front)
	AD2		64	240		XC90 T8 (Rear)
BMW Group Japan	P251		83	250		740e
	P251		65	250		330e
	P160		65	165		225xe
Volkswagen Group Japan	EAJ	—	85	330		Passat GTE
Tesla Motors	—	—	193	—	EV	model X

ISO 6469-3 (Protection of persons against electric shock), which it aims to issue in 2018.

ISO/TC197 is continuing to deliberate on ISO 19880-1 (General regulations for gaseous hydrogen fueling stations) and plans to issue this standard in 2018. These deliberations on hydrogen station regulations included discussions on the necessity of a standard for hydrogen quality control, prompting new deliberations under ISO 19880-8, with Japan serving as the host and committee chair. The aim is to issue this standard sometime in 2017. At the same time, revisions to the hydrogen fuel quality standards are progressing in anticipation of the upcoming era of mass FCV dissemination, with the intent to issue ISO 14687 (Hydrogen fuel product specifications) in 2018. Revision work and voting are also currently underway for the scheduled issuing of ISO 17268 (Gaseous hydrogen land vehicle refueling connection devices) sometime in 2017. This series of international standards concerning hydrogen technologies are regarded as critical and scheduled to be cited in upcoming European legislation as the market for hydrogen fuel in Europe develops.

The ongoing deliberations on ISO 19881 (Gaseous hydrogen: Land vehicle fuel tanks) and ISO 19882 (Thermally activated pressure relief devices for hydrogen fuel tanks) have entered the final stages to bring these standards in alignment with the above-mentioned UN Regulation (UNR 134).

4 Traction Motors

4. 1. Introduction

In 2016 domestic and foreign automobile manufacturers made many announcements concerning HEVs, EVs, FCVs and other vehicles powered by electricity. This section presents the recent trends in the field of electric motors mounted on electric, as well as the trends in research and development of these motors.

4. 2. Electric Motors

Table 3 shows the main electric motors providing drive power to the vehicle that were mounted on either newly released (including lease sales) or completely redesigned passenger vehicles in Japan between January and December 2016[48]-[66]. DC synchronous motors were equipped on some mild HEVs, but most of the vehicles listed here were equipped with an AC synchronous motor. The HEVs were equipped with motors that featured a wide variety of power output levels, with a maximum output that ranged from 10 to 135 kW depending on the vehicle model. In contrast, the EVs and FCVs were equipped with high output motors producing a maximum output between 130 and 193 kW.

No new commercial HEVs or EVs went on sale in 2016, but there were two press releases announcing EV trucks[67][68]. According to these releases, one of these trucks will be equipped with an electric motor featuring a maximum power output and maximum torque of 185 kW and 380 Nm and the other will have two motors providing 125 kW and 500 Nm.

Recent research and development on electric motors focuses on downsizing and achieving high efficiency. Examples of approaches used to achieve downsizing include optimizing the manufacturing method and shape of the winding to improve its space factor. High efficiency is being pursued through methods such as high-voltage driving, iron loss reduction, and winding switching. With inverters also achieving higher power density and efficiency, improvements are not confined to motors, and the combined advances in both motors and inverters are leading to the further downsizing and higher density of the entire motor drive system[69].

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