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 regard hybrid electric vehicles (HEVs), which combine an internal combustion engine and electric motors, as one way of improving fuel efficiency. The number of plug-in hybrid vehicles (PHEVs), which allow external charging of the on-board battery that powers the electric motors, is also increasing. This section describes the recent trends for HEVs and PHEVs.

1. 2. Popularization of Hybrid Vehicles in Japan

Figure 1 shows that the number of HEVs and PHEVs on the roads in Japan is increasing year after year. In 2017 the number of passenger HEVs on the road in Japan, not including mini-vehicles, increased by nearly 930,000 vehicles compared to the previous year to reach approximately 7.4 million vehicles (19% of the total number of passenger vehicles (approximately 39.49 million)). The number of passenger PHEVs on the road in Japan has also continued to increase since 2011, reaching approximately 100,000 vehicles in 2017. In addition, in 2017, the number of hybrid mini-vehicles on the road in Japan increased by approximately 230,000 vehicles compared to the previous year, and now stands at approximately 770,000 vehicles.

1. 3. New HEVs Launched in Japan

Table 1 lists the HEVs and PHEVs launched in Japan in 2018 according to the date they went on sale. The main trends were as follows.

In March, Nissan Motor Co., Ltd. launched the Serena e-Power. The e-Power hybrid system is capable of driving the Serena on motor power alone, using electricity generated by the engine[2].

In April, BMW launched a redesigned version of the i8. The hybrid system in the new i8 has a motor output of 105 kW and a battery capacity of 33 Ah, 9 kW and 13 Ah higher than the previous model, respectively, enabling a cruising range (converted EV driving distance) of 54.8 km (in the JC08 test mode) using only external electric power as an energy source, and a hybrid fuel economy of 15.9 km/L (JC08)[3].

In June, Toyota Motor Corporation launched the Century, Crown, and Corolla Sport. The hybrid system in the Century pairs motors with a 5.0-liter V8 gasoline engine. In contrast, two different hybrid systems are offered in the Crown: the Toyota Hybrid System II (THS II), which is equipped with a reduction gear, and a multistage hybrid system that includes a shift device in series with the hybrid system. The Corolla Sport utilizes the reduction gear THS II[4]. In the same month, Mercedes-Benz launched the CLS 450 4MATIC Sports. The hybrid system in this model features a motor with both an alternator and starter function located between the engine and transmission (called the integrated starter generator (ISG)), paired with a 48 V lithium ion battery[5].

In July, Nissan launched a new Note e-Power equipped with a motor-assisted four-wheel drive system. Compared to the hybrid system in the previous model, the new model includes an additional motor that drives the rear

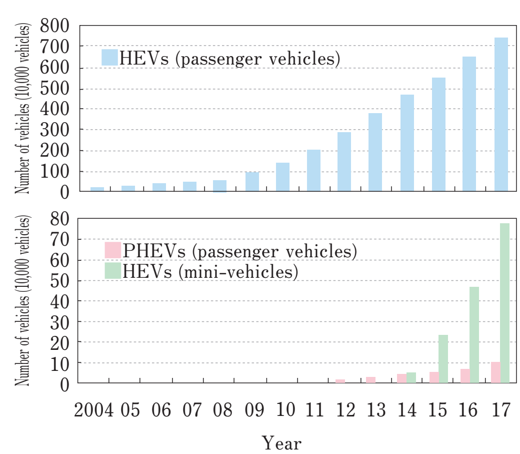

Fig. 1 Trends in the Number of HEVs and PHEVs on the Road in Japan[1]

Table 1 Main HEVs Launched in Japan in 2018[(2)-(12)]

Date announced/went on sale		2018/3/1	2018/4/9	2018/6/22	2018/6/25	2018/6/26
Name of company		Nissan	BMW	Toyota	Mercedes-Benz	Toyota
Name		Serena e-Power	i8	Century	CLS 450 4MATIC Sports	Crown
Type of hybrid system		Series (HEV)	Series-parallel (PHEV)	Series-parallel (HEV)	Parallel (HEV)	Series-parallel (HEV)
Drivetrain		Front-wheel drive	Four-wheel drive	Rear-wheel drive	Four-wheel drive	Front-wheel drive/ four-wheel drive
Fuel economy (JC08 test cycle, km/L)		26.2	15.9	13.6	11.9	18.0/24.0
Engine	Designation	HR12DE	B38K15A	2UR-FSE	256	A25A-FXS/8GR-FXS
	Displacement (cc)	1,198	1,498	4,968	2,996	2,487/3,456
	Output (kW)	62	170	280	143	135/220
Motor	Type	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor
	Output (kW)	100	105	165	10	105/132
Battery	Type	Lithium-ion	Lithium-ion	Nickel-metal hydride	Lithium-ion	Nickel-metal hydride/lithium-ion
	Capacity (kWh)	—	—	—	—	—

Date announced/went on sale		2018/6/26	2018/7/5	2018/7/19	2018/7/19	2018/7/25
Name of company		Toyota	Nissan	Subaru	Honda	Mercedes-Benz
Name		Corolla Sport	Note e-Power	Forester Advance	Clarity PHEV	C200 Avantgarde
Type of hybrid system		Series-parallel (HEV)	Series (HEV)	Parallel (HEV)	Series-parallel (PHEV)	Parallel (HEV)
Drivetrain		Front-wheel drive	Four-wheel drive	Four-wheel drive	Front-wheel drive	Rear-wheel drive
Fuel economy (JC08 test cycle, km/L)		34.2	18.2	18.6	28.0	13.6
Engine	Designation	2ZR-FXE	HR12DE	FB20	LEB	264
	Displacement (cc)	1,797	1,198	1,995	1,496	1,496
	Output (kW)	72	58	107	77	135
Motor	Type	AC synchronous motor	AC synchronous motor/DC motor	AC synchronous motor	AC synchronous motor	—
	Output (kW)	53	80/3.5	10	135	10
Battery	Type	Nickel-metal hydride	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Capacity (kWh)	—	—	—	—	1

Date announced/went on sale		2018/8/23	2018/9/6	2018/9/25	2018/10/15	2018/10/19
Name of company		Mitsubishi	Audi	Volvo	Audi	Subaru
Name		Outlander PHEV	A7 Sportback	V60 T6/T8 Twin Engine AWD Inscription	A8	XV Advance
Type of hybrid system		Series-parallel (PHEV)	Parallel (HEV)	Series-parallel (PHEV)	Parallel (HEV)	Parallel (HEV)
Drivetrain		Four-wheel drive	Four-wheel drive	Four-wheel drive	Four-wheel drive	Four-wheel drive
Fuel economy (JC08 test cycle, km/L)		18.6	12.3	—	10.5/8.7	19.2
Engine	Designation	4B12 MIVEC	DLZ	—	CZS/CXY	FB20
	Displacement (cc)	2,359	2,994	1,988	2,994/3,996	1,995
	Output (kW)	94	250	186/233	250/338	107
Motor	Type	AC synchronous motor	—	AC synchronous motor	—	AC synchronous motor
	Output (kW)	25/25	—	22/28	—	10
Battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Capacity (kWh)	13.8	—	—	—	—

Table 1 Main HEVs Launched in Japan in 2018[(2)-(12)] (Cont.)

Date announced/went on sale		2018/10/24	2018/11/1	2018/11/27	2018/12/13	2018/12/14
Name of company		Lexus	Honda	Lexus	Mercedes-Benz	Honda
Name		ES300h	CR-V Hybrid EX/ Masterpiece	UX250h	S560e Long	Insight
Type of hybrid system		Series-parallel (HEV)	Parallel (HEV)	Series-parallel (HEV)	Series-parallel (PHEV)	Series-parallel (HEV)
Drivetrain		Front-wheel drive	Front-wheel drive/ four-wheel drive	Front-wheel drive/ four-wheel drive	Rear-wheel drive	Front-wheel drive
Fuel economy (JC08 test cycle, km/L)		23.4	25.8	27.0	11.4	34.2
Engine	Designation	A25A-FXS	LFB	M20A-FXS	276M30	LEB
	Displacement (cc)	2,487	1,993	1,986	2,996	1,496
	Output (kW)	131	107	107	270	80
Motor	Type	AC synchronous motor	AC synchronous motor	AC synchronous motor/ AC induction motor	AC synchronous motor	AC synchronous motor
	Output (kW)	88	135	80/5	60	96
Battery	Type	Nickel-metal hydride	Lithium-ion	Nickel-metal hydride	Lithium-ion	Lithium-ion
	Capacity (kWh)	—	—	—	13.5	13.5

Date announced/went on sale		2018/12/20
Name of company		Suzuki
Name		Specia Gear
Type of hybrid system		Parallel (HEV)
Drivetrain		Front-wheel drive/ four-wheel drive
Fuel economy (JC08 test cycle, km/L)		28.2
Engine	Designation	R06 A
	Displacement (cc)	658
	Output (kW)	47/38
Motor	Type	DC synchronous motor
	Output (kW)	2.3
Battery	Type	Lithium-ion
	Capacity (kWh)	—

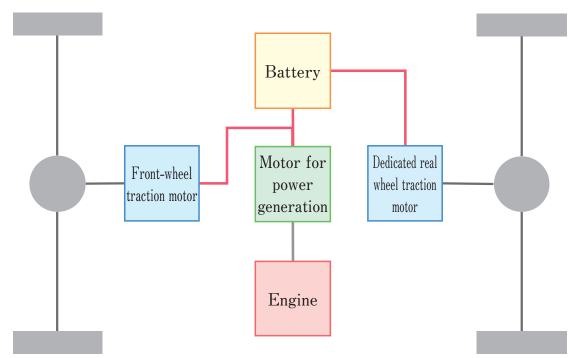

Fig. 2 Drive System of the Note e-Power[(2)]

wheels, powered from the battery used to drive the front wheels[(2)] (Fig. 2).

In the same month, Subaru launched the Forester Advance, Honda Motor Company launched the Clarity PHEV, and Mercedes-Benz launched the C200 Avantgarde. The Forester Advance features the e-Boxer parallel hybrid system, which incorporates a motor between its horizontally opposed engine and Lineartronic continuously variable transmission[(6)]. The Clarity PHEV uses Honda's Sport Hybrid i-MMD Plug-in system, a hybrid system that pairs two motors with an inline 4-cylinder 1.5-liter Atkinson cycle engine. This PHEV has a converted EV driving distance of 114.6 km (JC08) and a hybrid fuel economy of 28.0 km/L (JC08)[(7)]. The C200 Avantgarde features a hybrid system that combines a belt-driven starter/generator (BSG) connected to the crankshaft with a 48 V lithium ion battery to boost dynamic performance (maximum output: 10 kW, maximum torque: 160 Nm). This motor also provides assist when shifting to minimize the time required for the engine to reach the ideal speed, thereby reducing the time taken to change gears and enabling a smooth shifting feel with little time lag[(5)].

In August, Mitsubishi Motors launched a redesigned Outlander PHEV. The 2.0-liter engine of the previous model has been replaced with a 2.4-liter engine that enables more efficient power generation at low engine speeds. The new model increases the maximum generator output by 10%, the traction battery capacity by 15%, the battery output by 10%, and the rear motor power by

10 kW. As a result, this PHEV has a converted EV driving distance of 65.0 km (JC08) and a hybrid fuel economy of 18.6 km/L (JC08)[8].

In September, Audi launched the A7 Sportback. The hybrid system in this model consists of a 48 V lithium ion battery and a belt-driven alternator/starter, and can regenerate 12 kW of energy during braking[9]. In the same month, Volvo launched the V60. This model powers the front wheels using an engine and motor, and the rear wheels using a motor alone. It switches between hybrid and EV mode depending on the driving conditions[10].

In October, Audi launched the A8 equipped with the same hybrid system as the A7 Sportback[9]. In the same month, Subaru launched the XV Advance and Lexus launched the ES300h. The XV Advance uses the same e-Boxer hybrid system as the Forester Advance[6] and the ES300h adopts the THS II[11].

In November, Honda launched the CR-V. This model uses the Sport Hybrid i-MMD, a hybrid system equipped with two motors for drive and power generation. This is the first use of the Sport Hybrid i-MMD with a four-wheel drive system[7]. In the same month, Lexus launched the UX250h. This model uses the THS II to drive both the front and rear wheels and includes a separate motor to drive the rear wheels in four-wheel drive mode[11].

In December, Mercedes-Benz launched a redesigned version of the S560e Long. The battery capacity of the new model is 13.5 kWh, approximately 55% higher than the previous model, enabling a converted EV driving distance of 40.1 km (JC08) and a hybrid fuel economy of 11.4 km/L (JC08)[5]. In addition, in the same month, Honda launched the Insight and Suzuki Motor Corporation launched the Specia Gear. The Insight uses the Sport Hybrid i-MMD system[7], and the Specia Gear uses a hybrid system that assists the engine during acceleration by generating power from the ISG using energy from deceleration[12].

2 Electric Vehicles

2. 1. Introduction

Battery electric vehicles (BEVs) are powered entirely by motors using electric energy supplied externally and stored in a traction battery. BEVs are attracting attention as environmentally friendly vehicles that emit no harmful tailpipe emissions. Starting in 2009 with the launch of the i-MiEV by Mitsubishi (this was the world's first mass-produced BEV equipped with a lithium-ion battery and was mainly sold to corporate customers), a total of 8 BEV models had been launched in Japan by the end of December 2018. The number of BEVs on the road in Japan exceeded 100,000 vehicles at the end of 2017, a 15% increase from the end of 2016. Issues slowing the widespread adoption of BEVs include those related to vehicle performance, such as short cruising ranges and long charging times, those related to infrastructure such as charging facilities at housing complexes, and those related to vehicle price derived from the high cost of traction batteries. Research and development are under way to extend cruising range by increasing the capacity or power density of the traction battery, or by raising the efficiency of the traction battery, motor, and inverter to improve power consumption. Long charging times are being addressed by increasing the output of rapid chargers. On the infrastructure front, systems are in place to introduce chargers and to provide incentives from the national and some local governments. The issue of vehicle price is being addressed through incentives and improvements in mass-production technologies to reduce cost. This section describes the current state of BEV use in Japan, as well as the recent trends in research and development, 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 BEVs on the road in Japan[13]. The number of BEVs in Japan continued to decrease until 2008. However, after the launch of the i-MiEV by Mitsubishi in 2009 and the Leaf by Nissan in 2010, the number of BEVs on the road has steadily increased, reaching 103,569 vehicles at the end of 2017.

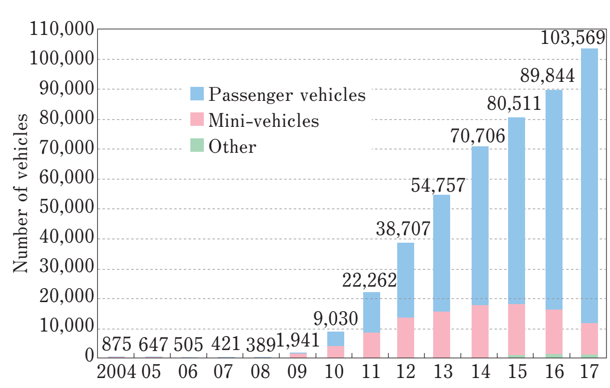

Fig. 3 Trends in the Number of BEVs on the Road in Japan (as of the End of March Each Year)[13]

Table 2 Specifications of Main BEVs Sold in Japan in 2018[(15)-(20)]

Manufacturer		Nissan	Nissan	Mitsubishi	Mitsubishi
Name		Leaf G	e-NV200 GX	i-MiEV X	Minicab-MiEV Van CD 16.0 kWh
Length × width × height (mm)		4,480 × 1,790 × 1,540	4,560 × 1,755 × 1,855	3,480 × 1,475 × 1,610	3,395 × 1,475 × 1,915
Occupant capacity		5	2/5 *3	4	2/4 *3
AC power consumption rate (JC08 test cycle, Wh/km)		120/155 *1	150	118	127
Cruising range on a single charge (km)		400/322 *1	300	164	150
Traction battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total voltage (V)	350	350	330	330
	Total power (kWh)	40	40	16	16
Motor	Rated output (kW)	85	70	30	25
	Max. output (kW)	110	80	47	30
	Max. torque (N・m)	320	254	160	196
Charging time	Normal charging (3 kW, h)	Approx. 16 (6 kW charging: 8)	Approx. 8	Approx. 7	Approx. 7
	Rapid charging (0 to 80%), mins)	Approx. 40	Approx. 40	Approx. 30	Approx. 35

Manufacturer		BMW	Volkswagen	Tesla	Tesla
Name		i3	e-Golf	Model S P100 D	Model X P100 D
Length × width × height (mm)		4,020 × 1,775 × 1,550	4,265 × 1,800 × 1,480	4,970 × 1,964 × 1,445	5,036 × 1,999 × 1,684
Occupant capacity		4	5	5	5/6/7 *3
AC power consumption rate (JC08 test cycle, Wh/km)		98	124	—	—
Cruising range on a single charge (km)		390	301	613 *2	542 *2
Traction battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total voltage (V)	398.4	323	—	—
	Total power (kWh)	33.2	35.8	100	100
Motor	Rated output (kW)	75	100	—	—
	Max. output (kW)	125	100	F : 193/R : 375	F : 193/R : 375
	Max. torque (N・m)	250	290	F : 330/R : 650	F : 330/R : 660
Charging time	Normal charging (3 kW, h)	Approx. 12 to 13	Approx. 12 (6 kW charging: 6)	—	—
	Rapid charging (0 to 80%), mins)	Approx. 45	Approx. 35	—	—

*1: WLTC test cycle, *2: NEDC test cycle, *3: Depending on the model specifications

However, the proportion of BEVs in Japan remains at around 0.1% of all vehicles, indicating that full-scale popularization has yet to be attained[(14)]. Table 2 shows the specifications of the main BEVs sold by automakers in Japan in 2018[(15)-(20)]. Although no new BEVs (passenger vehicles) were launched in Japan in 2018, Mitsubishi released a partially updated version of the i-MiEV in April 2018, which changed its registration status to that of a mini-vehicle[(16)].

Moreover, in November 2018, Honda began lease-based sales of an electric motorcycle called the PCX Electric[(21)]. Based on the PCX, the electric version is equipped with two Honda Mobile Power Pack removable traction batteries, which provide a range of 41 km on a single charge.

2. 2. 2. Initiatives to Promote EV Popularization

In April 2018, the Japanese Ministry of Economy, Trade and Industry (METI) set up the Strategic Commission for the New Era of Automobiles. In an interim report issued at the end of August, the Commission announced the following long-term goal: by 2050, to advance the shift of vehicles produced by Japanese automakers in global markets to xEVs and contribute to realizing a "Well-to-Wheel Zero Emission" policy to reduce a vehicle's total emissions footprint to zero, from fuel to operation[(22)].

Then, in June 2018, the Japanese government approved the "Investments for the Future Strategy 2018"[(23)]. This report assessed the progress toward increasing next-generation vehicle sales to 50 to 70% of all new passenger car sales by 2030, which was one of the key performance indicators (KPIs: a means of evaluating the degree of achievement of corporate objectives) cited in the 2017 strategy. The report declared progress of 36.7% in 2017 toward this goal.

In the same month, the Tokyo Metropolitan Government started a business to encourage introduction of charging facilities and the like at housing complexes through the provision of incentives. This incentive system also covers solar power generation systems[24].

As of 2018, METI is allocating money to help subsidize the cost of measures to promote the adoption of clean-energy vehicles and to promote the development of the required BEV and PHEV charging infrastructure. The aim of this measure is to support the purchase of BEVs and the like, and to support the installation of charging facilities at housing complexes, service areas on expressways, and elsewhere[25][26].

Also as of 2018, the Japanese Ministry of Land, Infrastructure Transport and Tourism (MLIT) is working in cooperation with the plans of regional governments to support the concentrated introduction of next-generation vehicles and buying these vehicles to replace older models. This is being implemented through MLIT's policy to promote the popularization of next-generation environmentally friendly vehicles to encourage the "greening" of local transportation[27].

2. 3. Trends in BEV Research and Development

In addition to research and development projects to extend the cruising range of BEVs, demonstration projects are also under way to facilitate the practical adoption of BEVs. These efforts are introduced in more detail in the following sections.

2. 3. 1. Vehicle Development

In March 2018, Mitsubishi Fuso Truck and Bus Corporation announced the development of the eCanter, the world's first mass-produced light-duty electric truck designed for garbage collection[28]. It plans to start a demonstration project in Kawasaki in around the spring of 2019.

In April 2018, UD Trucks announced its next-generation technology roadmap called "Fujin & Raijin. Vision 2030"[29]. In it, the company is aiming to achieve mass-production of a fully automated driving truck and a fully electric heavy-duty truck by 2030.

In June 2018, Honda and General Motors (GM) announced an agreement to collaborate on the development of next-generation battery components including traction battery cells and modules with the aim of accelerating the launch of BEVs from both companies[30]. The two companies are aiming to develop more compact next-generation battery components with higher energy density and shorter charging times than conventional traction batteries, and plan to install these components in vehicles for the North American market.

In July 2018, Honda and Panasonic announced plans to start a traction battery sharing demonstration project in Indonesia in December of the same year, using the Honda Mobile Power Pack and an electric motorcycle installed with these battery packs[31]. This project will be implemented using an information and communication technology (ICT) system to centrally manage the jointly developed mobile power packs and charging stations, as well as the operational status of the power packs.

In September 2018, Yamaha Motor Co., Ltd. and Gogoro Inc. began studying the feasibility of collaborating in an EV business in Taiwan[32]. The two companies are aiming to roll out a new electric motorcycle business using a shared traction battery swap system.

In September 2018, Nissan and Traton AG announced plans to cooperate in the fields of electrified vehicles and electrification technologies and to work toward establishing a purchasing joint venture[33] with the objective of shortening development and commercialization lead times.

2. 3. 2. Demonstration Projects

In January 2018, Toyota and Chubu Electric Power Co., Inc. announced the launch of a project to construct a large-capacity storage battery system from re-used traction batteries from electrified vehicles, and to recycle used batteries[34]. This project aims to introduce the equivalent of 10,000 batteries with a power generation output of approximately 10,000 kW in 2020.

In May 2018, Nissan and Mitsubishi started a project to demonstrate vehicle-to-grid (V2G) technology in cooperation with Kyushu Electric Power, Co., Inc., the Central Research Institute of the Electric Power Industry, and Mitsubishi Electric Corporation[35][36]. In addition to normal charging of BEVs, this project is aiming to validate the feasibility of adjusting power supply by discharging power stored in BEVs into the grid.

In June 2018, six companies, including Mitsubishi and Tokyo Electric Power Company Holdings, Inc. announced the start of a V2G project that uses BEVs as virtual power plant resources[37]. This project is working to establish a V2G business model with the aims of enabling the continuous utilization of renewable energy and the stabilization of power grids. In 2018, this project intends

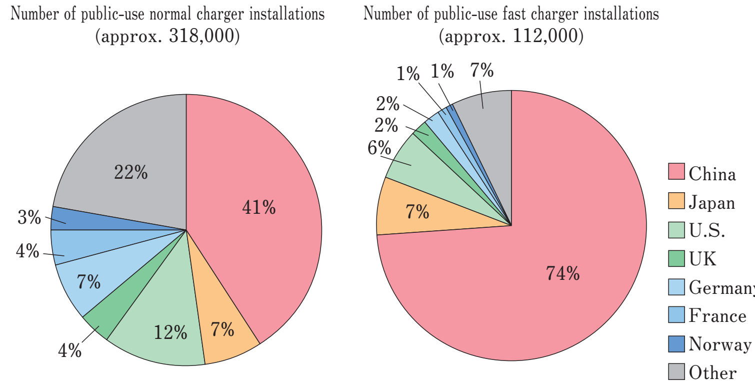

Fig. 4 Country-by-Country Percentage of Normal and Fast Charger Installations as of 2017 (Source: International Energy Agency (IEA). A normal charger is defined as AC 22 kW or less, and fast chargers include those from more than AW 22 kW to AC 43 kW and DC chargers)[41]

to build the demonstration environment and verify what can be accomplished by V2G.

In October 2018, Nissan announced a joint demonstration project with Tohoku Electric Power Co., Inc., Mitsui & Co., Ltd., and Mitsubishi Estate Co., Ltd. to build a V2G system[38]. This project aims to verify the feasibility of using BEVs to adjust the power supply balance and will examine a new business model to generate added value while cars are parked in anticipation of the future popularization of BEVs.

Please be aware that numerous other efforts are also under way in addition to the research trends and demonstration projects summarized here.

2. 4. Charging Infrastructure

This section first introduces trends concerning the installation of normal and fast chargers inside and outside Japan, and then describes the trends related to higher output chargers, wireless charging, and on-board solar power generation.

2. 4. 1. State of Charger Installation

It is estimated that by 2017 the total number of normal and fast charging stations for public use that had been installed around the world had reached 430,000 units, an increase of approximately 110,000 units from 2016[41]. Figure 4 shows the cumulative number of normal and fast chargers installed in various countries. The breakdown of normal chargers shows that China has the most, followed by the U.S., Japan, and Germany. Similarly, China also has the highest number of fast chargers, followed by Japan, the U.S., the UK, and Germany. Table 3 compares the rate of normal and fast chargers in the total number of chargers in various countries up to 2016 and up to 2017. The calculated rate increased in China,

Table 3 Global Proportion of Public-Use Normal and Fast Charger Installations

Country	Number of public-use normal charger installations / number of public-use fast charger installations	
	As of 2016	As of 2017
China	0.6	1.6
Japan	3.1	2.8
U.S.	6.6	5.7
UK	9.0	5.7
Germany	3.9	9.9
France	9.6	11.4
Norway	15.4	8.5

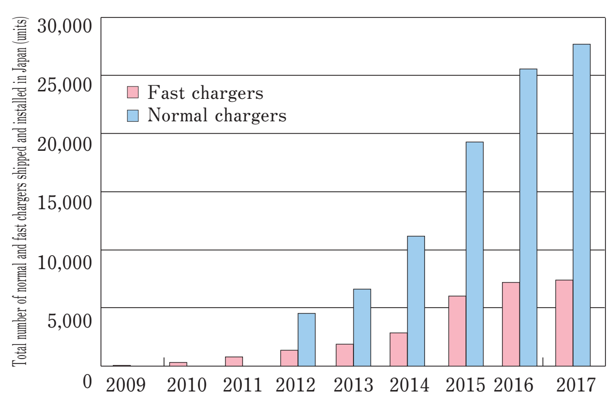

Fig. 5 Total Number of Normal and Fast Chargers Shipped and Installed in Japan up to 2017[42][43] (The number of normal chargers is the number shipped, the number of fast chargers is the estimated number installed based on the number of installation locations.)

Germany, and France, which shows that these countries increased the rate of normal charger installation over the course of the year in question. In contrast, the calculated rate decreased in the U.S., UK, and Norway, indicating that the rate of fast charger installation is increasing in these countries.

Figure 5 shows the total number of normal and fast chargers that were shipped and installed in Japan[42][43]. The number of installed normal chargers has continued to increase since 2012, which is the first year with statistical data. In 2017 the number of new normal chargers increased by approximately 10% compared to the previous year and the total number now exceeds 27,000 units. At the same time, the number of fast chargers is also increasing. In 2017 the total number of fast chargers exceeded 7,300 units, an increase of around 2% compared to the previous year. This rate of increase is lower than in 2016, and the lowest rate recorded so far.

2. 4. 2. Increasing Fast Charger Output

Following on from last year, active initiatives are under way to boost the output of fast chargers. In June 2018, the CHAdeMO Association issued the CHAdeMO specifications v.2.0[44], which raised the maximum output of these fast chargers to 400 kW (1,000 V × 400 A). In addition, in November 2018, a plan was agreed with China to formulate a 900 kW (1,500 V × 600 A) fast charging standard by around 2020[45]. CHAdeMO v.2.0 also considers specifications for liquid-cooled cables. Cable cooling and temperature control is regarded as an important countermeasure technology for larger currents as charger output increases[46].

2. 4. 3. Wireless Charging

Although discussions have been held by the Society of Automotive Engineers (SAE), International Organization for Standardization (ISO), and the International Electrotechnical Commission (IEC) about the standardization of wireless charging[47], technical and regulatory issues remain to be addressed. Technical studies and the establishment of necessary regulations are required. Examples include compatibility with charging systems from different manufacturers and the establishment of installation standards for wireless charging systems on public roads. Demonstration projects are regarded as an effective means to address these issues. In October 2018, Daihen Corporation and Tajima EV Corporation announced support from the Osaka municipal government and elsewhere to carry out a wireless charging demonstration project around Osaka Castle Park[48]. Feedback from these demonstration projects should prove a useful means of accelerating the practical adoption of wireless charging.

2. 4. 4. On-Board Solar Power Generation

Charging systems using on-board solar power generation are regarded as a new method of charging electrified vehicles. In 2017, Toyota showcased a PHEV that could be charged by solar cells installed on the vehicle roof[49]. Outside Japan, a venture company in Germany announced an EV with solar cells integrated into the whole surface of its body[50].

Investigations and studies are already underway into on-board solar power generation systems. In Japan, the committee for studying automotive solar power generation systems within the New Energy and Industrial Technology Development Organization (NEDO) evaluated the use patterns of these systems, their CO_2 emissions reduction potential, and the like[51]. Proposed by NEDO, an international investigation and study framework has been created with plans to further examine the CO_2 emissions reduction potential, usability, and required specifications of automotive solar power generation systems on an international basis under the International Energy Agency Photovoltaic Power System Programme (IEA PVPS)[52].

2. 5. Trends in Standardization

The standardization of BEVs is carried out by the ISO and IEC.

The ISO is charged with creating international standards for the overall vehicle, as well as for electric drive systems and parts. Although the safety requirements for BEVs have been defined in the ISO 6469 series of standards, safety requirements related to charging and rechargeable energy storage systems (RESS) have been discussed recently. Revisions are under way for the third version of Part 1 (RESS safety). A thermal runaway test for lithium-ion batteries has been discussed and is due to be incorporated into Part 1. In addition, Part 2 (operational safety) and Part 3 (electrical safety) were also published in February and October 2018, respectively[39].

For traction batteries, the ISO 12405 series related to lithium-ion battery packs and systems was re-organized. Part 4 (performance tests) was published in July 2018, combining Parts 1 and 2. Environmental tests are currently being discussed as ISO 19453-6. The revision of Part 3 (safety performance requirements is being considered by merging it with ISO 6469-1. For lithium-ion battery cells, the second editions of Part 1 (performance tests) and Part 2 (reliability and abuse testing) of the IEC 62660 series were published in December 2018.

With regard to charging, a wide range of standards are under discussion for new establishment or revision, including the IEC 61851 series related to conductive charging systems, the IEC 61980 series related to wireless charging systems, the IEC 62196 series related to accessories such as charging connectors, the ISO 15118 related to V2G communication interfaces, and the IEC 63119 series related to charging roaming services[40].

3 Fuel Cell Electric Vehicles

3. 1. Introduction

According to the results of the 2019 KPMG global automobile industry survey[53] that was sent to 981 executive level managers at major automotive companies around the world, the most important trends in the worldwide automotive industry up to the year 2030 are connected vehicles (59%), closely followed by electric and fuel cell electric vehicles (56%). (These percentages indicate the proportion of managers who believe these trends to be "extremely important.") The figure for FCEVs has increased every year since 2017, from 47% and 52% to 56% in 2019, showing the growth in attention given to FCEVs.

In Japan, METI released a revision version of the Strategic Road Map for Hydrogen and Fuel Cells on March 12, 2019[54]. This road map sets targets for the adoption of FCEVs in Japan of about 40,000 vehicles by 2020, about 200,000 vehicles by 2025, and about 800,000 vehicles by 2030 (Fig. 6). In addition, the plan also includes targets to establish around 160 hydrogen refueling stations by 2020, around 320 by 2025, and around 900 by 2030.

3. 2. Trends Related to FCEVs

This section introduces new information related to FCEVs released since 2018. It should also be noted that, at the FC Expo 2019, a specialist technical seminar held in February 2019, virtually every manufacturer of FCEVs announced the development status of large FCVs or the future development of them.

3. 2. 1. Toyota Motor Corporation

Aiming to achieve annual sales in excess of 30,000 vehicles from around 2020, Toyota is currently expanding its production facilities. Toyota plans to establish production facilities for fuel cell stacks in a new building in its Honsha Plant and build a new dedicated production line for high-pressure hydrogen tanks at the Shimoyama Plant[55]. In addition, to encourage initiatives using hydrogen, Toyota and JR East Japan have signed a basic partnership agreement to establish hydrogen refueling stations on land owned by JR East, introduce FCEVs and FC buses, apply FC technologies in railway carriages, and so on. The aim of this agreement is to advance specific studies into hydrogen use and to build a hydrogen supply chain[56].

Outside Japan, Toyota has agreed to supply FC systems for buses to CaetanoBus SA, a bus manufacturer in

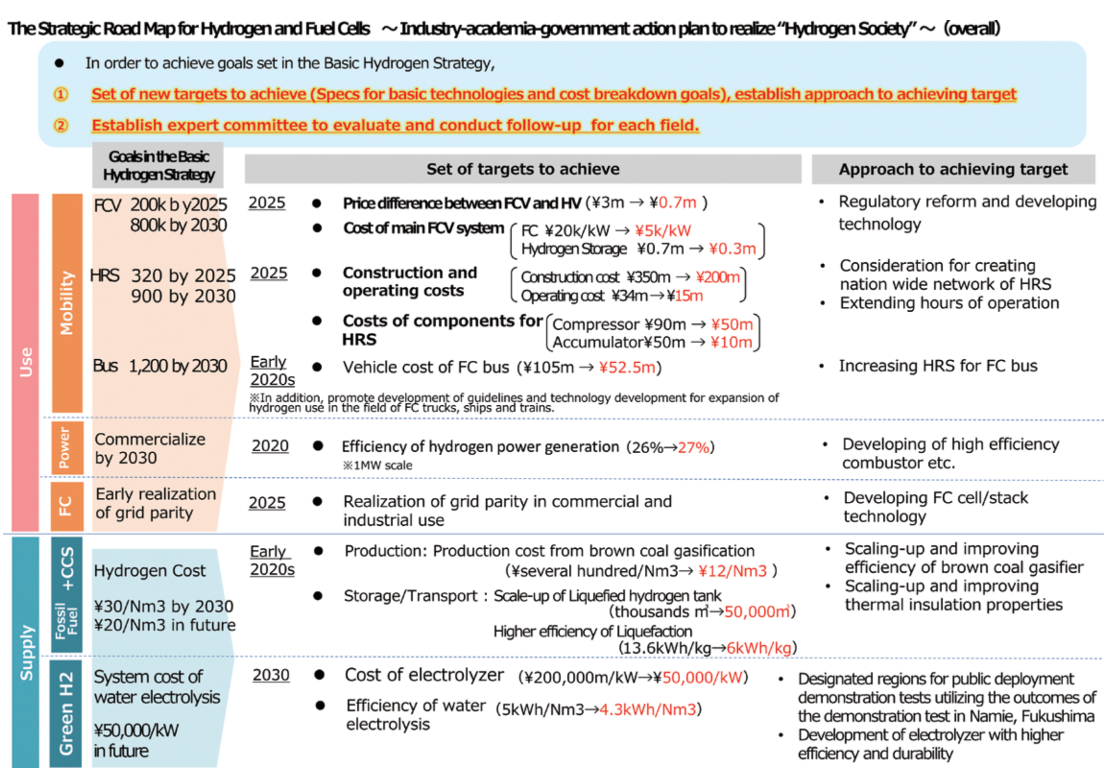

Fig. 6 Strategic Road Map for Hydrogen and Fuel Cells (METI)[54]

Portugal, with whom it has a partnership to supply commercial vehicles in Europe. The two companies are planning to conduct demonstration tests of these buses in the autumn of 2019[57].

3. 2. 2. Mercedes-Benz

In September 2017, Mercedes-Benz announced the GLC F-Cell EQ Power, an FCEV that can be recharged from an external power source. This FCEV went on sale at the end of 2018. In addition, Mercedes-Benz changed the name of NuCellSys, a wholly owned subsidiary that was established in 1997 to develop FC systems, to Mercedes-Benz Fuel Cell GmbH at the beginning of 2019. The aim of this name change is to demonstrate that FC technologies are an indispensable part of Mercedes-Benz's drive system strategy[58].

3. 2. 3. Hyundai Motor Company

In January 2018, Hyundai unveiled the new Nexo FCEV at the 2018 Consumer Electronics Show (CES). In June 2018, it also announced a patent cross-licensing agreement for FC development with Audi. Hyundai has also announced a tie-up with H_2 Energy AG in Switzerland to introduce 1,000 FC trucks on the Swiss market between 2019 and 2023[59].

3. 2. 4. GM

At the FC Expo 2019, GM pushed its FCEV credentials by announcing the establishment of a joint venture with Honda. Through this agreement, GM and Honda are aiming to speed up development by a 24-hour approach taking advantage of their development facilities throughout the world[60].

3. 3. Trends in Standardization

This section describes the particular standardization trends related to FCEVs. With regard to SAE J2572 (Recommended Practice for Measuring Fuel Consumption and Range of Fuel Cell and Hybrid Fuel Cell Vehicles Fueled by Compressed Gaseous Hydrogen), the February 2019 meeting of the SAE received a proposal about the measurement of fuel consumption in heavy-duty vehicles from Nikola Motor, a company regarded as the Tesla of the truck world. Work is under way to revise ISO/FDIS 17268 (Gaseous Hydrogen Land Vehicle Refueling Connection Devices) after the issuance of an IS to add specifications for a 70 MPa high-flow (HF) connector for heavy-duty vehicles (FC buses). With regard to ISO/FDIS 14687 (Hydrogen Fuel Quality) and ISO/FDIS 19880-8 (Gaseous Hydrogen- Fueling Stations - Part 8: Fuel Quality Control) issues are being identified for the next revision for the purpose of cost reduction (by, for example, narrowing down materials to be controlled to help lower analysis costs and the like).

4 Traction Motors

4. 1. Introduction

This section describes the recent trends in the field of electric motors installed in electrified vehicles, as well as the trends related to motor research and development.

4. 2. Electric Motors

Table 4 shows the main electric traction motors installed in passenger vehicles that were either newly launched in Japan or completely redesigned from January to December, 2018[61]-[66]. In 2018, new or completely redesigned PHEVs were launched by Honda (the Clarity PHEV) and Mitsubishi (the Outlander PHEV). Virtually all the motors in these models are alternating current (AC) synchronous motors.

Automotive motors are required to operate over a wide range, from low-speed high-torque conditions to high-speed, low-torque conditions. Therefore, research and development is being carried out into pole changing and winding switching methods[67]. In addition, as countermeasures for cost and material distribution concerns with permanent magnet motors, research and development and proceeding into rare-earth-free motors. However, to address issues that cause reductions in torque, the direction of research and development efforts is likely to change toward increasing motor speeds and combining motors with reduction gears[67].

Recently, there has been a pick up in research and development into electrification technologies for aircraft. One example was the establishment of an aircraft electrification consortium[68] under the auspices of the Japan Aerospace Exploration Agency (JAXA). The development of automotive electrification technologies is making a major contribution to the electrification of aircraft. Technologies to increase the power density of motors are extremely important for this field. Although the target power/weight density of motors for aircraft and vehicles differs, the introduction of advanced technologies, such as magnetic circuits using Halbach arrays, is being actively tested[69]. In the future, there are strong expectations for the mutual development of motor technologies for vehicles and aircraft.

Table 4 Main Electric Motors Equipped on Electric Passenger Vehicles[(61)-(66)]

Manufacturer	Designation	Type	Max. output (kW)	Max. torque (Nm)	System	Main vehicles equipped with this motor
Toyota	1KM	AC synchronous motor	105	300	HEV	Crown 2.5 L Hybrid
			165	300		Century
	1NM		53	163		Corolla Sport Hybrid
	2NM		132	300		Crown 3.5 L Hybrid
	3NM		88	202		ES300h
			80	202		UX250h (front)
	1MM	AC induction motor	5	55		UX250h (rear)
Honda	H4	AC synchronous motor	96	267		Insight
			135	315		CR-V 2.0 L
			135	315	PHEV	Clarity PHEV
Subaru	MA1		10	65	HEV	Forester Advance
Mitsubishi	S61		60	137	PHEV	Outlander PHEV (front)
	Y61		70	195		Outlander PHEV (rear)
Mercedes-Benz Japan	EM0014		16	250	HEV	CLS 450 4MATIC Sports
Jaguar Land Rover Japan	TZ-204	—	294	696	EV	I-Pace

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