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 approach to 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, has also increased. This section describes the recent trends seen in HEVs and PHEVs.

1. 2. Popularization of HEVs in Japan

Figure 1 shows that the number of HEVs and PHEVs on the roads in Japan is increasing year after year. In 2016 the number of HEVs (passenger vehicles) on the road in Japan, not including mini-vehicles, increased by nearly 970,000 vehicles compared to the previous year to reach approximately 6.5 million vehicles (16% of the total number of passenger vehicles (approximately 39.49 million)). The number of PHEV (passenger vehicles) on the road in Japan has also continued to increase since 2011, and had reached approximately 70,000 vehicles in 2016. In addition, the number of HEV (mini-vehicles) on the road in Japan has nearly doubled, standing at approximately 4.72 million vehicles in 2016.

1. 3. New HEVs Launched in Japan in 2017

Table 1 lists the HEVs and PHEVs launched in Japan in 2017 according to the date they went on sale. The main trends were as follows.

In January, Toyota Motor Corporation released the Vitz hybrid which combines a 1.5-liter engine with a reduction gear-equipped Toyota Hybrid System II (THS II) [2]. In the same month Mitsubishi Motors also released its Delica D:2 (OEM supply provided by Suzuki Motor Corporation)[3].

In February, Suzuki Motor Corporation released its Wagon R and Wagon R Stingray models with a hybrid system in which an electric generator with a motor function (ISG) generates electric power from deceleration energy and then uses this to assist the engine during acceleration[4]. The same month, BMW released its 530e iPerformance, and Toyota released its Prius PHV. The hybrid system in the BMW 530e iPerformance pairs the engine with an 8-speed automatic transmission integrated with an electric motor, offering a cruising range of 52.2 km (JC08) using only external electric power as its energy source (converted EV running distance), and a hybrid fuel economy of 17.4 km/L (JC08)[5]. Figure 2 shows the Dual Motor Drive System of the Prius PHV, which enables the electricity-producing motor (generator) to provide drive to the wheels in combination with the dedicated drive motor, providing more powerful acceleration. In addition, the installation of large capacity lithium-ion batteries and a more efficient plug-in-hybrid system give the vehicle a converted EV running distance of 68.2 km (JC08) and a hybrid fuel economy of 37.2 km/L (JC08)[2].

In March, Lexus released the LC500h which is equipped with a multi-stage hybrid system that arranges the transmission mechanism in series with the Lexus hy-

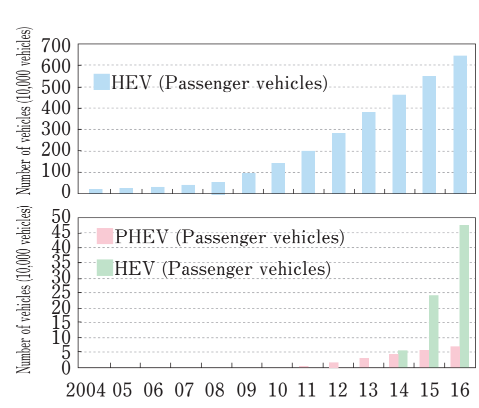

Fig. 1 Trends in the Number of HEVs and PHEVs on the Road in Japan[1]

Table 1 Main Hybrid Electric Vehicles Launched in Japan in 2017[(2)-(14)]

Date announced/went on sale		2017/1/12	2017/1/26	2017/2/1	2017/2/11	2017/2/15
Name of company		Toyota	Mitsubishi Motors	Suzuki	BMW	Toyota
Name		Vitz	Delica D:2	Wagon R / Wagon R Stingray	BMW 530e iPerformance	Prius PHV
Type of hybrid system		Series-parallel (HEV)	Parallel (HEV)	Parallel (HEV)	Series-parallel (PHEV)	Series-parallel (PHEV)
Drivetrain		Front-wheel drive	Front-wheel drive	Front-wheel drive / Four-wheel drive	Rear-wheel drive	Front-wheel drive
Fuel economy (JC08 test cycle, km/L)		34.4	32.0	33.4	17.4	37.2
Engine	Designation	1 NZ-FXE	K12C	R06A	B48B20A	2ZR-FXE
	Displacement (cc)	1 ,496	1 ,242	658	1 ,998	1 ,797
	Output (kW)	54	67	47	135	72
Motor	Type	AC synchronous motor	AC synchronous motor	DC synchronous motor	AC synchronous motor	AC synchronous motor
	Output (kW)	45	10	2.3	55	53
Battery	Type	Nickel-metal hydride	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Capacity (kWh)	—	—	—	9.2	8.8

Date announced/went on sale		2017/3/16	2017/6/8	2017/6/19	2017/6/30	2017/7/7
Name of company		Lexus	Nissan	Toyota	Honda	Honda
Name		LC500h	X-Trail	Aqua	Fit	Grace
Type of hybrid system		Series-parallel (HEV)	Parallel (HEV)	Series-parallel (HEV)	Series-parallel (HEV)	Series-parallel (HEV)
Drivetrain		Rear-wheel drive	Front-wheel drive / Four-wheel drive	Front-wheel drive	Front-wheel drive / Four-wheel drive	Front-wheel drive / Four-wheel drive
Fuel economy (JC08 test cycle, km/L)		15.8	20.8	34.4	37.2	34.8
Engine	Designation	8 GR-FXS	MR20DD	1NZ-FXE	LEB	LEB
	Displacement (cc)	3 ,456	1 ,997	1 ,496	1 ,496	1 ,496
	Output (kW)	220	108	54	81	81
Motor	Type	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor
	Output (kW)	132	30	45	22	22
Battery	Type	Lithium-ion	Lithium-ion	Nickel-metal hydride	Lithium-ion	Lithium-ion
	Capacity (kWh)	—	—	—	—	—

Date announced/went on sale		2017/7/10	2017/7/10	2017/7/10	2017/7/12	2017/8/24
Name of company		Toyota	Daihatsu	Mini	Suzuki	Mercedes-Benz
Name		Camry	Altis	Mini Cooper S E Countryman All4	Swift	E 350 e Avantgarde Sports
Type of hybrid system		Series-parallel (HEV)	Series-parallel (HEV)	Series-parallel (PHEV)	Parallel (HEV)	Series-parallel (HEV)
Drivetrain		Front-wheel drive	Front-wheel drive	Four-wheel drive	Front-wheel drive / Four-wheel drive	Rear-wheel drive
Fuel economy (JC08 test cycle, km/L)		33.4	28.4	17.3	32.0	15.7
Engine	Designation	A25 A-FXS	A25A-FXS	B38A15A-P160	K12C	274
	Displacement (cc)	2 ,487	2 ,487	1 ,498	1 ,242	1 ,991
	Output (kW)	131	131	100	67	155
Motor	Type	AC synchronous motor	AC synchronous motor	AC synchronous motor	DC synchronous motor / AC synchronous motor	AC synchronous motor
	Output (kW)	88	88	65	2.3/10	65
Battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Capacity (kWh)	—	—	7.6	—	6.28

Table 1 Main Hybrid Electric Vehicles Launched in Japan in 2017[2]-[14] (Cont.)

Date announced/went on sale		2017/9/15	2017/9/29	2017/10/11	2017/10/16	2017/10/19
Name of company		Honda	Honda	Toyota	Volvo	Lexus
Name		Shuttle	Stepwgn Spada	Corolla Fielder Corolla Axio	XC90 T8 Twin Engine AWD Inscription	LS500h
Type of hybrid system		Parallel (HEV)	Series-parallel (HEV)	Series-parallel	Series-parallel (PHEV)	Series-parallel (PHEV)
Drivetrain		Front-wheel drive / Four-wheel drive	Front-wheel drive	Front-wheel drive	Four-wheel drive	Rear-wheel drive
Fuel economy (JC08 test cycle, km/L)		27.2	25.0	34.4	15.7	15.8
Engine	Designation	LEB	LFA	1NZ-FXE	B420	8GR-FXS
	Displacement (cc)	1,496	1,993	1,496	1,968	3,456
	Output (kW)	81	107	54	233	220
Motor	Type	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor
	Output (kW)	22	135	45	22 (Front) / 28 (Rear)	132
Battery	Type	Lithium-ion	Lithium-ion	Nickel-metal hydride	Lithium-ion	Lithium-ion
	Capacity (kWh)	—	—	—	—	—

Date announced/went on sale		2017/10/19	2017/11/1	2017/12/14	2017/12/25
Name of company		Volkswagen	Hino Motors, Ltd.	Suzuki	Suzuki
Name		Golf GTE	Dutro Hybrid	Spacia / Spacia Custom	XBee
Type of hybrid system		Series-parallel (PHEV)	Parallel	Parallel	Parallel
Drivetrain		Front-wheel drive	Rear-wheel drive	Front-wheel drive / Four-wheel drive	Front-wheel drive / Four-wheel drive
Fuel economy (JC08 test cycle, km/L)		19.9	13.2 (JE05)	30.0	22.0
Engine	Designation	CUK	N04C-UL	R06A	K10C
	Displacement (cc)	1,394	4,009	658	996
	Output (kW)	110	110	38	73
Motor	Type	AC synchronous motor	AC synchronous motor	DC synchronous motor	DC synchronous motor
	Output (kW)	80	36	2.3	2.3
Battery	Type	Lithium-ion	Nickel-metal hydride	Lithium-ion	Lithium-ion
	Capacity (kWh)	8.7	—	—	—

brid system consisting of a V6 engine and two electric motors[6].

In June, the X-Trail from Nissan Motor Co., Ltd. went on sale. This model features various aerodynamic improvements to the previous model, as well as improved control functions that increase the amount of electric power regeneration when the accelerator is not depressed, that improve fuel economy by 0.2 km/L[7]. In the same month, Toyota also released the Aqua and Honda Motor Company released the Fit. Improvements to the engine and an overhaul of the hybrid system controls of the previous model gave the Aqua an improvement in fuel economy of 1.0 km/L[2]. This newer version of the Fit improves fuel economy by 0.8 km/L over the previous model[8].

In July, Honda released the Grace, which features the SPORT HYBRID Intelligent Dual Clutch Drive (i-DCD) hybrid system that combines a 1.5-liter direct injection engine with a 7-speed dual clutch transmission (DCT) and an electric motor. Fuel economy improved by 0.4 km/L compared to the previous model[8]. The same month also saw several other vehicle releases, including the Camry from Toyota, the Altis from Daihatsu Motor Co., Ltd. (OEM supply provided by Toyota)[9], the Mini Cooper S E Countryman All4 from Mini, and the Swift from Suzuki. The Camry is equipped with a combination of the Toyota hybrid system (THS II) and the new TNGA engine called the Dynamic Force Engine 2.5, which achieves both a maximum thermal efficiency of 41% and high power output, which improved fuel econo-

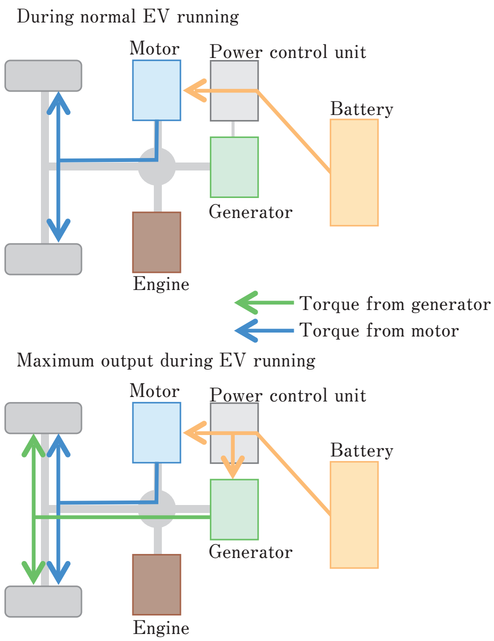

Fig. 2 Dual Motor Drive System[2]

my by 10.0 km/L over the previous model[2]. In the Mini Cooper S E Crossover All4, the front wheels are driven by the engine, while the rear wheels are driven by the electric motor. Front-, rear-, or four-wheel drive are available based on the driver's selection or driving conditions (same system as in the BMW 225xe Active Tourer). The converted EV running distance is 42.4 km (JC08) and the hybrid fuel economy is 17.3 km/L (JC08)[10]. The Swift offers two different types of parallel hybrid systems. One is a mild hybrid equipped with an ISG, while the other combines a drive motor that can also generate electricity (MGU) with an auto gear shift transmission (AGS)[4].

In August, the E 350 e Avantgarde Sports was released by Mercedes-Benz. It has a converted EV running distance of 20.1 km (JC08) and a hybrid fuel economy of 15.7 km/L (JC08)[11].

In September, Honda released both the Shuttle and the Stepwgn Spada. There were no changes to the hybrid system of the Shuttle, but system tuning and other tweaks improved the fuel economy by 0.4 km/L compared to the previous model[8]. The Stepwgn Spada is equipped with the Intelligent Multi-mode Drive (i-MMD) hybrid system that contains a generator and a drive motor and offers three different driving modes: EV running mode, hybrid running mode (the engine is used only to generate electricity), and engine running mode[8].

In October, Toyota released both the Corolla Fielder and the Corolla Axio. The improved controls of the motors and engines in these vehicles resulted in a fuel economy improvement of 0.6 km/L compared to the previous models[2]. The same month also saw the release of the XC60 Twin Engine AWD Inscription from Volvo, the LS500h from Lexus, and the Golf GTE from Volkswagen. In the XC60 Twin Engine AWD Inscription, the front wheels are driven by the engine and an electric motor, while the rear wheels are driven solely by another motor making this a four-wheel drive vehicle. However, EV running mode the vehicle switches to just rear-wheel drive. The converted EV running distance is 45.4 km (JC08) and the hybrid fuel economy is 15.7 km/L (JC08) [12]. The LS500h is equipped with a multi-stage hybrid system that combines a V6 3.5-liter engine and an electric drive motor with an automatic transmission mechanism[6]. In the Golf GTE, the hybrid system is composed of an electric motor placed between the 1.4-liter TSI engine and the six-speed direct shift gearbox (DSG), which have been integrated into a single unit. The converted EV running distance is 45.0 km (JC08) and the hybrid fuel economy is 19.9 km/L (JC08)[13].

In November, Hino Motors, Ltd. released the Dutro Hybrid truck (wide cab model). The previous 5-speed AMT transmission was replaced with a new 6-speed AMT and other improvements to the controls of the hybrid system improved fuel economy from the previous 12.2 km/L to 13.2 km/L[14].

In December Suzuki released the Spacia, Spacia Custom, and XBee, which are all equipped with a hybrid system that uses the ISG to generate electric power from the energy produced during deceleration and applies that power to assisting the engine during acceleration[4].

1. 4. Trends in Standardization

The trends in standardization that concern hybrid vehicles will be presented in Section 2.5 along with the trends in electric vehicles (EVs).

2 Electric Vehicles

2. 1. Introduction

Electric vehicles (both EVs and BEVs), which run exclusively on externally-supplied electricity stored in the on-board batteries rather than using an engine for power generation or being equipped with fuel cells, are attracting attention as environmentally-friendly vehicles because they do not emit harmful substances while being driven and also do not produce much running noise. The

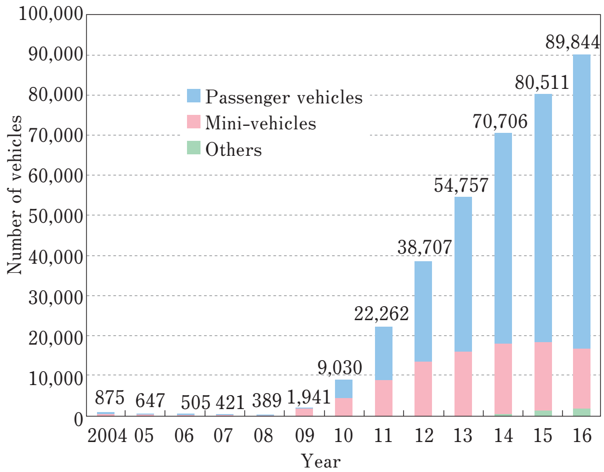

Fig. 3 Change in Number of EVs Owned (at end of each fiscal year)[15]

first mass-produced EV, the Mitsubishi Motors i-MiEV, was equipped with a lithium-ion battery and mainly sold to corporate customers in 2009. Despite increasing steadily since then, the number of EVs owned in Japan had still not reached 100,000 vehicles (less than 0.2% of all vehicles owned in Japan) by the end of 2016[15], reflecting the insufficient popularity of such vehicles. Reasons for this state of affairs include EV performance problem such as the long battery charging times and the short cruising range on a single electrical charge, as well as infrastructure problems such as the lack of charging facilities at existing apartment complexes. However, efforts to help boost the popularity of EVs include subsidies offered by the Japanese government and some municipal governments for the purchase of EVs and battery chargers as a complement to steady improvements in EV performance achieved through higher on-board battery capacity and lower electricity costs, and initiatives such as new charging standards that allow for higher voltage outputs to shorten the charging time. This section describes the current state of EV use in Japan, as well as the 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[15]. The number of EVs owned in Japan had continuously decreased until 2008, remaining below 1,000 vehicles. However, since the release of the i-MiEV by Mitsubishi Motors in 2009 and of the Leaf by Nissan Motor Co., Ltd. in 2010, the number of EVs on the roads in Japan has increased every year, reaching 89,844 vehicles at the end of 2016. Table 2 shows the specifications of the main EVs sold by automobile manufacturers in Japan in 2017[16-21]. In 2017 the Nissan Leaf was completely redesigned, receiving an increase in battery capacity that extended its cruising range on a single charge to 400 km (in the JC08 fuel economy test). The Volkswagen e-Golf also went on sale in Japan for the first time. It is equipped with a 35.8 kWh battery and achieved a cruising range on a single battery charge of 301 km (in the JC08 fuel economy test).

2. 2. 2. Initiatives to Promote EV Popularization

In June 2017 the Cabinet Office of the Japanese government approved the Investments for the Future Strategy 2017[22]. One of the key performance indicators (KPI, a means of evaluating the degree of achievement of corporate objectives) cited in this strategy was aiming to have next-generation vehicles account for 50% to 70% of all new passenger car sales in Japan in 2030 (with an auxiliary indicator of achieving 100,000 EVs and PHEVs on the road in Japan by 2020). In addition, the Ministry of Economy Trade and Industry (METI) is allocating money to subsidize the cost of measures to promote the adoption of clean-energy vehicles and the development of the required EV and PHEV charging infrastructure in an effort to support the purchase of EVs as well as the installation of charging infrastructure at housing complexes, lodging facilities and similar locations[23][24]. Through programs that integrate the introduction of environmentally friendly vehicles and greener local transportation to make such next-generation vehicles and green transportation more widespread, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is working in concert with regional government plans to support projects focused on the concentrated introduction of environmentally friendly vehicles and replacement of older models.

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. Development of Vehicles and Batteries

In February 2017, Honda and Hitachi Automotive Systems, Ltd. established a joint venture company called, Hitachi Automotive Electric Motor Systems, Ltd. to devel-

Table 2 Specifications of Main EVs Sold in Japan in 2017[(16)-(21)]

Manufacturers		Nissan	Nissan	Nissan	Mitsubishi Motors Co., Ltd.	Mitsubishi Motors Co., Ltd.
Name		Leaf (ZE0 model)	Leaf (ZE1 model)	e-NV200	i-MiEV M/X	Minicab-MiEV Van
Length × width × height [mm]		4,445 × 1,770 × 1,550	4,480 × 1,790 × 1,540	4,560 × 1,755 × 1,855/1,850	3,395 × 1,475 × 1,610	3,395 × 1,475 × 1,915/1,810
Passenger capacity		5	5	Van: 2/5 Wagon: 5/7	4	04-2
AC power consumption rate [Wh/km]*1		114/117	120	142	110	125
Cruising range on a single charge (km)		228/280*1, 3	400*1	Van: 190/188*1, 3 Wagon: 188/185*1, 3	120/180*1, 3	100/150*1, 3
Drive battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total voltage [V]	360	350	360	270/330*3	270/330*3
	Total amount of power [kWh]	24/30	40	24	10.5/16*3	10.5/16*3
Motor	Rated output (kW)	70	85	70	30	25
	Max. output [kW]	80	110	80	30/47	30
	Max. torque [Nm]	254	320	254	160	160
Charging time	Normal (h)	Approx. 8 / Approx. 11 (200V)*3	Approx. 16 (200V)*3	Approx. 8 (200V)	Approx. 4.5 / Approx. 7 (200V)*3	Approx. 4.5 / Approx. 7 (200V)*3
	Fast [min]	Approx. 30 (80%)	Approx. 40 (80%)	Approx. 30 (80%)	Approx. 15 (80%) / Approx. 30 (80%)	Approx. 15 (80%) / Approx. 35 (80%)

Manufacturers		Mitsubishi Motors Co., Ltd.	BMW	Volkswagen	Tesla	Tesla
Name		Minicab-MiEV Truck	i3	e-Golf	Model S	Model X
Length × width × height [mm]		3,395 × 1,475 × 1,820	4,010 × 1,775 × 1,550	4,265 × 1,800 × 1,480	4,979 × 1,950 × 1,453	5,037 × 2,070 × 1,680
Passenger capacity		2	4	5	5	5/7
AC power consumption rate [Wh/km]*1		120	98	124	—	—
Cruising range on a single charge (km)		110*1	229/390*1, 3	301*1	408/490/557/613*2, 3	417/489/565*2, 3
Drive battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total voltage [V]	270	393.6/398.4	323	—	—
	Total amount of power [kWh]	10.5	21.8/33.1	35.8	60/75/90/100*3	75/90/100*3
Motor	Rated output (kW)	25	75	100	—	—
	Max. output [kW]	30	125	100	235	245
	Max. torque [Nm]	196	250	290	440	525
Charging time	Normal (h)	Approx. 4.5 (200 V)	Approx. 8 (200 V)	Approx. 12 (200 V)*3	—	—
	Fast [min]	Approx. 15 (80%)	Approx. 45 (80%)	Approx. 35 (80%)	—	—

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

op, manufacture, and sell motors for electric vehicles, as well as to help accelerate the adoption and popularization of electric-powered vehicles[(26)]. In addition, in September 2017, Toyota, Mazda Motor Corporation, and Denso signed a joint development agreement and established a new company called, EV C.A. Spirit, Co., Ltd. to develop basic structural technologies and a common architecture for electric vehicles[(27)]. In October 2017, Nissan launched the second generation of the Leaf. Motor performance was improved (maximum output of 150 ps and maximum torque of 320 Nm) and battery capacity was increased (40 kWh) in comparison to the previous model[(28)]. The adoption of one-pedal driving (a function that automatically engages the brakes when the accelerator is completely released and keep the car stopped) improved both driving performance and the cruising range on a single charge.

Under the auspices of a New Energy and Industrial Technology Development Organization (NEDO) project to develop advanced technologies for the application and practical use of lithium-ion batteries carried out between 2012 and 2017, companies such as Hitachi, Toshiba Infrastructure Systems, NEC, Nissan, and Toyota worked to develop next-generation batteries for electric vehicles[(29)]. This project resulted in the development a high-capacity silicon-based negative electrode and a high-capacity Fe-Mn-based positive electrode, as well as a lithium-ion battery exceeding 300 Wh/kg. In December 2017, Toyota

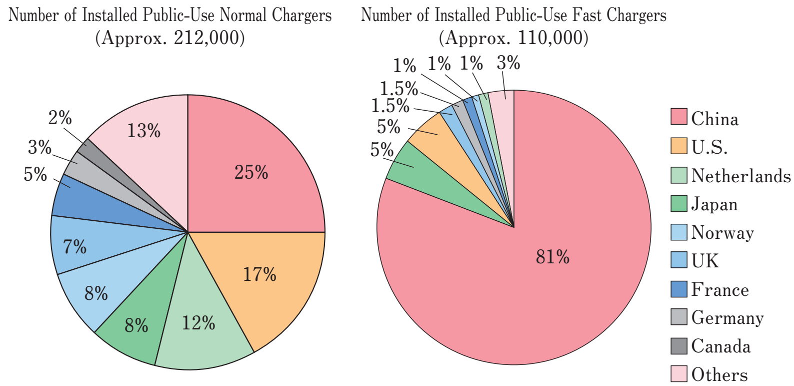

Fig. 4 Percentage of the Total Number of Normal and Fast Chargers in the World as of 2016 by Country (Aggregate values from IEA. A normal charger is defined as having AC 22 kW or less, a fast charger includes both AC 43 kW chargers and DC chargers)(35)

and Panasonic announced the launch of a study on forming an automotive battery partnership, and are jointly pursuing further advances in lithium-ion batteries(30). The aforementioned Investments for the Future Strategy 2017 proposes popularizing EVs by accelerating the development and commercialization of high performance solid-state lithium-ion batteries for automobiles that surpass current liquid-electrolyte lithium-ion batteries in terms of aspects such as safety. To this end, METI has implemented a project to develop the basic technologies to commercialize innovative batteries in an effort to advance the development of new batteries that would combine high energy density with robust durability and safety, and replace lithium-ion batteries(31).

2. 3. 2. Demonstration Projects

In July 2017 the Tokyo Metropolis announced it would conduct an electric vehicle popularization model project in the Tokyo Islands to promote economic development in the small chain of islands(32). The advantages of introducing electric vehicles to those islands are being clarified, and effective ways of using them are being validated.

Nissan, NEC, and Daikyo Astage, Inc. announced the launch of a demonstration project to install EV chargers in already sold condominiums in August 2017(33). This project will construct a new plan for installing EV charging stations at large condominiums in Tokyo to address one of the major hurdles to the popularization of EVs, and verify its feasibility by implementing it in the Tokyo metropolitan area.

In October 2017, Mitsubishi announced the implementation of a vehicle to grid (V2G) pilot project in the Dutch market with the help of two local companies, NewMotion and TenneT. This demonstration project will use V2G technology and vehicle-mounted batteries to help balance peak demand on the electric grid and stabilize the system(34). The companies intend to demonstrate that connecting parked electric vehicles and homes to each other and the electric grid via a bi-directional charger can compensate for unexpected power outages and make adjustments to the electrical power frequency.

There are also numerous other efforts underway 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 for EVs in and outside Japan, and then presents the trends in the development of wireless charging and higher output chargers.

2. 4. 1. State of Charger Installation

The total number of normal and fast charging stations for public use installed around the world by 2016 is estimated at 320,000 units(35). Figure 4 shows the cumulative number of normal and fast chargers installed in various countries. A breakdown of the normal chargers reveals that China has the most, followed by the U.S., the Netherlands, Japan, and Norway. Similarly, China also has the highest number of fast chargers installed, followed by Japan, the U.S., the U.K., and Germany. These rankings for normal and fast chargers by country follow the same trend as in 2016. China accounts for 81% of installed fast chargers in the world, an overwhelming number explained by the rapid increase in the number of EV buses in use(35). China has formulated development roadmap and specific installation targets for regional and location-specific charging infrastructure and is marshalling its re-

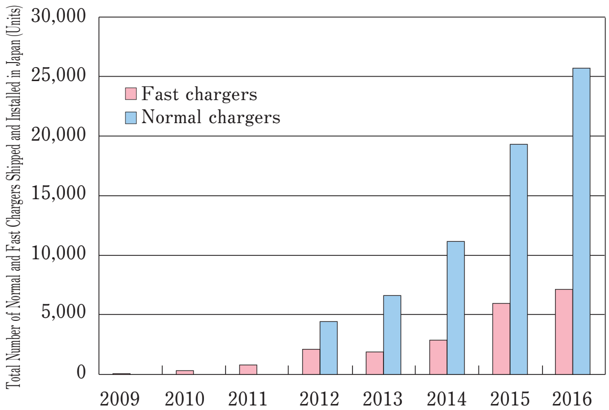

Fig. 5 Total Number of Normal and Fast Chargers Shipped and Installed in Japan up to 2016[37][38] (Number of normal chargers is the number shipped, number of fast chargers is the estimated number installed based on the number of installation locations)

sources to establish an electric vehicle charging infrastructure that will be support the charging of 5 million electric vehicles by 2020[36].

Figure 5 shows the total number of normal and fast chargers shipped and installed in Japan[37][38]. The number of installed normal chargers has continued to increase since 2012, the first year for which there is statistical data. In 2016 the number of new normal charger installations increased by 130% compared to the previous year, and the total number now exceeds 25,000 units. At the same time, the number of fast chargers is also increasing. In 2016 the total number of fast chargers was 7,200 units, an increase of 120% compared to the previous year, but also the lowest rate of increase recorded until now. The number of installed fast chargers is sufficient for large cities such as Tokyo and Osaka, as well as for Okinawa, but in other areas a trial calculation showed that the number is still insufficient to prevent that the electricity of EVs run out. According to the trial calculation, in a scenario based on sales of EVs and PHEVs accounting for 15% of new vehicle sales (the value forecast for 2020), it would be necessary to increase the total number of fast chargers to around 40,000 units to keep the waiting time for an open charger down to 15 minutes or less.

Currently, it is estimated that 90% or more of EV and PHEV users in Japan are residents of a single-family, stand alone house, which is why the installation of chargers at condominiums and apartment buildings has been raised as a critical issue in further expanding charging infrastructure[36]. Moving forward, it will be necessary not only to set up rules and systems concerning the installation of chargers at shared residences and reduce costs through subsidies, but also to address issues such as the reduction of running costs.

2. 4. 2. Increasing Fast Charger Output

In March 2017, the CHAdeMO Association issued version 1.2 the CHAdeMO specifications, which raise the maximum output of the fast chargers to 150 kW[40]. At the same time, the sale of a 100 kW or more high-output fast charger in Japan was also announced. Shindengen Electric Manufacturing Co., Ltd. began receiving orders for 120 kW fast chargers in April of 2017[41]. In addition, the media reported that Signet EV Inc. of South Korea will partner with Marubeni Corporation of Japan to sell 100 kW fast chargers[42].

Similarly, the Combined Charging System (CCS), a standardized charging environment, is scheduled for an update between 2018 and 2019 that will make it compatible with high-output fast chargers and increase output from 150 kW to 350 kW[43].

2. 4. 3. Inductive Charging

Japan carried out the structured implementation of a wireless charging system for EVs and PHEVs to enable inductive charging of parked vehicles in 2016, stipulating charging conditions such as the usage frequency (85 kHz band) and the maximum transmission power (7.7 kW)[44]. The commercialization of inductive charging is anticipated to begin sometime around 2020, as described in documents such as the roadmap formulated by the Japanese Ministry of Internal Affairs and Communications (MIC)[45].

International standardization of the inductive charging of parked vehicles has been discussed in SAE J2945, ISO 19363, and ISC 61980, and all of these standards are scheduled to be published between 2018 and 2019[46]. In addition, technical studies are underway in the context of the EU conducted project STILLE (2016 to 2018), which aims to design an interoperable interface for inductive charging systems covering functions such as power transfer, positioning, and communication[47].

Inductive charging of vehicles in motion is also subject to active research and development, especially outside Japan. The EU FABRIC project is researching on-road charging at a test site built in France in which embedded inductive charging technology has been installed[48]. In the U.S., SELECT is also conducting a project to research the inductive charging of moving vehicles[49]. The feasibility of inductive charging while driving is also being studied by Highways England[50], the government-owned company charged with operating England's motorways[51].

2. 5. Trends in Standardization

The standardization of electric vehicles (EVs), of both hybrid electric vehicles that can and cannot be connected to an external power supply or not (PHEVs and HEVs), and of fuel cell vehicles (FCVs) is carried out by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC).

International standards for the whole vehicle, the electric propulsion system, and parts are formulated by the ISO. They include the ISO 6469 series (Safety), ISO 8714 (Reference energy consumption and range), the ISO 23274 series (Exhaust emissions and fuel consumption measurements), ISO 23828 (Energy consumption measurement - Vehicles fuelled with compressed hydrogen), ISO 20762 (Determination of power for propulsion of hybrid electric vehicle: work in progress), and the ISO 21782 series (Test specifications for electric propulsion components: work in progress).

The main standards for the batteries that provide the drive power to the wheels in an EV are being determined by the IEC 62660 series concerning lithium-ion battery cells (Part 1: Performance testing, Part 2: Reliability and abuse testing, Part 3: Safety requirements, and Part 4: Candidate alternative test methods for the internal short circuit test of IEC 62660-3), as well as the ISO standards concerning lithium-ion battery packs and systems, such as ISO 12405-4 (Performance testing), ISO 19453-6 (Environmental conditions and testing for electrical and electronic equipment for drive system of electric propulsion vehicles), and ISO 6469-1 (Safety specifications - Part 1: On-board rechargeable energy storage system (RESS)).

The main standards being formulated and maintained with respect to vehicle battery charging include the IEC 61851 series, which covers conductive charging systems and the IEC 62196 series, which covers accessories such as connectors. In addition, ISO 17409 covers the electric safety requirements for the vehicle, while inductive charging systems are covered by the IEC 61980 series (Electric vehicle wireless power transfer (WPT) systems - Part 1: General requirements) and ISO 19363 (Magnetic field wireless power transfer). Also, the ISO 15118 series (Vehicle to grid communication interface) and the IEC 63110 series (Protocol for management of EV charging and discharging infrastructures) cover communications and the smart grid.

3 Fuel Cell Electric Vehicles

3. 1. Introduction

According to the results of the 2018 KPMG global automobile industry survey[52] sent to 907 executive level managers at 43 major automobile companies around the world, the most important trends in the worldwide automobile industry up to 2025 will be fuel cell vehicles (52%), closely followed by connected vehicles (50%) and electric vehicles (49%). Fuel cell vehicles came in third behind electric vehicles and connected vehicles in the responses to this same survey in 2017, but are clearly garnering more attention.

In Japan, the Strategic Road Map for Hydrogen and Fuel Cells (revised On March 22, 2016)[53] released by METI sets targets of about 40,000 vehicles by 2020, about 200,000 vehicles by 2025, and about 800,000 vehicles by 2030 for the dissemination of FCVs. Similarly, targets for the establishment of hydrogen refueling stations have also been set to approximately 160 stations by 2020 and 320 stations by 2025.

3. 2. Establishment of Organizations to Promote a Hydrogen-Based Society

In January 2017, the Hydrogen Council[54] was established as the world's first global hydrogen initiative. It is composed of a group of leading companies within the energy, transport, and manufacturing industries. Although it initially had 13 members, this number had doubled after one year.

In December 2017 eleven Japanese companies, including Toyota and JXTG Nippon Oil & Energy Corporation, announced the formation of a joint venture to establish a new hydrogen fuel filling station company[55] called Japan H2 Mobility, LLC (JHyM for short). JHyM plans to use joint investments to strategically accelerate the deployment of hydrogen filling stations for FCVs, as well as work toward the standardization of related equipment in an aim to reduce construction and operating costs.

3. 3. Trends in FCV Development

This section introduces new information concerning FCVs that announced in 2017 or later.

3. 3. 1. Toyota Motor Corporation

Toyota and Seven-Eleven Japan Co., Ltd. have started a joint project to introduce fuel cell trucks and fuel cell electric generators to their stores in 2019, and hydrogen refueling stations built next to convenience stores have already opened at three locations in Japan[56]. California started a demonstration project involving heavy-duty commercial trucks running on fuel cells (FC) the summer of 2017 to address air pollution at ports as well as to validate the applicability of FC technology to heavy-duty commercial vehicles[56]. The Mirai is equipped with two FC stacks and a 12 kWh battery providing drive to the wheels, and has a cruising range of approximately 320 km.

It first went on sale in 2014, and about 4,500 vehicles had been sold in Japan, the U.S., and Europe by October 2017. Production will increase gradually with a target of over 10,000 vehicles a year in and after 2020[56].

3. 3. 2. Mercedes-Benz

In September 2017, Mercedes-Benz announced the GLC F-Cell EQ Power, an externally rechargeable fuel cell vehicle. The vehicle makes it possible to use the more widely available EV recharging infrastructure while hydrogen refueling stations are trying to catch up. This vehicle's specifications have changed greatly from the predecessor B-Class F-Cell, and the sandwich floor used since the original F-Cell has been replaced with a structure that places the main systems beneath the hood[57].

3. 3. 3. Hyundai Motor Company

In January 2018, Hyundai announced a new model FCV called the Nexo at CES 2018. The Nexo is said to possess 60% system efficiency, a cruising range of 800 km (NEDC), and a durability of 160,000 km or 10 years. While shape of the fuel cell stack separator differs from that in the Toyota Mirai, it also has a three-dimensional structure. Cost has been reduced to creative approaches such as giving all three hydrogen fuel storage containers the same shape and using many of the same parts as in internal combustion engine vehicles[58].

3. 4. Challenges of Expanding the Hydrogen Filling Station Infrastructure

The goal of independent development of new hydrogen refueling station businesses from the latter half of the 2020s and onward set in the Japanese government strategic roadmap makes the reduction of costs associated with such stations a critical issue. Since about 60% of the total construction cost is taken up by the cost of equipment, prospects to essentially halve those costs are being initiated. Addressing the remaining 40% of the overall construction cost will require revising current regulations and cutting down on excessive design. Modularizing the facility design, standardizing the interfaces for pipe and control signals, optimizing the excessive charging protocols, and other measures are viewed as potential solutions to excessive design. Repair and maintenance costs account for about 60% of the total operating cost. Exposure to the harsh environment of 80 MPa of pressure and a temperature of − 40° C makes insufficient reliability and durability of fueling hoses and O-rings a particular concern. With labor costs accounting for about 30% of the total operating cost, the eventual management of multiple hydrogen stations by a single security supervisor and the establishment of self-service filling stations are expected to significantly reduce these labor costs[59].

3. 5. Deregulation

The report compiled at the 18th meeting of the Regulatory Reform Promotion Council held on May 23, 2017 included 37 specific regulatory reform items covering all industry demands. Among these, items expected to contribute to quicker adoption and popularization of hydrogen refueling station and FCVs, such as allowing security supervisor to monitor multiple stations at the same time, and the easing of safety inspection methods, are under examination[60].

4 Traction Motors

4. 1. Introduction

This section introduces the recent trends in the field of electric motors mounted on electric vehicles, as well as the attendant research and development trends.

4. 2. Electric Motors

Table 3 shows the main electric motors providing drive power to the wheels installed on passenger vehicles that were either newly released in Japan or subject to a complete redesign between January and December 2017[61)-(69].

Although DC synchronous motors were installed on some mild HEVs, other HEVs, as well as many of the PHEVs and EVs listed here, were equipped with AC synchronous motors. In 2017, the motor in the Nissan Leaf was redesigned and its power output was increased to 110 kW. Although it is the same type of motor as before the redesign, a new power module that boosts the motor drive current and improvements to the control technologies raised the overall power output[62], hinting at room for improvement with respect to inverters and control methods.

Another major topic in 2017 was the introduction of

Table 3 Main Electric Motors Equipped on Electric Passenger Vehicles[(61)-(69)]

Manufacturers	Designation	Type	Max. output [kW]	Max. torque (Nm)	System	Main vehicles equipped with this motor
Toyota	1LM	AC synchronous motor	45	169	HEV	Aqua G GR Sport
	1NM		37	163	PHEV	Prius PHV
	2NM		132	300	HEV	LC500 h, LS500 h
	3NM		88	202		Camry
	1SM		15.8	40	PHEV	Prius PHV
Nissan	EM57		110	320	EVs	Leaf
Daihatsu	3NM		88	202	HEV	Altis
Suzuki	PB05A		10	30		Swift Hybrid SL, SG
	WA05A	DC synchronous motor	2.3	50	Mild HEV	Wagon R Hybrid FZ, FX Spacia Hybrid X/G
BMW Group Japan	P160	AC synchronous motor	65	165	PHEV	Mini Cooper SE Country-man All4
	P251		83	250		530 e iPerformance
Volvo Car Japan	AD2		65	240		V90 , XC90
	T28		34	160		XC90
	T35		34	160		V90
Volkswagen Group Japan	EAZ		100	290	EVs	e-Golf
Mercedes-Benz Japan	EM0009		65	450	PHEV	E 350 e Avantgarde Sports
Porsche Japan	—	—	100	400		Panamera 4 E-Hybrid

EV trucks and FC buses into the market. Mitsubishi Fuso Truck and Bus Corporation began domestic production of its electric truck, the "e-Canter", and started to supply them to businesses such as home delivery companies[(70)(71)]. The electric motor in the e-Canter is an AC synchronous motor with a maximum output of 135 kW and a maximum torque of 390 Nm. Toyota also began to supply FC buses to the Tokyo Metropolis[(72)]. These FC buses are equipped with two AC synchronous motors with a maximum output and maximum torque per motor of 113 kW and 335 Nm, respectively.

In addition to downsizing, weight reduction, and the reduction of rare earth in permanent magnets, increasing the battery voltage and raising the voltage in the motors to improve their efficiency represent crucial areas of focus in the research and development of motors[(73)]. Motor design is also likely to have to pay greater attention to the influence of the inverter and peripheral circuits, both to reduce the surge voltage caused by inverter switching, and to raise the breakdown voltage of the motor.

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