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

1 Introduction

1. 1. Introduction

Automotive emissions are a cause of air pollution and the greenhouse gases in those emissions are a cause of global warming. With automotive emissions regulations becoming increasingly stringent in response to these issues, the reduction of emissions by improving fuel efficiency and the development of technology to clean up emissions have become urgent tasks. As one way of improving fuel efficiency, automakers have been developing hybrid electric vehicles (HEVs) that combine an internal combustion engine (ICE) with motors. The number of plug-in hybrid vehicles (PHEVs), which allow external charging of the on-board storage battery that powers the motors (i.e., the traction battery), is also increasing. This section describes the recent trends for HEVs and PHEVs.

1. 2. Popularization of HEVs in Japan

Figure 1 shows that the number of HEVs and PHEVs on the road in Japan is increasing year after year. In 2018 the number of passenger HEVs on the road in Japan, not including mini-vehicles, increased by nearly 920,000 vehicles from the previous year to reach approximately 8.33 million vehicles (21% of the total number of passenger vehicles (approximately 39.47 million)). The number of passenger PHEVs on the road in Japan has also continued to increase since 2011. In 2018, the number increased by 18,000 from the previous year, reaching approximately 120,000 vehicles. The number of mini hybrid vehicles on the road in Japan in 2018 increased by approximately 330,000 vehicles from the previous year, and now stands at approximately 1.1 million vehicles (4.9% of the total number of mini-vehicles (approximately 22.66 million))[2].

1. 3. New HEVs Launched in Japan in 2019

Table 1 lists the HEVs and PHEVs launched in Japan in 2019 according to the date sales began. The main trends were as follows.

In March, Audi launched the A6 Sedan and A6 Avant. The A6 series features a choice between inline 4-cylinder 2.0-liter turbocharged gasoline or diesel engines, or a V6 3.0-liter gasoline engine. All engines have been paired with a 48 V hybrid system. The main components of this hybrid system are a belted alternator starter (BAS) and lithium-ion battery. The BAS functions to re-start the engine and to regenerate energy during braking (up to a maximum of 12 kW)[3]. In the same month, Mercedes-Benz launched the E 200 Avantgarde, Nissan launched the completely redesigned Dayz, and Mitsubishi launched the eK Cross. The E 200 series includes the rear-wheel drive Avantgarde and the four-wheel drive (4WD) 4MATIC Avantgarde options. Buyers can choose between a sedan and a station wagon. The engine is a 1.5-liter inline 4-cylinder turbocharged gasoline engine. The hybrid system in these models mainly consists of a belt-driven starter generator (BSG) connected to the crankshaft and a 48 V lithium-ion battery. Power regenerated from the brakes and other components is stored in the lithium-ion battery, which supplies power when required to help enable low-vibration engine starts, smooth and powerful acceleration, and so on[4]. The Dayz lineup includes both a

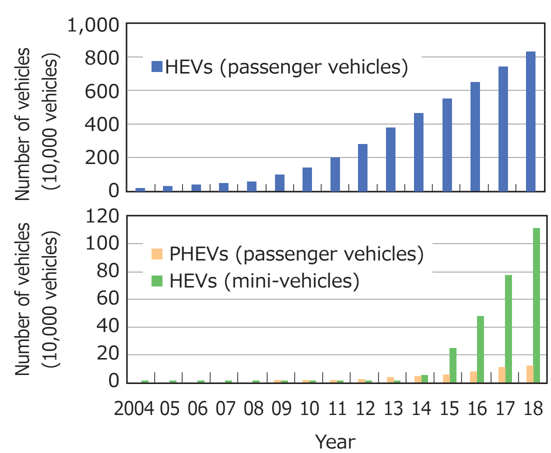

Fig. 1 Trends in the Number of HEVs and PHEVs on the Road in Japan[1]

Table 1 Main HEVs Launched in Japan in 2019[(3)-(12)]

Date announced/went on sale		2019/3/20	2019/3/22	2019/3/28	2019/3/28	2019/4/10
Name of company		Audi	Mercedes-Benz	Nissan	Mitsubishi	Toyota
Name		A6 40 TDI Quattro	E 200 (4MATIC) Avantgarde Sedan/station wagon	Dayz Highway Star X	eK X M grade	RAV4 Hybrid X
Type of hybrid system		Parallel (HEV)	Parallel (HEV)	Parallel (HEV)	Parallel (HEV)	Series-parallel (HEV)
Drivetrain		Four-wheel drive	Rear-wheel drive (four-wheel drive)	Front-wheel drive/ four-wheel drive	Front-wheel drive/ four-wheel drive	Front-wheel drive/ four-wheel drive
Fuel economy (WLTC, km/L)		16.1	12.9(12.1)/12.5 (11.6)	21.2/18.8	21.2/18.8	21.4/20.6
Engines	Designation	DFB	264	BR06-SM21	BR06	A25A-FXS
	Displacement (cc)	1,968	1,496	659	659	2,487
	Max. output (kW)	150	135	38	38	131
Motor	Type	—	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor
	Max. output (kW)	—	10	2.0	2.0	88 (front)/40 (rear, 4 WD only)
Battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion	Nickel-metal hydride
	Capacity (kWh)	—	—	—	—	—

Date announced/went on sale		2019/6/1	2019/6/18	2019/8/22	2019/9/17	2019/10/23
Name of company		Land Rover	Hino Motors, Ltd.	Volvo	Toyota	Mercedes-Benz
Name		Range Rover Evoque	Profia Hybrid	XC90 T8 Twin Engine AWD	Corolla/Corolla Fielder S grade	E 350 e Avantgarde Sports
Type of hybrid system		Parallel (HEV)	Parallel (HEV)	Series-parallel (PHEV)	Series-parallel (HEV)	Series-parallel (PHEV)
Drivetrain		Four-wheel drive	2 -4 D·4 , 2 -4 D·4 D	Four-wheel drive	Front-wheel drive/ four-wheel drive	Rear-wheel drive
Fuel economy (WLTC, km/L)		8.6	4.75^{*1}	12.8	29.0/26.8	—
Engines	Designation	P300	A09C-K1<AT-XI>	B420	2ZR-FXE	M274
	Displacement (cc)	1,995	8,866	1,968	1,797	1,991
	Max. output (kW)	221	279	233	72	155
Motor	Type	—	AC synchronous motor	AC synchronous motor	AC synchronous motor (front/AC induction motor (rear, 4WD only)	—
	Max. output (kW)	18	92	34 (front)/65 (rear)	53 (front)/5.3 (rear, 4WD only)	122
Battery	Type	—	Lithium-ion	Lithium-ion	Lithium-ion/nickel-metal hydride	Lithium-ion
	Capacity (kWh)	—	—	—	—	13.5

Date announced/went on sale		2019/10/23	2019/11/5	2019/12/5	2019/12/13
Name of company		Mercedes-Benz	Volvo	Mazda	BMW
Name		E 350 de Avantgarde Sports	S60 T6 Twin Engine AWD	Mazda3	X5 xDrive45 e
Type of hybrid system		Series-parallel (PHEV)	Series-parallel (PHEV)	Parallel (HEV)	Series-parallel (PHEV)
Drivetrain		Rear-wheel drive	Four-wheel drive	Front-wheel drive/ four-wheel drive	Four-wheel drive
Fuel economy (WLTC, km/L)		—	13.7	17.2^{*2}/16.2^{*2}	10.3
Engines	Designation	OM654	B420	HF-VPH型	B58B30C
	Displacement (cc)	1,950	1,968	1,997	2,997
	Max. output (kW)	143	186	132	210
Motor	Type	—	AC synchronous motor	AC synchronous motor	AC synchronous motor
	Max. output (kW)	122	34 (front)/65 (rear)	4.8	83
Battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Capacity (kWh)	13.5	—	—	24

*1 : Heavy-duty vehicle test cycle fuel economy, *2 : AT specifications turbocharged and a non-turbocharged model. These models feature a hybrid system with a new lithium-ion battery. The hybrid system motor is smaller than the previous system but retains the same output power and has twice the regenerative capacity, which enables waste-free re-use of energy lost via the brakes[5].

The eK Cross lineup also includes a turbocharged and a non-turbocharged model that are equipped with a new hybrid system. During acceleration, battery power is used by the motor to assist the driving force. During deceleration, electrical energy is regenerated and used to efficiently charge the lithium-ion battery[6].

In April, Toyota released the completely redesigned RAV4. The hybrid model mates an inline 4-cylinder 2.4-liter gasoline engine with the Toyota Hybrid System II (THS II), which is equipped with a reduction gear. The RAV features a choice of a front wheel drive (FWD) system or an electrical four-wheel drive (4WD) system called E-Four[7].

In June, Land Rover launched the Range Rover Evoque, equipped with an inline 4-cylinder 2.0-liter turbocharged gasoline engine mated with a 48 V battery, belt-integrated starter generator (BISG), and a DC/DC converter. This system stops the engine when the vehicle is travelling at speeds of 17 km/h or below, charges the battery during deceleration, and assists acceleration using energy stored in the battery when the vehicle moves off[8].

June also saw the launch of the Hino Profia Hybrid. This model is equipped with a turbocharged diesel engine that generates maximum power of 279 kW and maximum torque of 1,765 Nm. It is mated with a newly developed large-capacity lithium-ion battery. The capacity of this battery is sufficient to regenerate the large amounts of energy generated by the weight of a heavy-duty truck on downhill descents or while gradually decelerating. At constant speeds on flat roads, the motor can drive the vehicle using regenerated energy. In addition, the system uses regenerative cooperative brake control to prioritize regenerative braking during foot braking that occurs frequently during ordinary driving, thereby boosting the energy recovery rate. This system is also equipped with a hybrid control that uses artificial intelligence (AI) to read gradients on the road ahead. This control minimizes power consumption and maximizes fuel efficiency[9].

In August, Volvo launched the XC90. The PHEV model uses an inline 4-cylinder 2.0-liter gasoline engine equipped with both a turbocharger and a supercharger to power the front wheels and a motor to drive the rear wheels when necessary. Compared to the previous model, the battery capacity has been increased from 30 to 34 Ah, enabling a cruising range (converted EV driving distance) of 39.2 km using only external electric power as an energy source[10].

In September, Toyota launched the sedan and wagon variants of the latest generation of the Corolla (the wagon version is called the Corolla Touring). At the same time, it launched a partially refreshed version of the Corolla Sports hatchback that was originally released in June 2018. The hybrid versions of these models mate an inline 4-cylinder 1.8-liter gasoline engine with the reduction gear-equipped THS II. Apart from the Corolla Sports, these models are available with FWD or 4WD (E-Four) options[7].

In October, Mercedes-Benz launched the E 350 de Avantgarde Sports and the E 350 e Avantgarde Sports. Both models are PHEVs equipped with inline 4-cylinder 2.0-liter turbocharged engines. The E 350 de uses a clean diesel engine (a first for Japan), whereas the E 350 e is equipped with a gasoline engine. The motors installed in both models have a maximum output power of 122 kW and a maximum torque of 440 Nm. The vehicles can be driven on motor power alone. In addition, cooperative control between the motors and engines enables smooth acceleration with low vibration and noise. The PHEV systems are installed with a 13.5 kWh lithium-ion battery. The maximum converted EV driving distance is 50 km for the E 350 de and 51 km for the E 350 e (both figures are European reference values calculated under the Worldwide Harmonized Light Vehicles Test Procedure (WLTP)).

In November, Volvo released the completely redesigned S60. The PHEV model uses an inline 4-cylinder 2.0-liter gasoline engine equipped with both a turbocharger and a supercharger to power the front wheels and a motor to drive the rear wheels when necessary. The converted EV driving distance is 45.1 km[10].

In December, Mazda launched a redesigned Mazda 3 equipped with the SKYACTIV-X engine. The main components of the hybrid system for this model are an alternator, a starter, a motor equipped with drive assist and energy regeneration functions (a belt ISG system), a 24 V lithium-ion battery, a regenerative cooperative braking system, and a DC/DC converter. The ISG motor functions provide driving assistance, thereby lowering the engine load and helping to enhance fuel efficiency. The system is also equipped with a control that uses the ISG to rapidly reduce and stabilize the engine speed, which helps to create smoother shifting and acceleration in models equipped with manual transmissions[11]. In the same month, BMW launched the X5 xDrive45e. Although the previous model was equipped with an inline 4-cylinder gasoline engine, the new X5 lineup also features a PHEV equipped with an inline 6-cylinder gasoline engine that boosts the maximum output power of the system to 290 kW. This PHEV is capable of driving in EV mode up to 140 km/h and incorporates several selectable modes, such as one that allows the vehicle to drive under engine power until the battery charge level set by the user is reached. The battery capacity was increased compared to the previous model from 26 to 68 Ah, resulting in a total power of 24 kWh. The converted EV driving distance of the new model is 79.2 km, 49.2 km longer than the previous model[12].

1. 4. Trends in HEV Standardization

The international standardization of electrified vehicles (including HEVs, battery electric vehicles (BEVs), and fuel cell vehicles (FCVs) as well as electrical drive systems and parts is mainly being pursued under the auspices of the Electrically Propelled Vehicles subcommittee of the International Organization for Standardization (ISO TC 22/SC 37). This subcommittee covers the vehicle as a whole, systems, and parts, as well as vehicle requirements related to charging and the performance and safety aspects of secondary batteries. Japan is currently the lead country for motor systems, as well as for the reliability and performance test methods of DC/DC converters. In addition, based on test methods for HEVs that have been established as international regulations (UN Global Technical Regulations (GTR)) and standards (ISO), the Japan Automobile Research Institute (JARI) is also leading studies into technologies (such as hardware in the loop simulations (HILS)) with an eye on achieving international standardization for other vehicles. Examples include methods for measuring the fuel efficiency of FCVs equipped with an external charging function, methods for measuring the fuel efficiency of heavy-duty FCVs, and methods for measuring the cruising range of BEVs and FCVs.

2 Electric Vehicles

2. 1. Introduction

Battery electric vehicles (BEVs) are powered entirely by motors using electricity supplied externally rather than from an internal combustion engine (ICE) or fuel cell, which is stored in an on-board battery. BEVs are attracting attention as extremely quiet 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 high capacity lithium-ion battery (LIB) and was mainly sold to corporate customers), the number of BEVs on the road in Japan has steadily increased, reaching around 110,000 by the end of fiscal 2018, a 10% rise since the end of fiscal 2017[13]. However, the proportion of BEVs in Japan remains at under 0.2% of all vehicles, indicating that full-scale popularization has yet to be attained[14]. Issues slowing the widespread adoption of BEVs include those related to vehicle performance, such as the length of charging times and the short range per charge, 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. Cruising range issues are being addressed 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, and the issue of long charging times is being addressed by raising the output of charging standards. On the infrastructure front, systems are in place to introduce chargers via incentives from the national and some local governments. The issue of vehicle price is being addressed through the introduction of incentives, and improvements to mass-production technologies to reduce cost. This section describes the current status of BEV popularization in Japan, as well as the recent trends in research, development, and standardization.

2. 2. Extent of EV Use and Efforts to Increase Popularization

(1) Market Introduction and Sales

Figure 2 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 113,754 vehicles at the end of 2018.

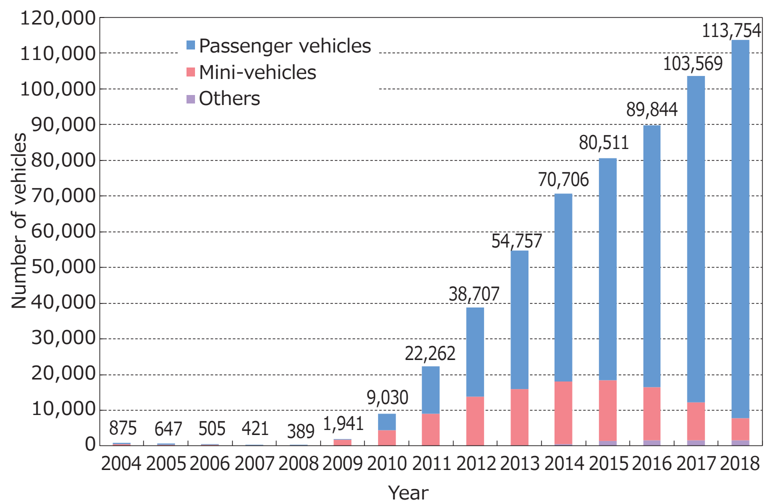

Fig. 2 Trends in the Number of BEVs on the Road in Japan (as of the end of March each year)[13]

Table 2 lists the specifications of the main BEVs sold by automakers in Japan in 2019[15-22]. In January 2019, Nissan launched the Leaf e+ featuring a higher capacity battery and motor output than the base Leaf model. Battery capacity was increased by 55% to 62 kWh and the range per charge was increased to 458 km in the Worldwide Harmonized Light Vehicles Test Cycle (WLTC)[23].

In February 2019, BMW launched a refreshed i3 with a higher capacity battery. Compared to the previous model, the battery capacity was increased by approximately 30%, from 33 to 42 kWh. The WLTC range per charge is now 360 km[24].

Also in February 2019, Tesla opened orders for the Model 3 in the North American market. In April, Tesla also launched new versions of the Model S and Model X with modified drivetrains and a longer range per charge[25][26].

In July 2019, Mercedes-Benz launched the EQC. The EQC is equipped with an 80 kWh LIB. When tested in European specifications, it achieved a range per charge of 400 km (WLTC)[27].

(2) Initiatives to Promote EV Popularization

In June 2019, the Tokyo Metropolitan Government followed on from its efforts in fiscal 2018 and started a business to encourage the introduction of charging facilities and the like at housing complexes through the provision of incentives. This incentive system also covers solar power generation systems[28].

As of 2019, again following on from its efforts in fiscal 2018, the Japanese Ministry of Economy, Trade and Industry (METI) is subsidizing the cost of measures to promote the adoption of clean-energy vehicles (in 2019, the incentives were expanded to also cover external power supply units and class 2 motor-driven cycles) 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[29][30].

Also as of 2019, again following on from its efforts in fiscal 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[31].

2. 3. Trends in EV Research and Development

In addition to research and development projects to extend the range per charge 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.

(1) Vehicle Development

In February 2019, Isuzu announced that it had started monitoring operations of the Elf EV light-duty trucks, with the aim of launching a practical model that is environmentally friendly, economically rational, and easy-to-use[32].

In April 2019, Toyota announced that it would make

Table 2 Specifications of Main BEVs Sold in Japan in 2019(15)-(22)

Manufacturer		Nissan	Nissan	Nissan	Mitsubishi
Name		Leaf G	Leaf e+ G	e-NV200 GX	i-MiEV X
Length × width × height (mm)		4,480 × 1,790 × 1,540	4,480 × 1,790 × 1,565	4,560 × 1,755 × 1,855	3,480 × 1,475 × 1,610
Occupant capacity		5	5	2/5*3	4
AC power consumption rate (JC08 test cycle, Wh/km)		120/155*1	125/161*1	150	118
Cruising range on a single charge (JC08 test cycle, km)		400/322*1	570/458*1	300	164
Drive battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total voltage (V)	350	350	350	330
	Total power (kWh)	40	62	40	16
Motor	Rated output (kW)	85	85	70	30
	Max. output (kW)	110	160	80	47
	Max. torque (Nm)	320	340	254	160
Charging time	Normal charging (3 kW) (h)	Approx. 16 (6 kW charging: 8)	Approx. 12.5 (6 kW charging)	Approx. 8 (6 kW charging)	Approx. 7
	Rapid charging (0 to 80%), minutes)	Approx. 40	Approx. 60	Approx. 40	Approx. 30

Manufacturer		Mitsubishi	BMW	Jaguar	Mercedes-Benz
Name		Minicab-MiEV Van CD 16.0 kWh	i3	I-Pace S	EQC 400 4MATIC
Length × width × height (mm)		3,395 × 1,475 × 1,915	4,020 × 1,775 × 1,550	4,695 × 1,895 × 1,565	4,770 × 1,925 × 1,625
Occupant capacity		2/4*3	4	5	5
AC power consumption rate (JC08 test cycle, Wh/km)		127	127*1	224*1	245*1
Cruising range on a single charge (JC08 test cycle, km)		150	360*1	438*1	400*1
Drive battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total voltage (V)	330	352.3	388.8	349
	Total power (kWh)	16	42.2	90	80
Motor	Rated output (kW)	25	75	—	145
	Max. output (kW)	30	125	294	300
	Max. torque (Nm)	196	250	696	765
Charging time	Normal charging (3 kW) (h)	Approx. 7	Approx. 12 to 13	Approx. 12.9 (7 kW charging)	Approx. 13 (6 kW charging)
	Rapid charging (0 to 80%), minutes)	Approx. 35	Approx. 50	Approx. 85	Approx. 85

Manufacturer		Tesla	Tesla	Tesla	Volkswagen
Name		Model 3 (Long Range)	Model S (Long Range)	Model X (Long Range)	e-Golf
Length × width × height (mm)		4,694 × 1,849 × 1,443	4,970 × 1,964 × 1,445	5,036 × 1,999 × 1,684	4,265 × 1,800 × 1,480
Occupant capacity		5	5	5/6/7*3	5
AC power consumption rate (JC08 test cycle, Wh/km)		—	—	—	124
Cruising range on a single charge (JC08 test cycle, km)		560*2	610*2	507*2	301
Drive battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total voltage (V)	—	350	—	323
	Total power (kWh)	—	—	—	35.8
Motor	Rated output (kW)	—	—	—	100
	Max. output (kW)	—	F : 205/R : 193	F : 205/R : 193	100
	Max. torque (Nm)	—	F : 420/R : 335	F : 420/R : 335	290
Charging time	Normal charging (3 kW) (h)	—	—	—	Approx. 12 (6 kW charging: 6)
	Rapid charging (0 to 80%), minutes)	—	—	—	Approx. 35

*1: WLTC, *2: WLTP, *3: Differs depending on the specifications

vehicle electrification technology patents related to motors, power control units (PCUs), and system controls, which it has developed and refined though the development of hybrid vehicles, available for royalty-free use. This offer includes 23,740 technical patents applicable to the development of various types of electrified vehicles, such as HEVs, PHEVs. BEVs, and FCVs. It also offered technical support toward the commercialization of electrified vehicles[33].

In April 2019, Kawasaki Heavy Industries, Suzuki, Honda, and Yamaha announced the establishment and start-up of a consortium to build replaceable batteries for electric motorcycles, with the aim of popularizing this segment of mobility. It is studying the standardization of replaceable batteries and replacement systems to help resolve the issues of electric motorcycles, such as short ranges per charge, long charging times, and high vehicle and infrastructure costs[34-37].

In June 2019, Toyota and Subaru announced an agreement to jointly develop a dedicated BEV platform and SUV model BEV. The two companies intend to take advantage of their mutual strengths to take on the challenge of building vehicles that maximize the inherent merits of BEVs[38,39].

In October 2019, Honda announced its own high-efficiency electrification initiative called Honda e:TECHNOLOGY, which encompasses electrification-related components and technologies for motorcycles, cars, and power products[40].

In the same month, Nissan demonstrated a test car it plans to use in the development of electric four-wheel control technologies to be installed in the next generation of BEVs. This test car is based on the Leaf e+ and uses two high-power motors at the front and rear to achieve four-wheel drive. The purpose of the test car is to develop new four-wheel controls for electric drivetrains[41].

(2) Demonstration Projects

In May 2019, Toyota, Tokyo University, and TRENDE Inc. announced the start of joint demonstration tests of a next-generation power system on June 17. This next-generation power system is capable of trading power between electrified vehicles (i.e., peer-to-peer (P2P)). These demonstration tests are intended to verify an algorithm for predicting the power demand of electrified vehicles[42].

In June 2019, four companies, including Mitsubishi and Tokyo Electric Power announced the start of a vehicle-to-grid (V2G) demonstration project that uses BEVs as virtual power plant (VPP) resources. In 2018, the first year of the project, the effectiveness of this approach in helping to stabilize the power grid was confirmed. In the second year, it is planned to take on the challenge of simultaneous control via an online system[43].

In October 2019, Nissan announced the start of a demonstration project called Charging Plus, which acts a matching service between BEVs and retail stores. It provides information on the location of stores equipped with chargers and coupons that can be exchanged for charging time. The project hopes to verify the business impact of such a service[44]. In the same month, three companies, including Nissan and Tohoku Electric Power announced the continuation of a V2G demonstration project to help build a VPP using BEVs. In 2018, this project identified the basic control method characteristics. In 2019, it intends to verify the accuracy of operations required by the power supply/demand balance adjustment function[45].

In the same month, Mazda and Chugoku Electric Power announced a joint initiative to build a stationary secondary battery system from re-used BEV traction batteries, and to carry out VPP demonstration tests using the system. The aim of this initiative is to develop control technologies that will help to maximize the use of renewable energy and to realize controls for balancing supply and demand[46].

2. 4. Trends in Standardization

The standardization of BEVs is carried out by the ISO and the International Electrotechnical Commission (IEC).

International standards for overall vehicles, electric drive systems, and parts are being created under the auspices of ISO/TC22/SC37. (Refer to Section 1.4. Trends in HEV Standardization for details.)

3 Fuel Cell Electric Vehicles

3. 1. Introduction

KPMG International, which is headquartered in the Netherlands, is a firm of accountants and business consultants with a global network stretching over 154 countries. It carried out a survey of 981 executives in key companies inside the global automotive industry about the main trends of the industry in 2030[47]. Figure 3 shows the analysis results categorized into four global regions. The figures on the central axis show the ranking of the main trends. Although there are differences in the rankings per item and region, three regions (excluding China) placed FCVs in the top two positions, indicating the high interest in FCVs as a trend for 2030.

In Japan, METI released a revision version of the Strategic Road Map for Hydrogen and Fuel Cells on March 12, 2019[48], which sets targets for the adoption of FCVs in Japan of about 40,000 vehicles by 2020, about 200,000 vehicles by 2025, and about 800,000 vehicles by 2030 (Fig. 4). 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. This was the first update of the road map in three years. Revisions included a reduction in the price difference between FCVs and HEVs from approximately 3 million yen today to 700,000 yen, clearer targets for reductions in the cost of the main systems that make up FCVs, and target values for the

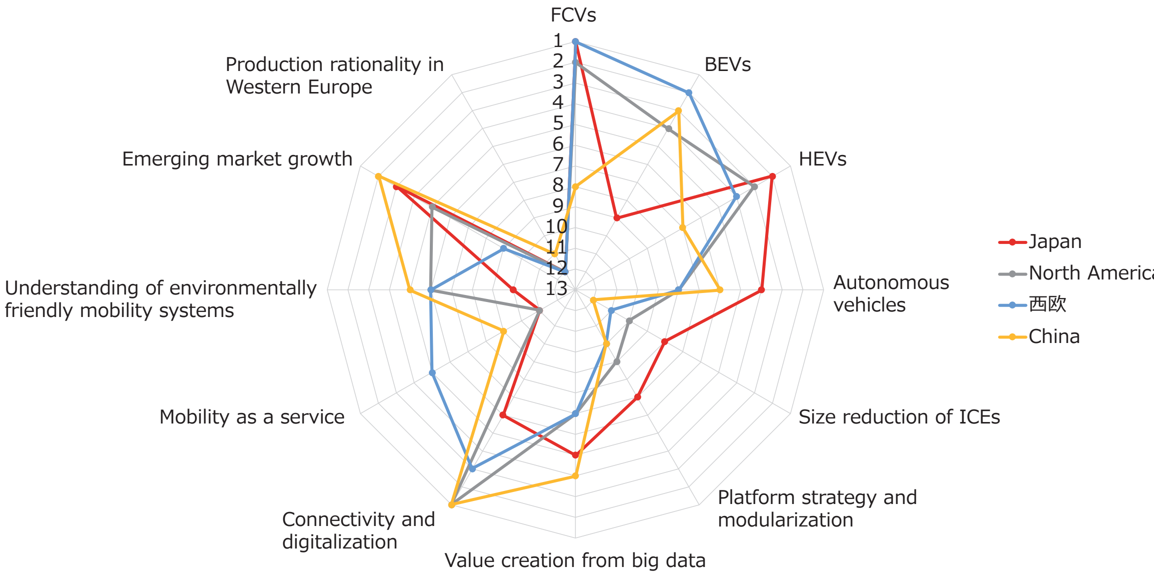

Fig. 3 Results of Investigation into Main Trends of Automotive Industry in 2030 (created based on results of investigation conducted by KPMG[47])

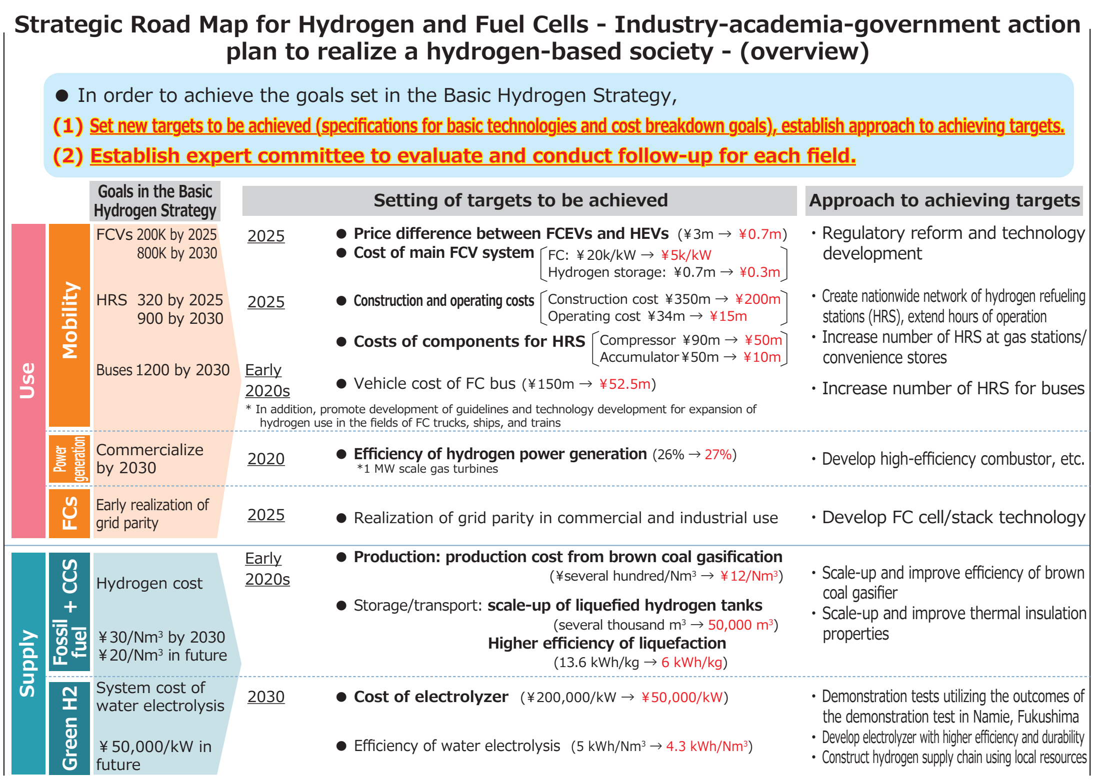

Fig. 4 Strategic Road Map for Hydrogen and Fuel Cells (METI)[54]

maintenance and operating costs of hydrogen refueling stations. It also describes the use of carbon capture and storage (CCS) technology and renewable energy in the establishment of carbon-free hydrogen production, as well as cost reductions related to hydrogen production and supply.

3. 2. Trends Related to FCEVs

This section introduces new information concerning FCVs, which was announced in 2019 or later.

(1) Toyota Motor Corporation

Aiming to achieve annual sales in excess of 30,000 vehicles from around 2020, Toyota is currently working to accelerate the popularization of FCVs. At the end of

2020, Toyota plans to launch the second generation of the mass-produced Mirai FCV that it originally released in 2014. The cruising range of the new model is at least 30% higher than the previous generation[49]. The Mirai uses a fuel cell (FC) system that can be adopted in a wide range of products, including medium- and heavy-duty trucks and forklifts. In China, Toyota has supplied Beiqi Foton Motor Co., Ltd. and Shanghai REFIRE Technology Co., Ltd. with FC systems for buses. In Portugal, CaetanoBus S.A. has also announced a fuel cell bus equipped with Toyota's FC system. In addition, the Japan Aerospace Exploration Agency (JAXA) and Toyota have launched studies into the required mobility for manned exploration on the moon's surface using FCV technology as part of international space exploration missions[50]. Furthermore, Toyota also announced plans to start building a connected city in Susono, Shizuoka Prefecture, to demonstrate a range of products and services to help realize sustainable infrastructure in the future, powered by FC technology. Construction is scheduled to start at the beginning of 2021[51].

(2) Isuzu Motors Limited and Honda R&D Co., Ltd.

Isuzu and Honda have agreed to jointly research a heavy-duty FC truck by combining the technological research targets of both companies, namely to enhance Isuzu's lineup of next-generation powertrains for heavy-duty trucks and to expand application of Honda's FC technology beyond passenger vehicles[52].

(3) Hyundai Motor Company

By 2025, Hyundai is aiming to bring the costs of a system including an FC system with an output of 100 kW, a hydrogen storage capacity of 3.5 kg, and a hybrid vehicle secondary battery, down to match the price of an EV equipped with a 65.4 kWh-capacity battery with the same performance. The company intends to start adopting FC systems in commercial vehicles in 2020 and expand its lineup to include long-distance buses, as well as medium- and heavy-duty trucks. It has plans to deliver 1,600 heavy-duty trucks (with a gross vehicle weight of 34 tons) to Switzerland by 2025. The Hyundai group is targeting annual FC system production of 700,000 units, including 500,000 units of FCVs, by 2030[49].

(4) Nikola Motor Company

The Nikola Two, a class 8 (gross vehicle weight: 40 tons) heavy-duty truck has already attracted around 14,000 pre-orders and is due for market launch in 2023. This truck has a hydrogen capacity of 80 kg and a cruising range of 1,000 km. The hydrogen filling pressure of the truck is 70 MPa, which will allow it to be refueled in 15 minutes. With regard to hydrogen refueling stations, a refueling station that can produce 2 tons of hydrogen a day is due to start operations in 2021, and a standard refueling station that can produce 8 tons of hydrogen a day is scheduled for 2022. This standard hydrogen refueling station will be available to ordinary truck users as well as users of Nikola's trucks, and should also be compatible with cars. The company is aiming to supply zero-emission hydrogen from renewable energy sources at a cost of $6.0/kg[53].

(5) Robert Bosch GmbH

Bosch has provisionally calculated the total cost of ownership (TCO) of a long-distance transportation truck, comparing a conventional diesel truck and an FC truck. It is possible that a diesel truck will be penalized in the future for its carbon dioxide emissions. In contrast, if the price of hydrogen fuel continues to drop, the TCO of an FC truck may fall below that of a diesel truck in the future. Bosch also estimated that, if the price of hydrogen falls to 3.0 euros/liter in 2030, tax collected on FC trucks may become equal to that collected on diesel trucks. Bosch has announced that is jointly developing an FC stack with the Swedish firm Powercell Sweden AB, and hopes to join the market in no later than 2022. If it can add an FC stack to its lineup, Bosch will have a complete portfolio of FC products. According to use case analysis incorporating vehicle grade, driving distance, and the like, FC applications have the advantage in terms of weight and size in cases involving longer distances[53][54].

4 Traction Motors

4. 1. Introduction

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

4. 2. Electric Motors

Table 3 shows the automotive traction motors equipped on passenger and heavy-duty vehicles that were either launched in Japan or that were subject to a complete redesign between January and December of 2019. Although most of these models adopted alternating current (AC) synchronous motors, the Corolla launched by Toyota and the EQC 400 launched by Mercedes-Benz adopted AC induction motors.

Table 3 Main Electrified Vehicles Launched in Japan in 2019[(55)-(62)]

Manufacturer	Designation	Type	Max. output (kW)	Max. torque (Nm)	System	Main vehicles equipped with this motor
Toyota	3NM	AC synchronous motor	88	202	HEV	RAV4 (front)
	4NM		40	121		RAV4 (rear)
	1NM		53	163		Corolla (front)
	1MM	AC induction motor	5.3	55		Corolla (rear)
Nissan	SM21	AC synchronous motor	2.0	40		Dayz
Mitsubishi						eK Cross
Mazda	MK		4.8	61		Mazda3
Hino Motors, Ltd.	—		90	784		Profia
Mercedes-Benz	EM0014		16	250		GLE 450 /580 4 MATIC
	E0016-E0021	AC induction motor	300	765	EV	EQC 400
BMW	—	AC synchronous motor	83	104	PHEV	400 X
	—		83	265		X5 xDrive45 e
Volvo	T45		34	160		S60 T6 /T8 Twin Engine (front)
	AD2		65	240		S60 T6 /T8 Twin Engine (rear)

Current trends include active development of integrated powertrain units incorporating motors, inverters, reduction gears (or transaxles), and the like. Both the 2019 Automotive Engineering Exposition and Tokyo Motor Show featured a wide range of such exhibits from suppliers inside and outside Japan. These powertrain units adopt a wide range of motors, including those for 12 to 48 V integrated starter generators (ISGs) or belt-driven starter generators (BSGs), 250 to 700 V rear-wheel drive motors for HEVs, and motors for BEVs. In the field of motor inverters, Hitachi Automotive Systems[(63)] and Delphi[(64)] announced the mass production of 800 V inverters for EV traction motors.

Other ongoing trends include the development of motors with higher rotational speeds to reduce size and weight, inverters capable of high-speed switching (a function that is required for these motors), and the development of high-performance magnetic materials that do not use rare earth elements[(65)].