HYBRID VEHICLES, ELECTRIC VEHICLES, FUEL CELL ELECTRIC VEHICLES

1 Hybrid Vehicles

1. 1. Introduction

Demand for vehicles with better fuel efficiency and cleaner exhaust emissions is growing in light of environmental problems such as air pollution and global warming. Automakers have been selecting hybrid electric vehicles (HEVs), which combine an internal combustion engine and electric motors, as one way of improving fuel efficiency. There has also been an increase in the number of plug-in hybrid vehicles (PHEVs), which allow external charging of the on-board battery that powers the electric motors. This section 1 describes 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 2014 the number of HEVs (passenger vehicles) on the road in Japan, not including mini-vehicles, increased by nearly 800,000 vehicles compared to the previous year to reach approximately 4.6 million vehicles (12% 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 45,000 vehicles in 2014. In addition, the number of HEVs (mini vehicles) on the road in Japan increased significantly in 2014 following the introduction of vehicles that employ a mild hybrid system, and now stands at approximately 55,000 vehicles. This number is expected to increase in the future as automakers continue to expand their line-up of PHEVs.

1. 3. New HEVs announced and launched in Japan in 2015

Table 1 lists the HEVs and PHEVs announced and launched in Japan in 2015 according to the month of release. The main trends were as follows.

In January, Toyota Motor Corporation launched the Alphard and Vellfire hybrid models. The drivetrain of these vehicles is an electric AWD system (E-Four) consisting of a rear motor that provides drive to the rear wheels that is independent of the front motor. Fuel economy is 19.4 km/L (under the JC08 test cycle)(2).

In February, the Jade and Legend hybrid vehicles were launched by Honda Motor Company. The Jade is equipped with the Sport Hybrid i-DCD that features a 1.5 L direct-injection engine, a 7-speed dual clutch transmission (DCT), and an electric motor(3). The Legend is equipped with the world's first 3-motor hybrid system. The front of the vehicle is equipped with a V6 3.5 L direct-injection engine and a 7-speed DCT with integrated motor, while the rear is equipped with the Twin Motor Unit (TMU), which contains two electric motors. In response to driver inputs and driving conditions, the hybrid system continuously automatically switches between the most energy-efficient driving mode among EV drive, hybrid drive, and engine drive, while making the optimal choice of front-wheel drive, rear-wheel drive, or four-wheel drive. The two motors on the rear axle allow torque vectoring that provides independent control of driving force and deceleration for the left and right rear wheels.

In May, the X-Trail from Nissan Motor Co., Ltd. went

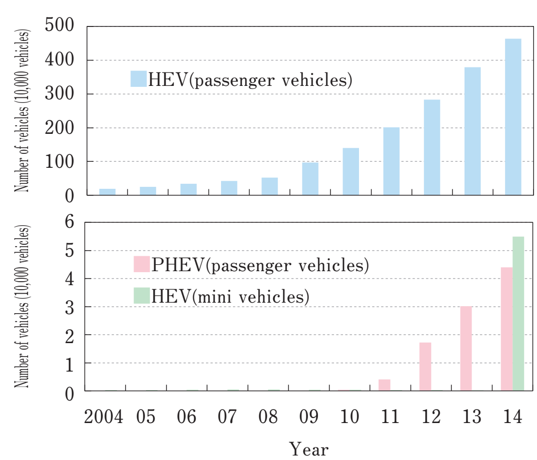

Fig. 1 Trends in the Number of HEVs and PHEVs on the Road in Japan(1)

Table 1 Main Hybrid Electric Vehicles Launched in Japan in 2015[(2)-(14)]

						
Date announced/went on sale		2015/1/26	2015/2/13	2015/2/20	2015/5/13	2015/5/13
Name of company		Toyota Motor Corporation	Honda Motor Company	Honda Motor Company	Nissan Motor Co., Ltd.	Suzuki Motor Corporation
Name of vehicle		Alphard/ Vellfire Hybrid	Jade Hybrid	Legend Hybrid	X-Trail Hybrid	Hustler S-Enecharge
Type of hybrid system		Series / Parallel (HEV)	Parallel (HEV)	Parallel (HEV)	Parallel (HEV)	Parallel (HEV)
Drivetrain		Four-wheel drive	Front-wheel drive	Front-wheel drive / Four-wheel drive	Front-wheel drive / Four-wheel drive	Front-wheel drive / Four-wheel drive
Fuel economy (JC08 test cycle, km/L)		19.4	25.0	16.8	20.6	32.0
Engine	Model	2AR-FXE	LEB	JNB	MR20DD	R06A
	Displacement (cc)	2 493	1 496	3 471	1 997	658
	Output (kW)	112	96	231	108	38
Motor	Type	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor	DC synchronous motor
	Output (kW)	Front 105 / Rear 50	22	Front 33 / Rear 27× 2	30	1.6
Battery	Type	Nickel-metal hydride	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Capacity (kWh)	—	0.86	1.3	—	0 .04

						
Date announced/went on sale		2015/5/14	2015/5/15	2015/5/19	2015/5/28	2015/7/9
Name of company		Mazda Motor Corporation	Honda Motor Company	Suzuki Motor Corporation	Mazda Motor Corporation	Toyota Motor Corporation
Name of vehicle		Flair Crossover S-Enecharge	Shuttle Hybrid	Spacia / Spacia Custom S-Enecharge	Flair Wagon S-Enecharge	Sienta Hybrid
Type of hybrid system		Parallel (HEV)	Parallel (HEV)	Parallel (HEV)	Parallel (HEV)	Series / Parallel (HEV)
Drivetrain		Front-wheel drive / Four-wheel drive	Front-wheel drive / Four-wheel drive	Front-wheel drive / Four-wheel drive	Front-wheel drive / Four-wheel drive	Front-wheel drive
Fuel economy (JC08 test cycle, km/L)		32.0	34.0	30.6	30.6	27.2
Engine	Model	R06A	LEB	R06A	R06A	1NZ-FXE
	Displacement (cc)	658	1 496	658	658	1 496
	Output (kW)	38	81	38	38	54
Motor	Type	DC synchronous motor	AC synchronous motor	DC synchronous motor	DC synchronous motor	AC synchronous motor
	Output (kW)	1.6	22	1.6	1.6	45
Battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion	Nickel-metal hydride
	Capacity (kWh)	0.04	0.86	0.04	0.04	0.9

on sale. The hybrid system of this vehicle features intelligent dual-clutch control (a system composed of one motor and two clutches)[(4)]. In the same month, Suzuki Motor Corporation released the Hustler, Spacia, and Spacia Custom, which are all equipped with its mild hybrid system (S-Enecharge) that features an electrical generator with a motor function. This generator is called the ISG (integrated starter generator)[(5)]. The Shuttle hybrid from Honda Motor Company that also features the Sport Hybrid i-DCD also went on sale[(3)]. Finally, the Flair Crossover and Flair Wagon vehicles were released by Mazda Motor Corporation. These vehicles also feature the S-Enecharge mild hybrid system[(6)].

In July, Toyota Motor Corporation released the Sienta, which is equipped with a 1.5 L compact hybrid system (THS II with reduction gear)[(2)].

In August, Suzuki Motor Corporation released the Solio and Solio Bandit. These vehicles are equipped with

Table 1 Main Hybrid Electric Vehicles Launched in Japan in 2015[(2)–(14)] (continued).

						
Date announced/went on sale		2015/8/26	2015/9/8	2015/9/8	2015/10/14	2015/10/22
Name of company		Suzuki Motor Corporation	BMW	VW	Subaru	LEXUS
Name of vehicle		Solio/Solio Bandit Hybrid	X5 xDrive40e	Golf GTE	Impreza Sport Hybrid	RX450h
Type of hybrid system		Parallel (HEV)	Parallel (PHEV)	Series / Parallel (PHEV)	Parallel (HEV)	Series / Parallel (HEV)
Drivetrain		Front-wheel drive / Four-wheel drive	Four-wheel drive	Front-wheel drive	Four-wheel drive	Front-wheel drive / Four-wheel drive
Fuel economy (JC08 test cycle, km/L)		27.8	13.8	23.8	20.4	18.8
Engine	Model	K12 C	N57D30A	CUK	FB20	2GR-FXS
	Displacement (cc)	1 242	2 992	1 394	1 995	3 456
	Output (kW)	67	190	110	110	193
Motor	Type	DC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor	AC synchronous motor
	Output (kW)	2.3	83	80	10	Front 123 / Rear 50
Battery	Type	Lithium-ion	Lithium-ion	Lithium-ion	Nickel-metal hydride	Nickel-metal hydride
	Capacity (kWh)	0.04	9.2	8.7	0.6	—

						
Date announced/went on sale		2015/11/12	2015/12/1	2015/12/1	2015/12/4	2015/12/17
Name of company		Audi	Toyota Motor Corporation	Hino Motors, Ltd.	Mercedes-Benz	Mitsubishi Motors Corporation
Name of vehicle		A3 Sportback e-tron	Prius	Blue Ribbon Hybrid	C350e/350eL	Delica D:2
Type of hybrid system		Parallel (PHEV)	Series / Parallel (HEV)	Parallel (HEV)	Series / Parallel (PHEV)	Parallel (HEV)
Drivetrain		Front-wheel drive	Front-wheel drive / Four-wheel drive	Rear-wheel drive	Rear-wheel drive	Front-wheel drive / Four-wheel drive
Fuel economy (JC08 test cycle, km/L)		23.3	40.8	5.1	17.2	27.8
Engine	Model	CUK	2ZR-FXE	A05C-K1	274	K12C
	Displacement (cc)	1 394	1 797	5 123	1 991	1 242
	Output (kW)	110	72	184	155	67
Motor	Type	AC synchronous motor	Front: AC synchronous motor / Rear: Induction motor	AC synchronous motor	AC synchronous motor	DC synchronous motor
	Output (kW)	55	Front 53 / Rear 5.3	90	60	2.3
Battery	Type	Lithium-ion	Nickel-metal hydride / Lithium-ion	Nickel-metal hydride	Lithium-ion	Lithium-ion
	Capacity (kWh)	8.7	0.75	—	6.38	0.04

the same S-Enecharge mild hybrid system as other Suzuki vehicles, but the motor output is higher than that in the systems equipped on those other mini vehicles[(5)].

In October, Subaru released its Impreza hybrid. This vehicle features a parallel hybrid system in which the transmission (Lineartronic CVT) is placed between the engine and the motor. In addition, the electric motor has been neatly integrated into the vehicle's transmission[(9)]. In the same month the RX450h from Lexus also went on sale. The lineup features both front-wheel drive and four-wheel drive versions, and the four-wheel drive version is equipped with the previously mentioned E-Four drivetrain[(10)].

In December, a new version of the Prius was released

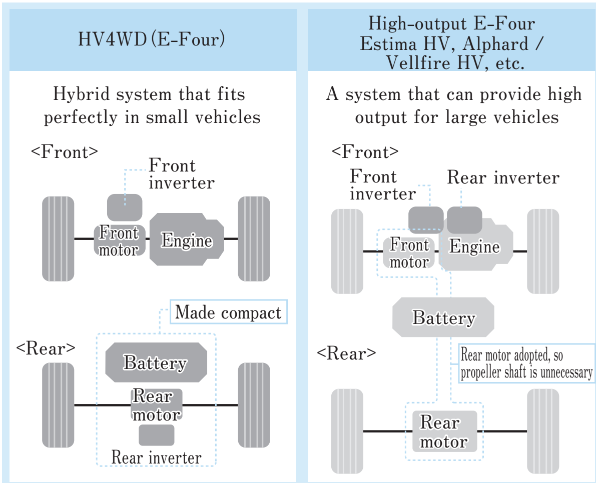

Fig. 2 The Toyota four-wheel drive system for HEVs.[2]

by Toyota Motor Corporation. For the first time, the vehicle is equipped with a drivetrain that features four-wheel drive (HV4WD) in addition to front-wheel drive. The Toyota E-Four conventional four-wheel drive system for hybrid vehicles is composed of three independent drive shafts: the motor drive shaft, the reduction gear drive shaft, and the differential gear drive shaft. However, in the newly designed HV4WD system the drive shafts for the motor and the reduction gear have been integrated into one so that the system now consists of two drive shafts, successfully reducing its mass and size by approximately 75% compared to the previous system. Figure 2 shows how the design of this new hybrid system made it more compact and optimized the positioning of the component parts[2].

The same month Hino Motors, Ltd. released its Blue Ribbon hybrid bus. This vehicle uses a parallel hybrid system where the clutch is placed between the engine and the motor, which not only increased the efficiency of the regenerative braking, but also made it possible to start off using only the electric motor (however, the engine is still idling)[12]. In addition, Mitsubishi Motors Corporation released the Delica D:2, which is equipped with the same mild hybrid system as the Suzuki Solio[14].

Among imported hybrid vehicles from non-Japanese manufacturers, BMW launched the X5 xDrive40e, a PHEV, in September. This hybrid vehicle combines the plug-in hybrid technology (eDrive technology) adopted on the i8 vehicle with the xDrive system of the X5 vehicle. The cruising range using only external electric power as its energy source (converted EV running distance) is 30.8 km and its fuel consumption is 13.8 km/L (in JC08 mode)[7]. The same month VW also launched a PHEV of its own, the Golf GTE. This is the first PHEV from VW and its hybrid system places the motor between the 1.4 L TSI engine and the 6-speed direct shift gear box (DSG), which has been integrated with the electric motor into a single unit. The converted EV running distance is 53.1 km, and fuel consumption is 23.8 km/L (in JC08 mode)[8].

In November, Audi released a PHEV called the A3 Sportback e-tron. The hybrid system in this vehicle uses the same solution as the one in the Golf GTE and has a system output of 150 kW, a converted EV running distance of 52.8 km, and a fuel consumption of 23.3 km/L (in JC08 mode)[11]. In December, Mercedes-Benz launched two PHEVs, the C350e and the C350eL. In the hybrid systems installed on these vehicles, the electric motor has been placed between the engine and the transmission and a clutch has been added between the motor and the engine, which makes it possible to drive the vehicle using only the motor. The system output is 205 kW, the converted EV running distance is 25.4 km, and the fuel consumption is 17.2 km/L (in JC08 mode)[13].

1.4. Trends in standardization

ISO/TC22 (Road vehicles)/SC37 (Electrically-propelled vehicles) is the committee carrying out the standardization activities for general vehicles that are powered by electricity (electrically-propelled road vehicles), including HEVs, fuel cell vehicles (FCEVs), and battery electric vehicles (BEVs). The main trend in the committee has been the revisions to ISO 6469-1 (Safety specifications for the on-board rechargeable energy storage system (RESS)), ISO 6469-2 (Vehicle operational safety means and protection against failures), and ISO 6469-3 (Protection of persons against electric shock), standards concerning the safety of electrically-propelled road vehicles during normal use, started in 2014 in WG1, the group in charge of safety. In regard to electrical safety issues, high voltage has been divided into two classifications, a new proposal to reduce the required protections for parts with low voltages is now being discussed. In addition, ISO 6469-4 (Post-crash electrical safety) was formally issued as an international standard (IS) in September 2015.

In contrast, WG2, the group responsible for performance and energy consumption, is currently discussing the method for determining the power output of HEV systems (ISO/WD20762) so that they can be compared easily to the power outputs of engines in internal com-

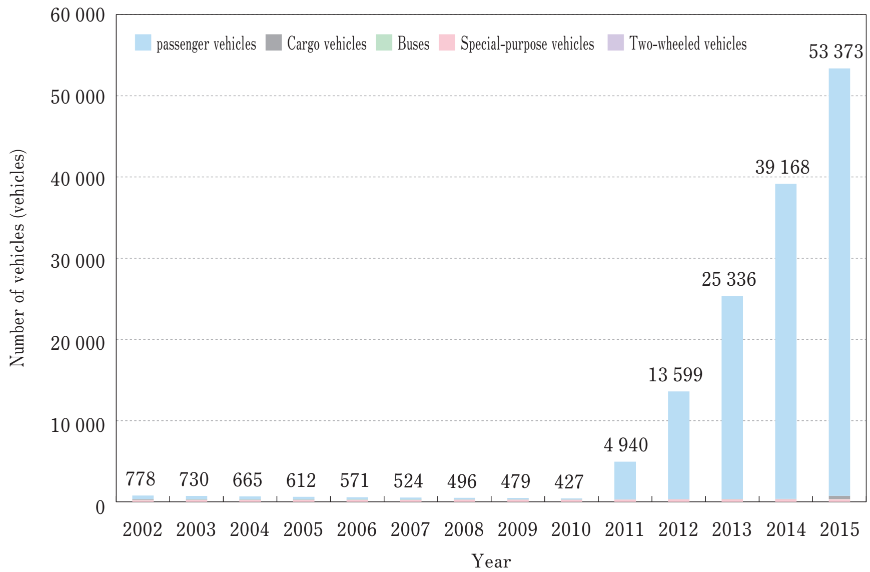

Fig. 3 Trends in the Number of EVs on the Road in Japan (as of the end of March each year)[16]

Table 2 Specifications of Main EVs Sold in Japan in 2015[19][20]

Manufacturer		Nissan Motor Co., Ltd.	Nissan Motor Co., Ltd.	Mitsubishi Motors Corporation	Mitsubishi Motors Corporation	Mitsubishi Motors Corporation
Name of vehicle		e-NV200	LEAF	i-MiEV M/X	MINICAB-MiEV VAN	MINICAB-MiEV TRUCK
External appearance						
Length × width × height [mm]		4 560×1 755×1 855/1 850	4 445×1 770×1 550	3 395×1 475×1 610	3 395×1 475×1 915 /1 810	3 395×1 475×1 820
Occupant capacity		Van: 2/5 Wagon: 5/7	5	4	2 (4)	2
AC power consumption rate [Wh/km]		142	114/117	110	125	120
Cruising range on a single charge*1 [km]		Van: 190/188 Wagon: 188/185	228/280	120/180	100/150	110
Battery for drive power	Type	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion
	Total voltage [V]	360	360	270/330	270/330	270
	Total amount of power [kWh]	24	24/30	10.5/16	10.5/16	10.5
Motor	Rated output [kW]	70	70	30	25	25
	Max. output [kW]	80	80	30/47	30	30
	Max. torque [N·m]	254	254	160	160	196
Charg-ing time	Normal [h]	8 (200 V) *2	8/11 (200 V) *2	4.5/7 (200 V) *2	4.5/7 (200 V) *2	4.5 (200 V) *2
	Fast [min]	Approx. 30 (80 %)	Approx. 30 (80 %)	Approx. 15 (80 %) / Approx. 30 (80 %)	Approx. 15 (80 %) / Approx. 35 (80 %)	Approx. 15 (80 %)
Price including tax [10,000 yen]		Van: 388.044～ Wagon: 462.456～	280.368～/319.788～	226.152～/283.824～	179.928～/242.892～	158.22～

＊1 : JC08 mode　＊2 : Can also be charged with 100 V

bustion vehicles, which are measured with existing international standards and criteria. The aim is to issue this standard as a formal IS sometime in 2018. ISO 23274-1 (revised), the standard for vehicles without an external charging function, was issued on January 13, 2013 and ISO 23274-2, the standard for vehicles with an external charging function, was issued on July 26, 2012. In addition, ISO/TR (Technical Report) 11955 (Guidelines for charge balance measurement) was also issued in October 2008 as the guidelines for the fuel consumption testing methods.

2 Electric Vehicles

2. 1. Introduction

Since electric vehicles (EVs) produce few greenhouse gas emissions over their life cycles[15], they have been garnering a lot of attention next-generation environmentally friendly vehicles. Mass production EV models equipped with lithium-ion batteries have been available since 2009, but the number of EVs on the roads remains less than 100,000 vehicles[16]. Reasons for this include battery charging time, cruising range, the charging infrastructure in Japan, and the price of the vehicles. However, improvements in cruising range, an increase in the number of charging stations, and revised vehicle prices, along with subsidies offered for the purchase of EVs and battery chargers by the Japanese government and some municipal governments, are contributing to efforts to increase EV popularity and ownership. 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[16]. The number of EVs on the roads in Japan continued to decrease until March 2010, remained below 1,000 vehicles, but started to increase steadily after Mitsubishi Motors Corporation released the i-MiEV and Fuji Heavy Industries released the Subaru Plug-in Stella in 2009 and Nissan Motor Co., Ltd. released the LEAF in 2010, reaching 53,373 vehicles at the end of the 2015 fiscal year.

No new EVs were released in Japan in 2015, but Mitsubishi Motors Corporation made some modifications and improvements to its Minicab MiEV van and Minicab MiEV truck in July 2015. In addition to making a fast charging function standard equipment on all vehicle model grades, the price of the base Minicab MiEV van was reduced by about 240,000 yen, while that of the Minicab MiEV truck was reduced by about 120,000 yen[17].

In November 2015, Nissan Motor Co., Ltd. made some minor changes and improvements to its LEAF EV. A new model grade with a cruising range improved from 228 km to 280 km (both in JC08 mode) was added. In addition, all model grades now come with emergency (automatic) brakes and lane departure warning (LDW) as standard equipment. The navigation system was also upgraded with new functions, such as automatic updates about the locations of nearby charging stations[18].

Table 2 shows the specifications of the main EVs sold by automobile manufacturers in 2015[19][20].

2. 2. 2. Japanese government initiatives to promote EV popularization

In November 2014, the Japanese Ministry of Economy, Trade and Industry (METI) announced the 2014 Automobile Industry Strategy[21], which set EV and PHEV Japanese passenger vehicle market share targets of 15% to 20% of the by 2020 and 20% to 30% by 2030. Other initiatives encourage greater EV adoption included earmarks in the FY 2014 supplementary budget of 10 billion yen to subsidize the cost of introducing clean energy vehicles through incentives on the purchase of EVs, and of 30 billion yen to subsidize the costs associated with the EV charging infrastructure and to help cover the cost of an EV highway usage survey[22]. The Ministry of Land, Infrastructure Transport and Tourism (MLIT) is carrying out a program to make regional transportation more environmentally friendly, which provides targeted support to automobile and transportation businesses to induce the adoption of electric buses, taxis, and trucks[23]. In 2015, six businesses making use of EV taxis were selected to receive support.

2. 2. 3. Initiatives to promote greater EV adoption by private citizens

Nissan Motor Co., Ltd. announced on June 3, 2015 that it had signed a cooperative agreement to construct an EV dissemination model with Yokosuka City[24]. The two parties pledge to develop and maintain an EV recharging environment that is the best in Japan and makes it possible to recharge EVs anywhere, to implement pioneering EV popularization measures that will serve as benchmarks for others in their role as the best EV producing municipality in Japan, and to publicize their best in Japan model for new urban development that focuses on EVs.

2. 3. Trends in EV research and development

2. 3. 1. Vehicles and batteries

The cells in the battery of the LEAF EV from Nissan Motor Co., Ltd. have been improved to achieve higher capacity, lower resistance, and better safety. In addition, the number of cells in a single module has been changed from the conventional 4-cell module (2 parallel, 2 in-series)

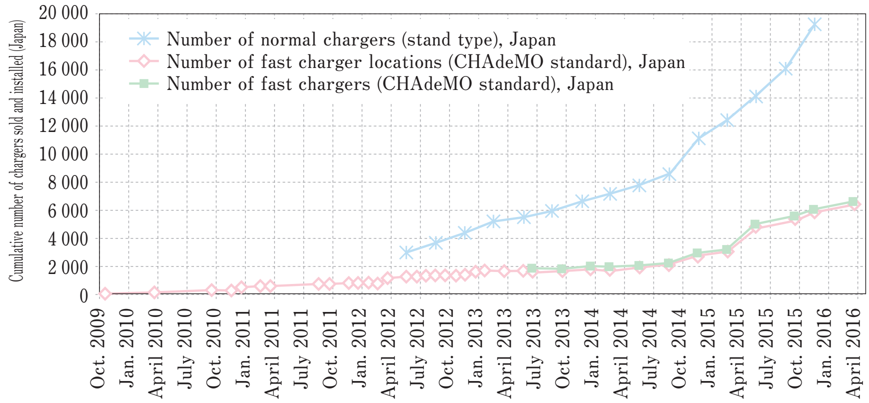

Fig. 4 Cumulative Number of Installed Chargers for EVs in Japan[33][34].
(However, fast chargers are limited to only those that received CHAdeMO certification[32].)

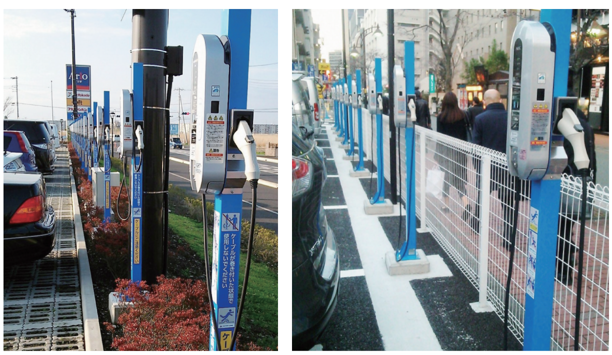

Fig. 5 Examples of Large-scale Normal Charger Installations (Left: Suburban large-scale commercial facility, Right: Metered parking lot).

Fig. 6 Porsche Turbo Charging Concept[38]

Fig. 7 Road Test of Battery-less EV Using a Tire-based Electric Power Collection Method[42]

to an 8-cell module (2 parallel, 4 in-series). Furthermore, the charging and discharging usage range was expanded by optimizing the measurement accuracy error tolerance and calculation error tolerance of the various battery sensors. These battery improvements extended the cruising range of the vehicle from 228 km to 280 km without changing the shape of the battery pack[25].

The lithium-ion batteries used in EVs degrade over time due to usage, and this affects cruising distance and power output, leading to reports concerning the degradation mechanism when the batteries are stored[26] and various degradation analysis methods that included actual vehicle usage[27].

2. 3. 2. Demonstration projects

Mitsubishi Motors Corporation announced on July 10, 2015 that it would begin a joint demonstration project for utilizing used lithium-ion batteries from electric-powered vehicles. The project will be executed in partnership with Mitsubishi Corporation, Electricité de France (EDF), Forsee Power, and PSA Peugeot Citroën[28]. The purpose of the project is to demonstrate efficient and economically feasible energy management practices based on the optimization of electricity storage, charging, and generation technology with respect to existing demand.

On September 2, 2015, Nissan Motor Co., Ltd. announced that its e-NV200 EV van would be equipped with an electrical outlet that will allow the vehicle battery to supply a maximum of 1,500 W of electric power to other outdoor electric devices. It was also announced that any Japanese municipalities that developed examples of how the e-NV200 could be used in a variety of different situations would be able to borrow the vehicle for 3 years free of charge[29]. This promotional endeavor is looking to amass numerous examples of how people can take advantage of the capabilities of the e-NV200 and then deploy these potential uses nationwide in Japan in an effort to further promote the adoption of EVs.

On October 21, 2015, Nissan Motor Co., Ltd. and the Japan-based trading company Kanematsu Corporation announced that the two companies have been officially selected by the New Energy Industrial Technology and Development Organization (NEDO) to analyze electric vehicle use patterns in Northern California. The project will seek to encourage the use of electric vehicles for longer distances and inter-city driving by installing and maintaining multiple fast chargers along specific inter-city routes[30]. Nissan's role in the project will be to install and operate the fast chargers and analyze any resulting changes in EV use. Kanematsu will provide real-time information services to EV users, as well as investigate potential business applications for real-time data and big data relating to EVs and EV charging systems. The project ultimately aims to create a concrete model to promote more extensive use of electric vehicles in California and beyond.

On October 19, 2015, Honda Motor Co., Ltd. announced plans to begin real-world demonstration testing of EV charging technologies in the Republic of the Marshall Islands. With support from METI, the testing will be conducted jointly with the government of the Marshall Islands and use Honda's electric vehicle, the Fit EV, and its solar power-ready AC normal charger, the Honda Power Charger, to evaluate the potential of widespread use of electric mobility products and of establishing a charging infrastructure. The testing will seek to find solutions to issues facing that country, such as energy independence[31].

The above examples illustrate how research and development conducted to extend EV cruising range, is being complemented by numerous other activities encompassing EVs, including vehicle battery, new ways to use EVs, and the infrastructure.

2.4. Charging infrastructure

The Japanese government and automotive industry groups are proposing various policies to promote the spread of the charging infrastructure for EVs and PHEVs. The following sections will touch on the state of

Fig. 8 Honda CLARITY FUEL CELL[46]

charging infrastructure development, the measures being used to promote this development, and technological trends.

2.4.1. Current progress

Figure 4 shows the cumulative number of rapid and normal chargers (in this article, a charger with an output of less than 10 kW) already installed in Japan. The significant growth in the number of installed normal chargers between September and December 2014 is due to a period of rapid progress in the installation of normal chargers by municipalities and stores overlapping with the period when the installation of 125 chargers Tokyo Midtown, the largest such installation in Japan at that time, was announced. The large increase in the number of normal chargers also recorded between September and December 2015 is attributed to the continuation of intensive charger installation at large-scale commercial facilities (Fig. 5). Similarly, the number of installed fast chargers recorded a significant increase between March and June 2015, and the promotion of fast charger installation at convenience stores throughout Japan is thought to have contributed to this result.

2.4.2. EV and PHEV Road Map

According to the report released by the Study Group on the Road Map for EVs and PHEVs in March 2016[35], some progress has been made in installing fast chargers (for en route charging), but there is still a need to deal with the remaining blank areas not covered by fast chargers, and to promote additional development and installation based on optimal charger placement. In terms of normal chargers (charging at destinations), public and private sectors initiatives to promote further installation will remain a prerequisite for the foreseeable future if the goal is to have 1 million EVs and PHEVs on the road in Japan by the year 2020 (accounting for approximately 1.5% of all passenger vehicle ownership). Furthermore, if a total of 20,000 normal chargers (including those already installed) are set up at locations such as large-scale commercial facilities and lodging facilities by 2020, then this will make a major contribution to improving the convenience of EVs and PHEVs.

2. 4. 3. Increasing charger output

Automobile manufacturers, battery charger manufacturers, and the CHAdeMO Association are all investigating the best way to develop high-output fast chargers that exceed 50 kW to further extend the cruising range of EVs and PHEVs (35). Leading the way is the Supercharger from Tesla Motors, Inc. of the U.S. with maximum output of 120 kW (which can only be used to charge Tesla EVs). As of April 2016, a total of 3,652 of these Superchargers had been installed at 617 locations around the world(36). Audi AG announced that it has developed a fast charger exceeding that of Tesla at 150 kW[(37)], and Porsche AG has also announced an 800 V fast charger called Porsche Turbo Charging[(38)] (Fig. 6), exemplifying the increasing move toward high-output chargers. The media has also been reporting that leading global companies from other industries, such as Apple, Google, and Dyson, are working to develop EVs[(39)–(41)], drawing attention to the choice of charging methods these companies will make.

2. 4. 4. New technologies

The Toyohashi University of Technology and the Taisei Corporation are studying a tire-based electric power collection method as a unique technology in the area of non-contact electric power supply to further the development of EVs (Fig. 7). This technology seeks to utilize the electrostatic capacity between the vehicle's wheels, as well as that between conductor plates beneath the road surface and the steel belts within the tires, as a high-frequency circuit[(42)]. Successful implementation of this technology would eliminate the need to equip EVs with expensive and heavy batteries. The Toyohashi University of Technology and other institutions are now tackling issues such as how to improve the basic performance of electrified roads, reduce the costs, improve safety, and develop universal standards. They are carrying out demonstration testing of this technology on expressways and are also aiming to apply this technology to indoor transportation systems for eventual commercialization.

2. 5. Trends in standardization

ISO/TC22 (Road vehicles)/SC37 (Electrically-propelled vehicles)/WG1 (Safety) is now deliberating potential revisions to ISO 6469-1 (Safety specifications for the on-board rechargeable energy storage system (RESS)), ISO 6469-2 (Vehicle operational safety means and protection against failures), and ISO 6469-3 (Protection of persons against electric shock). The majority of the content of ISO 12405-3 (Safety performance requirements for lithium-ion battery packs) is scheduled to be integrated into ISO 6469-1 as special notes and instructions during this round of revisions. In addition, ISO 6469-4 (Post-crash electrical safety) was formally issued as an IS in September of 2015.

3 Fuel Cell Electric Vehicles

3. 1. Introduction

As a renewable energy source that can be made from a variety of different substances, hydrogen is seen as one effective means of addressing the threat of global warming. On April 11, 2014, the Japanese Cabinet approved the Fourth Strategic Energy Plan, which assigned hydrogen a critical position in the section on the future of secondary energy structures such as hydrogen that contribute to a stable supply and global warming countermeasures[(43)]. Fuel cell vehicles (FCVs), which use hydrogen as fuel, do not emit any CO_2 while driven, and there are calls to increase the adoption of these vehicles as next-generation vehicles that will lead to reducing greenhouse gas emissions.

FCVs began to be leased to government agencies in Japan in December 2002. Since then, their cruising range has been extended by increasing the hydrogen storage pressure from 35 MPa to 70 MPa, and improvements in warm-up performance have enabled them vehicles to start in sub-zero temperatures, giving FCVs about the same level of convenience as gasoline engine vehicles. At present, the Mirai from Toyota Motor Corporation and the Clarity Fuel Cell from Honda Motor Company have been sold in Japan since 2014.

On March 22, 2016, METI released a revised version of its strategic Road Map for Hydrogen and Fuel Cells[(44)], which sets targets for the dissemination and 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.

3. 2. Trends in Research and Development

3. 2. 1. Trends in FCV research and development

Japan continues to lead the world in FCV research, and Japanese automobile manufacturers are actively developing these vehicles with commercialization in mind. On December 15, 2014 Toyota released the Mirai, the world's first mass-produced FCV. The fuel cell stack in the Mirai has a maximum output of 114 kW (155 PS), the maximum output of the motor is 113 kW (154 PS), the vehicle weighs 1,850 kg, and the maximum speed is 175 km/h. The on-board pressurized tank that holds the hydrogen fuel has a nominal working pressure of 70 MPa and a total volume of 122.4 L (60 L in the front and 62.4 L in the rear). Hydrogen refueling requires about three minutes, and the vehicle has a cruising range of approximately 650 km (in JC08 mode), which is a level of practical performance comparable to that of a gasoline engine vehicle(45).

Following the FCV from Toyota, Honda released its new model FCV, the Clarity Fuel Cell, on March 10, 2016. Fig. 8 shows this vehicle, which was reportedly developed with the following concepts in mind.

(a) Environmentally-friendly
(b) Seats 5 adults with a spacious interior
(c) Expanded driving range per refueling
(d) Practicality as same as a gasoline engine vehicle
(e) Sufficiently appealing as an automobile

From a technical standpoint the fuel cell powertrain of the Clarity has been downsized and is contained entirely under the hood, making it the first sedan-type FCV in the world with room for five adult passengers. Other design innovations led to a 1.5 times increase in per cell power generation performance, allowing a reduction of about 30% in the number of fuel cells, which were also made about 20% thinner. In addition, the adoption of a 70 MPa hydrogen fuel tank, a more efficient powertrain, and a reduction in the amount of energy required for driving all contributed to a driving range of approximately 750 km (in JC08 mode)(46). Table 3 shows the main specifications of the Clarity Fuel Cell vehicle.

Honda also released the Power Exporter 9000 portable external electric power supplier at the same time as the Clarity Fuel Cell. This device was developed by taking full advantage of the many years of experience that Honda has amassed in the development of inverter generators, and it can provide electrical power to an average household for approximately seven days when combined with the Clarity FCV. This device makes it possible for the electricity generated by the vehicle to be provided to the community in a disaster or other emergency[46]. Fig. 9 shows the external appearance of the Power Exporter 9000, while Table 4 shows its main specifications.

The Power Exporter 9000 is an external electric power supplier that can be connected easily to a FCV, take electricity from the vehicle's CHAdeMO port, and provide a maximum output of 9 kVA. The device is extremely versatile due to the fact that it conforms to the Charging and discharging system guidelines for electric vehicles, version V2L DC. It can be used for outdoor applications and as an emergency power source in the event of a natural disaster. In addition, it can provide a stable supply of alternating current with clear waveforms, and the electricity it provides was also confirmed to power medical devices without issues.

3. 2. 2. Trends in establishing hydrogen refueling station infrastructure

The Fuel Cell Commercialization Conference of Japan (FCCJ) aims to realize the steady development of hydrogen fueling stations and the full-scale adoption and popularization of FCVs in the future. To this end, they have drawn up a new FCV popularization scenario from a long-term point of view based on FCV-specific infrastructure constraints and other issues[47].

One of the targets set by the Japanese government to help realize a sustainable society in the future is to reduce the amount of greenhouse gas emissions by 80% by the year 2050. In an effort to contribute to this goal, the scenario drawn up by the FCCJ sets its own targets of disseminating 3 million FCVs by 2040, and then 8 million by 2050. A very ambitious scenario with high expectations for significant technological progress in this area was also drawn up in an effort to show the requirements for even earlier attainment of a sustainable society.

Hydrogen stations are absolutely essential if FCVs are going to grow in popularity, so more of these stations must be established in advance to expand the areas where FCVs can be introduced. Consequently, various initiatives are now being promoted to significantly reduce the construction costs, operating costs, and hydrogen procurement costs associated with such stations. The aim is to establish hydrogen stations with self-sustaining operations that average a capacity utilization of around 900 FCV per station by the latter half of the 2020s.

Of course, if the goals and targets of this scenario are to be realized, then private companies must proactively tackle the challenges of reducing the cost of FCVs and helping the hydrogen station businesses become self-reliant. However, to overcome structural issues such as establishing hydrogen stations in advance, which would be difficult for private companies to solve on their own, it is

Table 3 Main Specifications of the Honda CLARITY FUEL CELL[46]

Passenger capacity			5 people
Powertrain	Motor	Max. output	130 kW/4 501−9 028 rpm (Max. speed: 13 000 rpm)
		Max. torque	300 N・m/0−3 500 rpm
		Type	AC synchronous motor
	Fuel cell stack	Max. output	103 kW
		Type	Solid polymer electrolyte
	Battery for drive power	Type	Lithium-ion
Fuel tank		Type	Compressed hydrogen
		Tank volume	141 L (Front 24 L / Rear 117 L)
		Nominal working pressure	70 MPa
Dimensions (length × width × height)			4 915 mm × 1 875 mm × 1 480 mm
Vehicle weight			1 890 kg

Table 4 Main Specifications of the Honda Power Exporter 9000[46]

Rated output	9 kVA
Output voltage / frequency	AC 100・200 V(single-phase three-wire)/50, 60 Hz(switchable)
Power conversion system	Inverter system
Weight	50.8 kg
Length × width × height	755 mm × 387 mm × 438 mm
Output terminals	121 / 100 V × 6 outlets / 200 V × 1 outlet
Applicable standards	Charging and discharging system guidelines for electric vehicles, version V2 L DC
Japanese manufacturer's suggested retail price (reference)	1.18 million yen (includes consumption tax)

Fig. 9 Honda Power Exporter 9000[46]

essential for partnerships between public and private entities to strengthen and continuously implement various initiatives such as promotional policies, technological development, and regulatory reviews.

The number of commercial hydrogen stations in Japan is currently increasing steadily. According to a survey by the Japanese Association of Hydrogen Supply and Utilization Technology (HySUT) dated March 31, 2016, hydrogen fueling stations are operating in 81 locations. By region, there are 37 stations in the Tokyo area, 20 in Nagoya, 13 in Osaka, and 11 in Kitakyushu. By type, 40 are off-site stations, 14 are on-site stations, and 27 are mobile stations.

HySUT has also drawn up and published the following guidelines that are mainly concerned with the operation of commercial hydrogen stations(48).

・Filling performance confirmation guidelines (latest version enacted: March 18, 2016)
・Operational guidelines for hydrogen quality control (latest version enacted: March 16, 2016)
・Operational guidelines for hydrogen weighing control (latest version enacted: March 18, 2016)

The 81 hydrogen stations described previously comply with all of the guidelines listed above, and as such they are spearheading the establishment of a functioning hydrogen fueling infrastructure for the world. Japan has led the world in being the first to fully enter the FCV market, and the high level of infrastructure that has been developed will serve as a strong engine to propel them toward providing a real sense that the FCCJ scenario will be achieved.

3.3. Trends in standardization

At the present time the development of international standards for FCVs is being handled by ISO/TC22(Road vehicles)/SC21 (Electrically-propelled vehicles) and ISO/TC197 (Hydrogen technologies). As a result of the deliberations in these committees, issues such as FCV safety, the fuel tanks equipped on FCVs, hydrogen fueling station safety, and hydrogen fuel specifications are all being actively discussed at the international level in accordance with the deliberation phase of the ISO.

ISO 6469-4 (Post-crash electrical safety) was formally issued in September of 2015 by ISO/TC22/SC21 as evidence of its recent moves to issue IS and its preparations to issue others in the near future.

ISO/TC197 is continuing to deliberate on ISO 19880-1 (General regulations for gaseous hydrogen fueling stations) with an aim to issue this standard sometime in 2017. In the course of these deliberations on the hydrogen station regulations, the necessity of a standard for hydrogen quality control was also discussed. Consequently, new deliberations have begun on this issue (ISO 19880-8) with Japan serving as the host and committee chair. The aim is to issue this standard sometime in 2016. On the other hand, work to revise the hydrogen fuel quality standards is being promoted on the assumption that the era of mass dissemination of FCVs is quickly approaching and so the committees are aiming to issue the hydrogen fuel product specifications (ISO 14687) in 2018. They are also aiming to issue the standards for gaseous hydrogen land vehicle refueling connection devices (ISO 17268) sometime in 2016 and so amendments are now being deliberated on. This series of international standards concerning hydrogen technologies are planned to be cited in upcoming European legislation as the market for hydrogen fuel in Europe develops and so they are being regarded as critically important.

The deliberations also continue on ISO 19881 (Gaseous hydrogen: Land vehicle fuel tanks) and ISO 19882 (Thermally activated pressure relief devices for hydrogen fuel tanks). These deliberations have entered the final stages and these standards should be issued sometime in 2016.

3. 4. Summary

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

4 Electric Power

4. 1. Introduction

The electrification of vehicles is continuing to advance both to reduce CO_2 emissions and to improve power performance. As this electrification advances, electric motors and batteries are being installed on vehicles in various different categories, and motors and batteries with the most suitable output characteristics for their respective applications and performance are being adopted. This section introduces the main 2015 trends in electric motors.

4. 2. Electric motors

Table 5 lists the main electric motors used to provide drive power installed in new Japanese passenger vehicles, as well as vehicles imported by members of the Japan Automobile Importers Association, sold in Japan between January and December 2015. Regardless of whether they are for HVs or EVs, many models have

Table 5 Main motors installed in electric-powered passenger vehicles.[1]

Name of company	Model	Type*	Max. output [kW]	Torque (Nm/min^{-1})	System	Main target vehicles
Toyota Motor Corporation	2 LM	PM	45/―	169/―	HEV	Sienta
	1 NM	PM	53/―	163/―	HEV	Prius (front)
	1 MM	IM	5.3/―	55/―	HEV	Prius (rear)
	6 JM	PM	123/―	335/―	HEV	RX450h<Front>
Nissan Motor Co., Ltd.	RM31	PM	30/―	160/―	HEV	X-Trail Hybrid
Suzuki Motor Corporation	WA05A	IM	2.3/1 000	50/100	Mild HEV	Solio
Mercedes-Benz Japan	EM0011	PM	60/―	340/―	HEV	C350e
	EM0007	PM	20/―	250/―	HEV	S300h
Porsche Japan	Unknown	PM	70/2 200～2 600	310/1 700	HEV	Cayenne, Panamera
BMW Japan	P250	PM	93/3 800	250/0 ～ 3 700	HEV	i8
Volkswagen Group Japan	EAH	PM	80/―	330/―	EV	GOLFGTE, A3e-TRON
Tesla Motors	Unknown	IM	193/―	330/―	EV	modelS<Front>
	Unknown	IM	375/―	330/―	EV	modelS<Rear>

* PM : AC synchronous motor IM : AC synchronous motor

Table 6 Main motors installed in electric-powered commercial vehicles.[1]

Name of company	Model	Type*	Max. output [kW]	Torque (Nm/min^{-1})	Vehicle usage	Main target vehicles
Isuzu Motors	HE11	PM	40/1 400～3 850	274/500～1 400	Truck	Elf
	HB1	PM	44/1 000	—	Bus	Elga
Hino Motors, Ltd.	Unknown	PM	36/1 024	333/1 024	Truck	Dutro
	Unknown	PM	90/—	—	Bus	Blue Ribbon
	Unknown	PM	36/—	350/—	Truck	Ranger
Mitsubishi Fuso Truck and Bus	S20	PM	40/—	200/—	Truck	Canter

* PM : AC synchronous motor

AC synchronous motors that use permanent magnets. The output of these motors is about 2 kW for those used in mild hybrid, and ranges from 20 to 120 kW for those used in HEVs that run as EVs. In motors for electric vehicles, the range is about 80 to 375 kW. The speed of the motors at maximum output is often left out of the specifications list and remains unclear. The four-wheel drive Prius launched in 2015 uses an induction motor as the motor installed in the rear the vehicle. This choice was likely made to reduce core loss since the rear motor idles during cruising.

The main electric motors used to provide drive power in commercial HEVs sold in 2015 are listed in Table 6. In commercial HEVs primarily run on the engine, where motors that use a parallel system to provide assistance during starts and acceleration, or perform regenerative braking are common, the motors are relatively small relative to the weight of the vehicle, with an output of about 40 kW in trucks. The motors used in large buses have an output of approximately 90 kW.

Recent research trends have been actively focusing on efficient magnet arrangements that reduce the need for rare earth, switched reluctance motors, motors move away from the use of rare earth, and other development aimed at moving away from the use of rare earth. At the same time, other new technological developments, such as using an electronic device to switch between the two different winding wires used, respectively, for low-speed and high-speed rotation are being pursued in conjunction with efforts to reduce size and weight by increasing rotation speed.

References

(1) http://www.cev-pc.or.jp/index.html
(2) http://toyota.jp/
(3) http://www.honda.co.jp/auto
(4) http://www.nissan.co.jp/
(5) http://www.suzuki.co.jp/car/
(6) http://www.mazda.co.jp/
(7) http://www.bmw.co.jp/ja/index.html
(8) http://www.volkswagen.co.jp/ja.html
(9) http://www.subaru.jp/
(10) https://lexus.jp/
(11) http://www.audi.co.jp/jp/brand/ja.html
(12) http://www.hino.co.jp/
(13) http://www.mercedes-benz.co.jp/
(14) http://www.mitsubishi-motors.co.jp/
(15) http://www.jari.or.jp/Portals/0/jhfc/data/report/2010/pdf/result.pdf (Apr.6, 2016), JARI
(16) https://www.airia.or.jp/publish/statistics/trend.html
(17) http://www.mitsubishi-motors.com/publish/pressrelease_jp/products/2015/news/detail4906.html
(18) http://www.nissan-global.com/JP/NEWS/2015/_STORY/151110-01-j.html
(19) http://www.nissan.co.jp/
(20) http://www.mitsubishi-motors.com/jp/
(21) http://www.meti.go.jp/press/2014/11/20141117003/20141117003-A.pdf
(22) http://www.meti.go.jp/press/2014/03/20150312001/20150312001.html
(23) http://www.mlit.go.jp/report/press/jidosha10_hh_000159.html
(24) http://www.nissan-global.com/JP/NEWS/2015/_STORY/150603-01-j.html
(25) Shimamoto et al., Proceedings of JSAE Annual Autumn Congress (2015)
(26) Fujimoto et al., Proceedings of the 56th Battery Symposium in Japan, IM15 (2015)
(27) Iwatsubo et al., Proceedings of the 56th Battery Symposium in Japan, IM16 (2015)
(28) http://www.mitsubishi-motors.com/publish/pressrelease_jp/corporate/2015/news/detailf710.html
(29) http://www.nissan-global.com/JP/NEWS/2015/_STORY/150902-01-j.html
(30) http://www.nissan-global.com/JP/NEWS/2015/_

STORY/151021-02-j.html
(31) http://www.honda.co.jp/news/2015/4151019.html
(32) http://www.chademo.com/wp/japan/mission/
(33) Transition number of CHAdeMO's fast charging station, CHAdeMO website (Mar. 27, 2016)
(34) EVPOSSA Website, Shipping Statistics Report (Sep. 2015)
(35) http://www.meti.go.jp/press/2015/03/20160323002/20160323002.html
(36) https://www.teslamotors.com/jp/supercharger
(37) http://www.audi.co.jp/jp/brand/ja/company/news.detail.news/pool/2015/09/150915.html
(38) http://www.porsche.com/microsite/mission-e/international.aspx#/reveal
(39) Nihon Keizai Shimbun (Feb. 24, 2015)
(40) https://www.google.com/selfdrivingcar/
(41) http://www.theguardian.com/environment/2016/mar/23/dysondeveloping-electric-car-government-documents
(42) http://www.tut.ac.jp/docs/PR160318.pdf
(43) http://www.enecho.meti.go.jp/category/others/basic_plan/pdf/140411.pdf
(44) http://www.meti.go.jp/press/2015/03/20160322009/20160322009-c.pdf
(45) http://toyota.jp/mirai/performance/
(46) http://www.honda.co.jp/news/2016/4160310.html
(47) http://www.fccj.jp/jp/information.html
(48) http://hysut.or.jp/information/index.html