THE ENVIRONMENT AND THE AUTOMOBILE INDUSTRY

1 Introduction

Sales of (four-wheeled) vehicles in Japan in 2017 were approximately 5.23 million, an increase of 260,000 from the previous year. Recent vehicle sales in Japan have remained around 5 million for several years, representing the third largest number of vehicle sales in the world following China and the United States. Considering that over 7 million vehicles were sold around 1990, however, the growth rate of the Japanese market has declined. Meanwhile, total Japanese production of (four-wheeled) vehicles in 2016 was approximately 9.2 million vehicles, which is nearly twice the number sold in Japan. This means that exported vehicles accounted for a large percentage of those produced, and that trends in overseas markets and regulations established individually by various countries are the key to further sales growth. In 2017 the French government drew attention with its announcement of a ban on the sale of exclusively internal combustion engine-driven vehicles by 2040. As it was made by the environment ministry, which is responsible for issues such as global warming, the announcement is unlikely to have involved careful consideration of the energy supply/demand balance, changes in industrial structure, and the user needs it may affect. Therefore, careful monitoring of whether the plan progresses as intended will be required.

Preliminary figures from fiscal 2016 indicate that the transportation sector in Japan produces 215 million tons of CO2 emissions. In spite of a slight increase in the total number of owned vehicles, CO_2 emissions continue to decrease, a result attributed in part to the success of efforts to spread of hybrid and other low-emissions and fuel efficient vehicles. Consequently, this article briefly examines the regulatory trends regarding vehicle fuel economy and exhaust emissions in and outside Japan, and also takes a look at the technical trends in representative models launched between 2017 and early 2018.

2 Laws and Regulations

2. 1. Fuel Economy (or CO_2) Standards

In Japan the standards for vehicle fuel economy are based on the Act on the Rational Use of Energy (Energy Saving Act) and formulated using the top-runner approach[1]. The latest standards apply to the 2015 target year for heavy-duty vehicles, and to the 2020 target year for light- and medium-duty vehicles such as passenger cars (2022 for commercial vehicles). To replace the current standards for heavy-duty vehicles, the Ministry of Economy, Trade and Industry and the Ministry of Land, Infrastructure Transport and Tourism started to examine measures for the next fuel economy standards (2025 target year) in 2017, to be formulated in early 2018[2]. The next fuel economy standard proposed is 7.63 km/L for trucks, which is 13.4% stricter than the 2015 standard (6.72 km/L) (Fig. 1). These figures were obtained using the test methods stipulated in each standard. Carrying capacity, high-speed driving ratios, and other factors presented in the released materials were partially revised

Comparison between new and current fuel economy standards

The average fuel economy values of the new fuel economy standards (target year: 2025) are shown below. Due to the revision, the standards for heavy-duty vehicles are strengthened by 13.5% from the current 2015 standards.

Comparison between current standards

－Trucks

Vehicle type	Current (2015) standard value [km/L]	New (2025) standard value [km/L]	Comparison between current standards
Trucks	7.10	8.13	14.5% increase
Tractors	2.84	2.94	3.7% increase
Overall	6.72	7.63	13.4% increase

－Passenger vehicles

Vehicle type	Current (2015) standard value	New (2025) standard value	Comparison between current standards
Route buses	4.77	5.01	5.1% increase
General buses	6.07	7.18	18.3% increase
Overall	5.71	6.52	14.3% increase

* The standard values are calculated on the assumption that the number of shipments in each category is the same as that of the reference year (2014).
* The current (2015) standard values comply with the conventional measurement method, whereas the new (2025) standard values comply with the new measurement method.

Fig. 1 Next fuel economy standards for heavy-duty vehicles

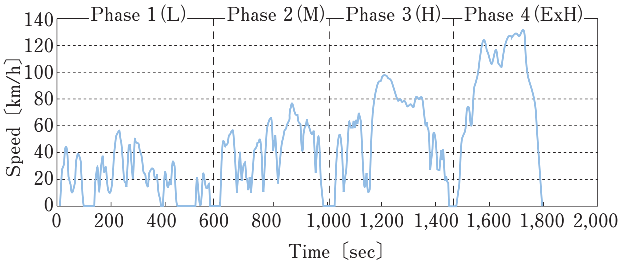

Fig. 2 WLTC Vehicle Speed Pattern (in Japan evaluations are performed without the extra high (ExH) portion)

from the current test method based on recent research results. Although a 13.4% improvement may not lead to a direct corresponding improvement in technology, achieving such a level of improvement based on figures more in line with actual conditions should make a similar amount of actual fuel consumption or CO_2 emissions reduction possible.

Taken as a whole, the 2020 standards for passenger vehicles were achieved as early as 2013, well ahead of schedule. With the target already achieved, and based on past examples, it is high time to begin examinations concerning the post-2020 standards. In March 2018, the Ministry of Economy, Trade and Industry and the Ministry of Land, Infrastructure Transport and Tourism announced the start of work on formulating new fuel economy standards[3]. It is regarded as certain that in the next standards the evaluation mode will introduce an internationally unified test cycle (WLTC, Fig. 2) to replace the current JC08 mode. Characteristics of the WLTC include placing greater emphasis on cold starts, as well as higher average and maximum vehicle speeds and less idling than the JC08 mode. Some measurements have shown that with these characteristics, the more hybrid and other vehicles actively rely on fuel-efficient technology designed to be effective under the JC08 mode, the greater the decrease in their fuel economy value decreases under the WLTC[4]. Achieving higher standards will require further promoting the spread of electric vehicles (EVs) and plug-in hybrid vehicles (PHEVs). Thus, evaluation methods for EVs, PHEVs, and HEVs under the new fuel economy standards are extremely important. The discussions will receive attention as the decisions made in that respect will have repercussions on the adoption rates of the vehicles.

One recent trend outside Japan involves an evaluation method based on making calculations with the Vehicle Energy Consumption Calculation Tool (VECTO). Europe, which has no established fuel economy evaluation method for heavy-duty vehicles, has been assessing this tool for a long time and announced it would be released in 2018. After its release, evaluation methods will be established in Japan, the U.S., and Europe. In Europe, fuel economy test methods already developed and introduced in Japan are used as reference in establishing test methods, but each country takes its own approach, resulting in mutually incompatible methods. Since a wide variety of models and types as well as differences in vehicle standards based on road regulations must be taken into account for heavy-duty vehicles, the standardization fuel economy-related issues, unlike that of emissions regulations, will remain difficult for the foreseeable future.

2. 2. Emissions Regulations

In 2016 exhaust emissions regulations for heavy-duty vehicles in Japan were strengthened further, a tightening that coincided with the introduction of international unified testing methods (the World Harmonized Transient Cycle (WHTC), World Harmonized Stationary Cycle (WHSC), and Off-Cycle Emissions (OCE) test). The regulations have gradually expanded in scope, applying to heavy-duty vehicles with a gross vehicle weight exceeding 7.5 t in 2016, tractors in 2017, and heavy-duty vehicles with a gross vehicle weight of 7.5 t or less in 2018. Regulations concerning on-board diagnostics (OBD) were strengthened two years after the 2016 regulations were announced (two years after 2017 or 2018 for categories starting in those years), followed by the introduction of the WWH-OBD (a high level OBD corresponding to the J-OBD II for passenger vehicles) based on international unified standards. Recent low-emission vehicles place more importance on whether the emissions reduction device functions properly rather than on the regulation values themselves, an approach that will enable WWH-OBD to contribute to improving the environment.

Meanwhile, the evaluation test cycles for light- and medium-duty vehicles will be replaced with the WLTC in 2018. No significant strengthening of regulation values and other items from the New Long Term Standards that Japan enacted in 2005 has taken place. There is a sense of having come close to the goal in terms of strengthening the regulations for exhaust emissions measured with a predetermined test cycle in a laboratory. One remaining element is the regulation concerning the PM emissions from direct-injection gasoline-engine vehicles introduced in Europe. The Central Environment

Fig. 3 Toyota Prius PHV

Fig. 4 Nissan Leaf[14]

Fig. 5 Toyota Camry (Hybrid)

Council reported that it would be appropriate to start applying this regulation in Japan by 2020[5]. In addition to the lean-burn engines that have been subject to regulation up to now, direct-injection gasoline-engine vehicles with stoichiometric control will also fall under these regulations and therefore require countermeasures.

There is no doubt that exhaust emissions performance and evaluation methods for vehicles (mainly for diesel passenger vehicles) during actual driving in the real world are currently drawing more attention than laboratory tests. In 2015, a diesel passenger car emissions scandal was brought to light in the U.S. Despite ongoing efforts to strengthen emissions regulations in Europe, the lack of improvement in NO_2 gas concentrations in urban areas is regarded as a problem. Consequently, the Real Driving Emissions (RDE) test, where vehicles are equipped with a Portable Emissions Measurement System (PEMS) and their emissions performance is evaluated while they are driven on the road, has begun in Europe in September 2017. Japan also responded to these events by establishing an investigative commission to review inspection methods for diesel passenger cars and other vehicles in light of the exhaust emissions cheating incidents[6] and announcing the final summary of the review results in April 2017. The summary proposes the introduction of protection control guidelines and on-road running inspections in 2022 that would allow NOx emissions up to twice the on-bench regulation value.

3 Technological Trends

3. 1. Fuel Economy Improvement Trends

The popularization of hybrid vehicles and start-stop systems has exceeded expectations and accelerated the remarkable improvement in the fuel efficiency of light- and medium-duty vehicles in recent years. Advances in other basic elements, such as the improvement of the transmission system efficiency, the reduction of friction, or weight reduction, are also being made. Further improvements in fuel efficiency are expected to continue for some time as these conventional technologies are refined even further and applied to a wider number of vehicle models.

The complete redesign of the Nissan Leaf, the world's highest-selling EV, and of the Toyota Prius PHV, which plays a leading role in the field of PHEVs, clearly stands out among topics concerning fuel-efficient vehicles in 2017 and the first half of 2018.

In February 2017 the Toyota Prius PHV (Fig. 3) was completely redesigned[7]. In addition to an extended EV cruising range, the new Prius PHV realizes better running performance by allowing the generator normally used for normal power generation to temporarily provide drive power. Instantaneous drive performance leveraging electric assistance is a selling point for high-performance-oriented HEVs and PHEVs in Europe, and the new Prius PHV appears to incorporate a control system different to that of the normal Prius. In March, one month after the announcement, the number of orders had reached approximately 12,500 units, which is five times the monthly sales forecast. With only a few models priced in the same range or higher than the Prius PHV selling more than 2,500 units a month, the number of sales was appropriate in scope. Close attention will be paid to whether this will promote the further expansion of PHEVs.

In September 2017, the Nissan Leaf (Fig. 4) was redesigned[8]. The cruising range-the largest bottleneck in EVs-ranged from 228 km (initial model) to 280 km (improved model) was increased to 400 km in JC08 mode while limiting weight increase, including other performance improvement elements, to approximately 40 kg. Charging time becomes an issue when extending the cruising range, and the batteries can be charged up to 80% in approximately 40 minutes during rapid charging. In an effort to conserve energy, some grades are equipped with a heat pump-based heating system.

Meanwhile, conventional hybrid vehicles, which use gasoline as an energy source and offer top class fuel

Fig. 6 Honda Stepwgn Hybrid

Fig. 7 Nissan Serena e-Power

Fig. 8 Mercedes-Benz S450

economy, have primarily been introduced in the sedan and minivan categories.

In July 2017, the Toyota Camry was completely redesigned[9] (Fig. 5). Fuel economy was improved significantly from the previous model, achieving 28.4 to 33.4 km/L. This was made possible by a newly developed 2.5 L engine with a maximum heat efficiency of 41% that also features a higher compression ratio, a longer stroke, and intensified tumble. This maximum heat efficiency of 41% exceeds the value of the engine on the Prius, which implies the intention to make this new engine mainstream.

In September 2017, a model equipped with a 2-motor hybrid system called Sport Hybrid i-MMD (Fig. 6) was added to the Stepwgn lineup[10]. While non-hybrid models use a 1.5 L turbocharged engine, the system in the hybrid model is combined with an Atkinson-cycle 2.0 L naturally aspirated engine. It offers a fuel economy of 25.0 km/L in the JC08 mode and 20.0 km/L under the WLTC.

In February 2018, the Nissan Serena series was expanded with a model equipped with e-Power[11] (Fig. 7). Highly acclaimed when it was mounted on this automaker's Note compact car, e-Power is a series hybrid system with a solely electric drive in which the 1.2 L gasoline engine is not connected to the wheels and only serves to generate power. It has a fuel economy of 26.0 km/L in JC08 mode.

In March 2018, Mercedes-Benz added the S450 to its high-grade S Class[12] (Fig. 8). The key feature of the S450 is the mounting of an integrated starter generator (ISG) on its 48 V mild hybrid system. An electric motor generating a maximum output of 16 kW and a maximum torque of 250 Nm is mounted between the engine and the transmission. The newly designed engine has an in-line 6-cylinder configuration, a first in approximately 20 years (since 1997) for Mercedes-Benz. Electric air conditioners and water pumps eliminate the need to provide belt-driven auxiliary devices, contributing to reducing its size. The electric supercharger that functions even at low engine speeds realizes powerful acceleration at low speeds. Despite interest in the fuel economy value with the inclusion of the ISG, no official announcement had been made as of March 2018.

3. 2. Exhaust Emissions Reduction Trends

Exhaust emissions regulations started with gasoline vehicles everywhere in the world, including Japan. The resulting rapid introduction of technological measures has been bringing emissions from current gasoline vehicles down to a level that is not particularly harmful. However, it may become necessary to equip direct-inject gasoline vehicles with the same particle filters required on diesel vehicles as a countermeasure against particulate matter (PM).

By the same token, the issue of diesel vehicle emissions has been tackled through the wide adoption of diesel particulate filters (DPF) and the reduction of the amount of sulfur (S) in diesel fuel, mostly erasing the old image of diesel vehicles as smelly, dirty, and noisy. Nevertheless, there is still a large difference between the performance of the three-way catalysts on gasoline vehicles and the DPFs on diesel vehicles in terms of durability and purification. Nevertheless, in terms of technologies for improving emissions, it is probably accurate to say that all the actors are currently on stage, and the probability that some totally new and as yet unknown technology will be adopted is low. Consequently, it is likely that efforts will focus on further improving individual technologies, such as the precise modeling of urea SCR, which is influenced by many factors and requires complex control. It is expected that further evolution will arise from adaptations applied to multiple technologies. Making these adaptations is extremely complex and will require many hours of labor. In addition, the number of technical matters to cover, such as emissions compliance with the RDE test, will only continue to increase. In addition to technological capability encompassing various elements, the ability to conduct rapid, low-cost development seems to be the key to success.

The reputed SkyActiv 2.2 L diesel engine has been im-

Fig. 9 Mazda CX-8

(a) Mitsubishi e-Evolution (b) Mercedes-Benz EQA

Fig. 11 EV concept vehicles exhibited at the 2017 Tokyo Motor Show[14]

proved in the Mazda CX-8 (Fig. 9) released in December 2017[13]. An SUV with three rows of seats, the CX-8 is the largest and heaviest model in the Mazda lineup. In diesel engines, higher loads generally make it more difficult to perform EGR, which is effective at reducing NOx, and since passenger vehicle class emissions evaluations are based on distance (g/km), NOx must be further reduced in heavier vehicles for the same amount of work. Therefore, most diesel engines in heavy SUVs are equipped with a post-NOx reduction processing device (mainly urea SCR). However, this is not the case in the CX-8. To achieve this, high pressure multiple injection of fine fuel spray was realized through rapid multiple combustion, and the low pressure turbocharger of the 2-stage turbocharging system was made geometrically variable to maintain turbocharging pressure at low speeds. This model can be described as a perfect showcase for Mazda's combustion-centered engine technologies.

From April to May 2017, various heavy-duty vehicle manufacturers announced heavy-duty vehicles with a gross vehicle weight of 7.5 tons or more equipped with engines complying with the 2016 regulations. Demand for improved fuel economy is stronger for heavy-duty vehicles than for light-duty vehicles, and a worsening of fuel economy in the name of compliance with stricter emissions regulations would severely damage product appeal. Each manufacturers is therefore applying is own innovations to successfully both reduce emissions and improve fuel economy. The A09C engine (Fig. 10) announced by Hino Motors, Ltd. is equipped with a 2-stage turbocharger offering enhanced performance by raising

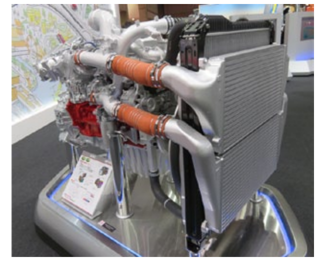

Fig. 10 Hino A09C Engine[14]

turbocharging efficiency through an intermediate cooler provided in each stage and improved response with the use of a smaller high pressure stage compressor. Insufficient turbocharging pressure due to a delay in turbocharger response (turbocharging lag) when power and torque are required for acceleration leads to an insufficient amount of air and excessive PM generation in spite of EGR, negatively impacting both power and emissions. The above measures are highly effective at mitigating or eliminating those negative factors, and potentially represent one of the future engine trends.

4 Looking Towards the Future

Although both fuel economy and emissions have been greatly improved from many years ago, regulations continue to be further strengthened worldwide. Electrification is increasingly brought up as a solution, and many EV concept vehicles were exhibited at the Tokyo Motor Show. Most of them, however, were high performance vehicles at or above the midpoint of the price range (Fig. 11). In the mini-vehicle or light-duty classes, which account for the vast majority on a number of units basis, no new models capable of competing with conventional vehicles were presented. Although the number of EVs is predicted to increase, it will be a long time before they become mainstream on a number of units basis. In the short term, advances in electrification will be found primarily in hybrid vehicles and PHEVs. Under these circumstances, as noted in section 3.1, highly efficient engines are essential to improve the performance of the vehicle as a whole. Maintaining advanced engine technologies will be a crucial factor in achieving greater competitiveness in terms of environmental performance, as well as in maintaining and expanding market share on a number of units basis.

References

(1) Website of Ministry of Land, Infrastructure,

Transport and Tourism, http://www.mlit.go.jp/jidosha/jidosha_fr10_000005.html (in Japanese)
(2) http://www.mlit.go.jp/common/001212397.pdf (in Japanese)
(3) http://www.mlit.go.jp/report/press/jidosha10_hh_000196.html (in Japanese)
(4) Youichi Suzuki, Kyohei Yamaguchi: Fuel Consumption and Emission Performance in Worldwide Harmonized Light Vehicle Test Procedure, Journal of Society of Automotive Engineers of Japan, Inc., Vol. 47, No. 4, p. 973-978 (2016) (in Japanese)
(5) Ministry of the Environment, Countermeasure to Reduce Automobile Emission Gas in the Future (13th Policy Report), https://www.env.go.jp/press/104118.html (in Japanese)
(6) Website of Ministry of Land, Infrastructure, Transport and Tourism: http://www.mlit.go.jp/jidosha/jidosha_tk10_000035.html (in Japanese)
(7) https://newsroom.toyota.co.jp/en/toyota/22701478.html
(8) https://newsroom.nissan-global.com/releases/release-5f454556692dea59782a3ffa3e0bf3b0-170906-01-e?year=2017
(9) https://newsroom.toyota.co.jp/en/detail/17680157
(10) http://www.honda.co.jp/news/2017/4170928a-stepwgn.html (in Japanese)
(11) https://newsroom.nissan-global.com/releases/release-cf48572264d65dd70eea9e326b00d242
(12) https://media.mercedes-benz.jp/ISG%E6%90%AD%E8%BC%89%E3%83%A2%E3%83%87%E3%83%AB-S-%E3%82%92%E7%99%BA%E8%A1%A8/ (in Japanese)
(13) http://www2.mazda.com/en/publicity/release/2017/201709/170914a.html
(14) Shot in Tokyo Motor Show 2017 (URLs as of April, 2018)