THE ENVIRONMENT AND THE AUTOMOBILE INDUSTRY

1 Introduction

In 2016 approximately 4.97 million (four wheeled) vehicles were sold in Japan. This was the first time since the Great East Japan Earthquake in 2011 that sales fell below 5 million vehicles. Although sales decreased, this figure still represents the third largest number of vehicle sales in the world following China and the United States, so Japan can still be described as one of the world's largest automobile markets. However, 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 are the key to further sales growth as the Japanese vehicle market remains flat. Consequently, this article will examine the regulatory trends regarding vehicle fuel economy and exhaust emissions in Japan and overseas, and then take a look at the technical trends targeting these issues.

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 method"[(1)]. The latest standards apply to the 2015 target year for heavy-duty vehicles, and to the 2020 (2022 for commercial vehicles) target year for light- and medium-duty vehicles, such as passenger cars. Taken as a whole, the 2020 standards for passenger vehicles were achieved ahead of schedule, as early as 2013. One of the main reasons for this is the increase in the number of hybrid vehicles with excellent fuel efficiency performance. Figure 1 shows the growing popularity of next-generation vehicles, the great majority of which are hybrids. Recently, more than one million next-generation vehicles are sold annually, making an obvious contribution to the overall improvement in vehicle fuel efficiency. However, this is not yet seen as sufficient and further strengthening of standards is planned in both Europe and the United States. The need to set the next fuel economy standards is also increasing in Japan.

In comparison to the fuel economy standards in Japan, European standards in are based on the UN Framework Convention on Climate Change and regulate the amount of CO_2 from the standpoint of reducing emissions of greenhouse gases (GHG), while in the U.S., regulations are implemented from the viewpoints of reducing both GHG and fuel consumption. Since CO_2 is produced and emitted by the combustion of hydrocarbon fuels, the difference between fuel economy and CO_2 emissions may not feel very significant. However, the legal systems that form the basis of these regulations are fundamentally different, and this has a major influence on how reference values and the target values are determined, as well as on the thinking behind the attendant penalties.

Figure 2 shows a comparison of the fuel economy and CO_2 regulation values in Japan, the U.S., Europe, and China in terms of the amount of CO_2 emissions[(2)]. This chart makes it obvious that the regulations in each country steadily become more stringent near and beyond 2020. At first glance it appears that the regulation values in Europe are stricter than those in Japan. The difference stems from how these values are determined. In Europe the regulation values are debated based on CO_2 reduction targets and other factors, making it is easier to operate under the premise of a large reduction rate. Japan, in contrast, formulates the fuel economy standards using the top runner method, where the most fuel efficient vehicle in the base year is identified as the benchmark, with the target standard values determined by adding technological improvements and market penetration rates onto this benchmark. Consequently, the Japanese target values can generally be described as more realistic. In Europe, this is counterbalanced by systems not

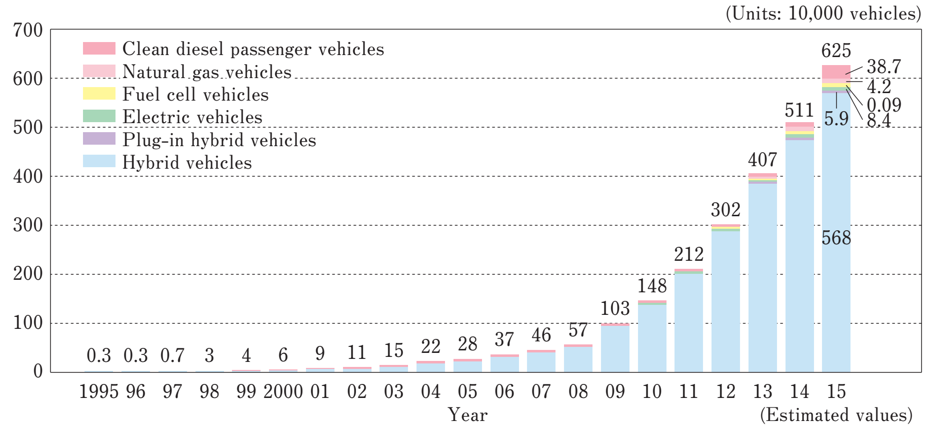
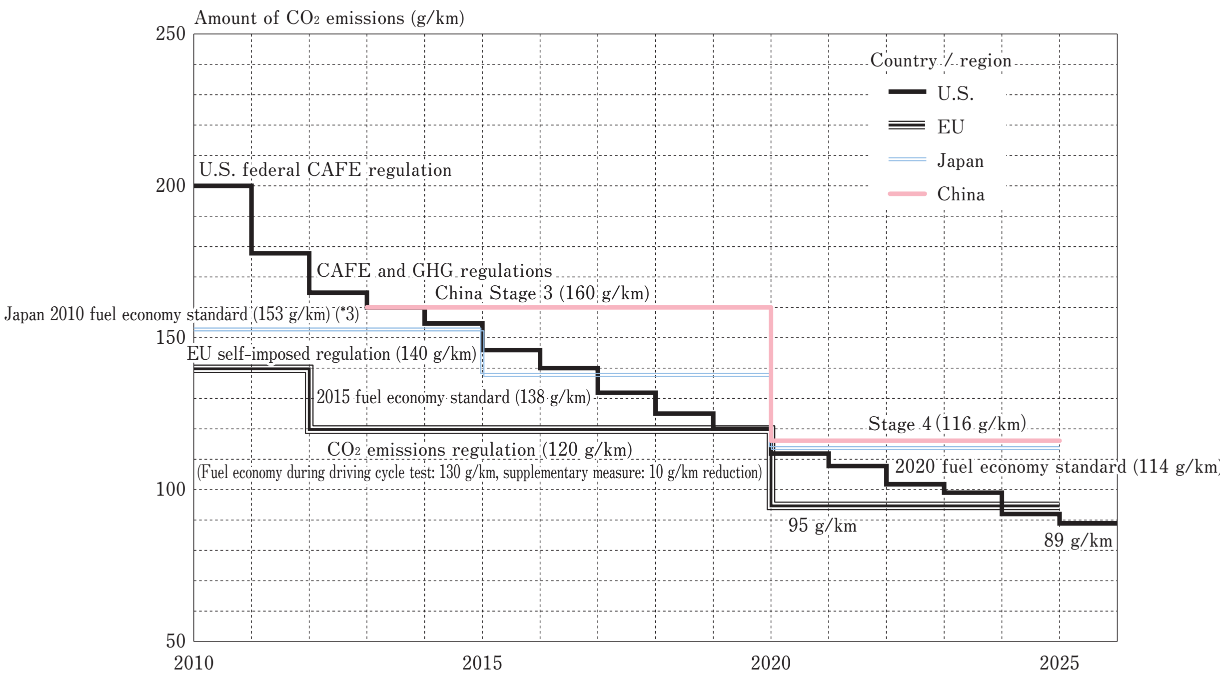


Fig. 1 Increase in Number of Next-generation Vehicles (Source: Survey by the Japan Automobile Manufacturers Association)



(Note) The amount of CO_2 emissions per 1 L of gasoline was calculated as 2,321 g/L. Furthermore, when the values in this graph were calculated, the values published when the regulations were introduced in the various countries were used as is, without taking the influence of factors such as driving patterns, test procedures and fuel, and the existence of a deregulatory measures system into account.

Fig. 2 Change Over Time in Vehicle Fuel Economy (CO_2) Regulation Values in Each Country

found in Japan, such as "eco-innovations", that include fuel economy improvement elements (LED lighting equipment, high efficiency alternators, etc.) not reflected in the fuel economy measured during driving cycle tests, so some aspects cannot be compared strictly by the numbers. In addition, as previously mentioned, Japanese vehicles have already achieved the 2020 fuel economy standards, implying a level of technology equal to or above that of Europe. Consequently, care must be taken when making comparisons based only on the regulations values.

In the U.S. CO_2 is treated as a regulated harmful ingredient in the same manner as CO and NO_x, so exceeding CO_2 emissions limits incurs very severe penalties that include cancellation of vehicle type approval certification in addition to fines based on the amount of insufficient emissions controls. Another difference is that, unlike in Japan where the fuel economy standard value is determined by the vehicle weight category, the U.S. reference value is determined based on the footprint expressed as the product of the tread and the wheel base. This is intended to prevent vehicle safety compromises

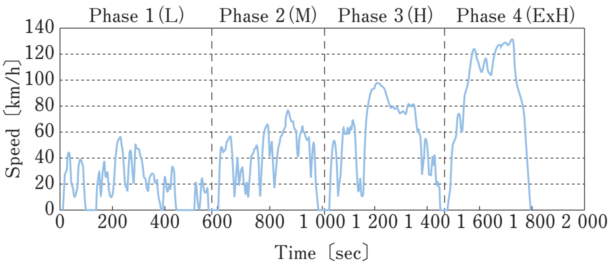


Fig. 3 WLTC Vehicle Speed Pattern (in Japan evaluations are performed without the extra high (ExH) portion)

made to improve fuel economy and reduce CO_2 emissions. In addition, the U.S. allows automobile manufacturers to use a banking system allowing credits earned by selling vehicles that exceed the fuel economy standards to be stored and used later to offset the sale of vehicles with poor fuel economy. This system also allows companies to trade accumulated credits between themselves, so it includes many concepts not found in the Japanese regulatory system. In any case, the calls for improvements in fuel economy and CO_2 emissions in countries around the world will continue for the time being, but their implementation will also continue to depend on the individual circumstances of each country (region). The competition between automobile manufacturers will likely include the development of technologies to address this situation.

2. 2. Exhaust 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 (World Harmonized Transient Cycle (WHTC), World Harmonized Stationary Cycle (WHSC), and the Off-Cycle Emissions (OCE) test). Similarly, starting in 2018 the evaluation test cycle for light and medium-duty vehicles, the majority of which are gasoline-engine passenger cars, will be changed to the Worldwide Harmonized Light Vehicles Test Cycle (WLTC) (Fig. 3). Although this test cycle places greater weight on cold starting and includes elements that require compliance over a wide range of speeds and accelerations, with some exceptions, there does not seem to be a significant strengthening of the regulations from the New Long Term Standards that Japan enacted in 2005. 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 Council reported that it would be appropriate to start applying this regulation in Japan in 2020[(3)]. 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. In addition to this, another test required in the U.S. and Europe, but not in Japan, is a low-temperature exhaust emissions test at -7℃. Discussions about the harmonization of international standards are anticipated to become more active in coming years.

There is no doubt that exhaust emissions performance and evaluation methods for vehicles (mainly for diesel-engine passenger vehicles) during actual driving on the road are currently drawing more attention than laboratory tests. In 2015 in the U.S., diesel-engine passenger cars from Europe were found to be equipped with a device to fraudulently pass emissions tests by only allowing the emissions reduction device to operate during the vehicle type approval certification testing. Despite ongoing efforts to strengthen the 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, will begin in Europe in September 2017[(4)].

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[(5)] and conducting verification tests concerning actual exhaust emissions during on-road driving. These test results were reported in the Interim Report (April 2016) (Table 1). No irregularities similar to those found in the U.S. were discovered, but examples of increases in NO_x emissions due to high and low temperatures were observed. Therefore, in an effort to prevent fraudulent test results and reduce vehicle emissions under the actual on-road driving environment, the commission examined the possibility of setting certain conditions under which the functions of an emissions reduction device would be allowed to be restricted for the purpose of protecting the engine when it is in a non-normal state (protection control guidelines).

Table 1 Results of Verification Tests concerning Emissions Performance during Actual On-Road Driving

Test results * Only results for NO_x are cited (regulation values for CO_2 were not exceeded)

(Units: g/km)

Automobile manufacturer	Vehicle model	On-bench test	On-road driving test (*2)					
		Combined JC08 test cycle	In city		Between cities		Highway	
			Outward	Return	Outward	Return	Outward	Return
Mazda	CX-5	0.06	0.079	0.05	0.052	0.04	0.095	0.101
	Demio	0.062	0.103	0.064	0.064	0.057	0.081	0.051
Nissan	X-Trail	0.144 (※1)	0.301	0.143	0.757	0.229	0.937	0.44
Mitsubishi	Delica D:5	0.104 (※1)	0.331	0.33	0.223	0.292	0.194	0.351
Toyota	Land Cruiser Prado	0.06	0.336	0.325	0.328	1.017	0.363	0.228
	HiAce (commercial)	0.11	1.422	1.664	1.394	1.48	0.241	0.254
BMW	320d	0.063	(※3)	0.077	(※3)	0.146	(※3)	0.031
Mercedes-Benz	ML350	0.105	0.311	0.110	0.253	0.168	0.148	0.072

(*1) Result of changing drivers, value became lower than regulation value from on-bench test, so no problem with vehicle
(*2) Date when measurements taken, temperatures, humidity, and traffic conditions were all different
(*3) Verification only from return trip due to measuring device malfunction

List of regulation values from on-bench tests * Average regulation values

	NO_x〔g/km〕	
	Diesel passenger vehicle	Medium-duty commercial diesel vehicle
Current regulation values	0.08	0.15

Source: MLIT

They also examined on-road driving inspection methods. The results of these examinations were published in the Final Report in April 2017, which recommends applying the protection control guidelines and on-road driving inspections starting in 2022.

3 Technology Trends

3. 1. Fuel Economy Improvement Trends

The popularization of hybrid vehicles and idling-stop functions, which has exceeded expectations, has accelerated the recent remarkable improvement in the fuel economies of light-duty and medium-duty vehicles in recent years. There have also been advances in other basic elements, such as the improvement of the transmission system efficiency, the reduction of friction, or weight reduction. Further progress in fuel economy improvements are fully expected to continue for some time as these conventional technologies are refined even further and applied to a wider number of vehicle models.

The biggest news concerning highly fuel-efficient cars

Fig. 4 Note e-POWER

Fig. 5 Daihatsu Mira e:S

in 2016 was the launch of the Note "e-Power" (Fig. 4) from Nissan in November. This vehicle is equipped with a series hybrid system in which 100% of the drive to the wheels is provided by the electric motor and the gasoline engine is dedicated solely to generating electricity for the batteries. This allows the vehicle to achieve a fuel economy of 34.0 km/L in a mass-production grade vehicle. This vehicle offers more than just excellent fuel economy. It also realizes powerful acceleration from a stop and operates quietly thanks to the motor-powered drive, while eliminating concerns over the issue of cruising range, which is the weak point of electric vehicles. This same technology is expected to be applied to other models in the near future.

However, making further improvements to fuel economy with existing technology at the state-of-the-art level is now becoming difficult. In May 2017 the Daihatsu Mira e:S (Fig. 5) was completely redesigned, but its fuel economy remained the same at 35.2 km/L despite a significant weight reduction of 80 kg compared to the previous model. When it was first launched in 2011, the Mira e:S gained notoriety for being the first non-hybrid vehicle to achieve a fuel economy of 30.0 km/L. After that, it competed with the Suzuki Alto Eco for the title of most fuel efficient gasoline-engine vehicle, eventually achieving the above fuel economy through a series of constant improvements. The fact that the fuel economy of the model at the top of its class in that respect has reached its up-per limits illustrates how difficult it is to improve fuel economy at the state-of-the-art level. This may be a sign that successive redesigns will no longer measurably improve the fuel economy of new vehicles. Consequently, increasing the popularity and adoption of plug-in hybrid vehicles and electric vehicles (EV) will be essential to any further overall improvements in fuel consumption and reductions in CO_2 emissions.

In China and India the introduction of EVs is being promoted through government policy as the key to both reducing air pollution in urban areas and reducing energy consumption. The number of EVs sold in China in 2015 was 247,000 vehicles, which is far beyond the number sold in Japan. Major factors that determine the popularization of next-generation vehicles include product appeal and economic principles and in the latter case, policies such as subsidies have a large influence. How they are implemented can greatly shift the distribution of technical resources toward electric, hybrid, diesel, or other vehicles. Topics such as the power sources of the future often attract the most attention, but it is necessary to note that the policies pursued by various countries according to their individual circumstances can influence the future more than mere technical progress.

In heavy-duty vehicles, improvements in fuel economy have mainly been achieved by promoting superchargers with smaller-sized engines and adopting multi-stage transmissions. Once all heavy-duty vehicles compliant with the exhaust emissions regulations enacted between 2009 and 2010 (Post New Long-term) became available, the fuel economy improvement seemed to subside. However, the latest heavy-duty truck models released by manufacturers comply with the 2016 emissions regulations and exceed the 2015 fuel economy standards by 5%. In some of these vehicles, large amounts of exhaust gas recirculation (EGR) are being implemented and two-stage supercharging systems are being introduced as a means to realize high levels of supercharging that include transient response. This has allowed these vehicles to both reduce emissions and improve fuel economy. In the near future, waste heat recycling systems will likely be adopted as additional elements for further improvements. Of course, producing a large amount of work from waste heat in the often-used partial load is not expected to be easy in high-efficiency diesel engines for heavy-duty vehicles. Nevertheless, few other elements have the potential to yield any sort of excess, making the adoption of these systems likely when further fuel economy improvements become necessary.

3. 2. Exhaust Emissions Reduction Trends

Exhaust emissions regulations started with gasoline vehicles everywhere in the world. The invention of the three-way catalyst is the crucial technological advancement that addressed vehicle emissions, and the refinement of this technology over many years (e.g., increased cell density, reduced usage of precious metals, and optimization, including oxygen storage materials) are continuously bringing countermeasures for emissions from gasoline vehicles closer to completion. 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), as noted earlier in this article.

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 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. The previously mentioned scandal concerning fraudulent exhaust emissions controls is highly likely to have stemmed from the fact that making significant reductions in NO_x emissions would be detrimental to durability and fuel economy. This is quite different from the situation where technology is developed to improve the fuel economy of a gasoline engine with minimal concern about how NO_x production during combustion will be affected.

In terms of technologies for improving emissions from diesel engines, 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 a urea SCR, which is influenced by many factors and requires complex control. It is expected that diesel engines will evolve by calibrating multiple technologies. Such calibration of these technologies in a diesel engine will require many hours of labor due to the lack of clear control guidelines, such as the stoichiometric control in a three-way catalyst. In addition, the number of technical matters to cover, such as emis-

Fig. 6 OM654 Engine for Mercedes-Benz E Class (2.0L, 143 kW, equipped with DPF and urea SCR)

Fig. 7 Mercedes-Benz E Class

sions compliance with the RDE test, will only continue to increase. Manufacturers certainly want to utilize the high fuel economy potential of diesel engines, but the level of difficulty of reaching that potential is also continuing to rise.

Despite these circumstances, in early 2016, Mercedes-Benz announced the introduction of their new E220d (Fig. 7) equipped with an OM654 engine (Fig. 6) designed to comply with not only Euro 6 emissions standards, but also with the RDE test. The model with Japanese specifications also went on sale in October of the same year. In addition to reducing the displacement down to 2.0 L from 2.2 L in the previous model, fuel economy, emissions, and power performance were all improved. The technologies that made this possible were the adoption of a common-rail fuel-injection system with a maximum injection pressure of 2,050 bar, as well as a unique combination of an aluminum engine block with steel pistons. Other often cited improvements are the stepped recess combustion process, optimized air ducting on both the intake and exhaust sides, and the use of a special coating to reduce internal friction forces. However, none of these individual improvements can be described as the silver bullet that achieved a dramatic improvement on its own. This suggests that the overall improvement in performance of this engine was achieved through the accumulation of numerous modest improvements and advances in existing technologies, and that an enormous amount of work went into calibrating all these technologies.

4 Looking Towards the Future

Both vehicle fuel economy and emissions have improved greatly from what they were many years ago, but they have now reached a point where making further improvements is neither technically easy nor inexpensive. However, automobiles are a major industry in many countries and must continue to operate on the cutting edge in the midst of intense competition. Consequently, it is likely that investigative research and technological development related to automobiles will be conducted more widely via industry, government, and academia collaborations, such as the Research Association of Automotive Internal Combustion Engines (AICE) rather than be limited to just individual companies. Furthermore, the pursuit of more environmentally-friendly vehicles will remain a powerful industry trend that will spur the development and advancement of a diverse array of technologies that will not only improve the fuel economy and emissions of engines, but also combine them with electric motors, as well as explore new energy sources such as fuel cells.

References

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