Gasoline Engines

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1) Mazda Motor

1 Introduction

Worldwide vehicle sales fell heavily in the wake of the U.S. financial crisis in 2008 and reached rock bottom in 2009. However, sales have since rebounded, increasing for three consecutive years from 2010. In 2012, despite negative factors such as the shrinking of markets in Europe due to the European debt problem, the ASEAN market continued its robust growth centered on Thailand and India, and the Japanese and U.S. markets also recorded large increases in sales compared to the previous year. The active formation of free trade and economic partnership agreements also continued to energize exports of vehicles manufactured in emerging markets. In contrast, tension between Japan and China in 2012 had a very serious impact on the sales of Japanese-brand vehicles in the Chinese market.

Global environmental consciousness is increasing and more stringent regulations concerning vehicle emissions and fuel economy are being enacted in many countries. In fact, in 2012 the strictest CO_2 emissions regulations in the world were enacted in Europe. Numerous automakers announced a succession of new modular design concepts that enable the development of multiple models across segments based on a few core vehicle platforms while reducing the number of types of parts used. The aim of this innovative approach to vehicle manufacturing is to dramatically improve productivity and lower costs.

Furthermore, every automaker is continuing to implement numerous different initiatives to improve the environmental performance of gasoline engines. These efforts can be largely classified into two main approaches. The first approach is to reduce the engine displacement (downsizing) and the number of cylinders, which is a trend that has been seen over the past several years. Several examples of new approximately 1.0-liter displacement 3-cylinder engines have been introduced into the market for use in compact vehicles. The second approach is to increase the compression ratio. The most prominent means of achieving a high compression ratio have been to improve the fuel injection system through the adoption of direct fuel injection or the like, and/or to adopt technologies that increase the knock limit. In addition, other significant trends include the increasing adoption of variable displacement oil pumps to reduce friction loss and the use of belt-driven timing chains.

This article introduces the new technologies and the main gasoline engines that were newly developed and launched between January and December 2012. It also summarizes the trends in the research and development of gasoline engines.

2 Japan

2. 1. Summary

In 2012 the Japanese automotive industry made a rapid recovery from the Great East Japan Earthquake and the massive flooding in Thailand that both occurred in 2011. At the same time, it also faced severe external business conditions, such as a strong yen at around 70 to 80 yen to the dollar, a weak euro, a shrinking European market, and declining sales of Japanese vehicles in the Chinese market due to tension between the Japanese and Chinese governments. However, the Japanese government's policies to stimulate demand through preferential tax and incentive schemes for environmentally friendly vehicles, the recovery of demand in the U.S. market, and the expansion of the ASEAN market created a tailwind that allowed many automakers to record some of the highest levels of global vehicle sales in history.

Sales of hybrid vehicles in the Japanese market continued to be strong, accounting for approximately 20% of all new vehicle sales (passenger mini vehicles plus registered light passenger vehicles). In addition, in a continuation of the trend seen in 2011, more fuel-efficient vehicles were launched with enhanced gasoline engines without the use of motors or other electric de-

Table 1 Main new gasoline engines in Japan.

Manufacturer	Engine code	Cylinder arrangement and turbocharging	Bore × stroke (mm)	Displacement (L)	Compression ratio	Valve train	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main installation vehicles	Key technologies
Honda	EARTH DREAMS TECHNOLOGY 2.4DI	L4	87.0×99.1	2.356	11.1	DOHC 4 V	141/6 400	247/3 900	Accord (U.S.)	Variable intake valve timing, variable intake valve lift, direct fuel injection
	EARTH DREAMS TECHNOLOGY 3.5 V6	V6	89.0×93.0	3.471	10.5	SOHC 4 V	207/6 200	342/4 900	Accord (U.S.)	Variable intake valve timing, variable intake valve lift, cylinder deactivation, cylinder heads with integrated exhaust manifold, timing belt drive
Toyota	2AR-FSE	L4	90.0×98.0	2.493	13.0	DOHC 4 V	131/6 000	221/4 200–4 800	Crown Hybrid	Variable intake and exhaust valve timing, direct fuel injection + PFI, cooled EGR
	1NZ-FE	L4	75.0×84.7	1.496	11.0	DOHC 4 V	80/6 000	136/4 800	Corolla, Auris, Porte, etc.	Variable intake valve timing, cooled EGR, variable displacement oil pump, stop-start
Fuji Heavy Industries	FA20	H4	86.0×86.0	1.998	12.5	DOHC 4 V	147/7 000	205/6 400–6 600	86 (Toyota) BRZ	Variable intake and exhaust valve timing, direct fuel injection + PFI
	FA20(DIT)	H4 T/C	86.0×86.0	1.998	10.6	DOHC 4 V	221/5 600	400/2 000–4 800	Legacy, Forester	Variable intake and exhaust valve timing, direct fuel injection (spray guide type), tumble generator valves (TGV), cooled EGR, twin-scroll turbocharger
Nissan	MRA8DE	L4	79.7×90.1	1.798	9.9	DOHC 4 V	96/6 000	174/3 600	Sylphy, Sentra (U.S.)	Variable intake and exhaust valve timing, variable intake
	QR25DE	L4	89.0×100.0	2.488	10.0	DOHC 4 V	136/6 000	244/4 000	Altima (U.S.)	Variable intake and exhaust valve timing, variable intake, tumble control valve
Mitsubishi	3A90	L3	75.0×75.4	0.999	10.5	DOHC 4 V	51/6 000	86/5 000	Mirage	Variable intake valve timing, stop-start
	3A92	L3	75.0×90.0	1.193	11.0	DOHC 4 V	59/6 000	106/4 000	Mirage (EU)	Variable intake valve timing, stop-start
	4J12	L4	88.0×97.0	2.359	10.5	SOHC 4 V	124/6 000	220/4 200	Outlander	Variable intake valve timing, intake valve lift, stop-start
Daihatsu	KF	L3	63.0×70.4	0.658	11.3	DOHC 4 V	38/6 800	60/5 200	Move	Variable intake valve timing, ion current control type EGR, stop-start
Suzuki	R06A	L3	64.0×68.2	0.658	11.0	DOHC 4 V	38/6 000	63/4 000	Wagon R	Variable intake valve timing, stop-start
Mazda	PY-VPR	L4	89.0×100.0	2.488	13.0	DOHC 4 V	138/5 700	250/3 250	Atenza	Variable intake and exhaust valve timing, direct fuel injection, 4-2-1 exhaust manifold, variable displacement oil pump, stop-start

vices. These vehicles achieved dramatic improvements in fuel efficiency by improving and combining existing technologies. Approaches included improving the thermal efficiency of the engine, reducing the weight of the vehicle body, and implementing coordinated control of the continuously variable transmission (CVT) and engine. Furthermore, new innovations were achieved in the area of auxiliary equipment and electronic parts, such as the adoption of a cold storage medium in the heating, ventilation and air-conditioning (HVAC) system to extend the idling stop time on the stop-start system, and the adoption of regenerative braking systems equipped with a dedicated electricity storage system.

2. 2. Automaker trends

Table 1 shows a list of the main new types of gasoline engines that were sold by Japanese automakers in 2012. A summary of the new engines developed by each manufacturer is provided below.

2. 2. 1. Honda

In November 2011, Honda announced the new Honda EARTH DREAMS TECHNOLOGY strategy, which aims to achieve further improvements in both driving performance and fuel efficiency. As one aspect of this technology, two new engines were introduced in the Accord in North America. The EARTH DREAMS TECHNOLOGY 2.4DI engine (an inline 4-cylinder 2.4-liter engine, Fig. 1) continues to use the variable valve timing and lift electronic control (VTEC) from the previous model. However, combustion was improved through the addition of direct fuel injection and changes to the shapes of the combustion chambers and ports to improve torque and engine power. Friction loss reduction technology, such as the use of an offset crank to reduce the thrust load was also adopted. In combination with a CVT, this technology helped the Accord sedan to achieve a U.S. highway fuel economy label of 36 mpg.

The cylinder deactivation mechanism in the 3.5-liter EARTH DREAMS TECHNOLOGY V6 engine was improved. The previous mechanism, which switched among three stages of combustion (6-cylinder, 3-cylinder, and 4-cylinder combustion), was consolidated to two stages (6-cylinder and 3-cylinder combustion). The VTEC system and active mount technology were also improved, increasing fuel efficiency by expanding the range of 3-cylinder operation. These technologies were coupled with other friction loss reduction technologies and then adopted on the Accord sedan, helping it to achieve a U.S.

Fig. 1 Honda EARTH DREAMS TECHNOLOGY 2.4DI.

Fig. 2 Toyota 2AR-FSE.

highway fuel economy label of 34 mpg.

2. 2. 2. Toyota

Previously, the Toyota Crown Hybrid used a 3.5-liter V6 gasoline engine. This was changed to the 2AR-FSE, which is an inline 4-cylinder 2.5-liter direct fuel injection engine (Fig. 2). This engine adopts the D-4S fuel injection system and has a compression ratio of 13.0. In addition, the adoption of other technologies, such as the Atkinson cycle with late closing intake valves, cooled EGR, and various friction loss reduction technologies helped this engine to achieve a maximum thermal efficiency of 38.5%.

Finer atomization of fuel droplets and a more homogeneous air/fuel mixture were achieved by increasing the fuel pressure to 20 MPa in the fuel injection system. In addition, to improve thermal efficiency, the shapes of the combustion chambers and intake ports were modified to enhance the tumble and increase the combustion speed. The operational area of the variable intake and exhaust valves was expanded to improve the effect of the Atkinson cycle and a highly-responsive step-motor type EGR valve was adopted to optimize the amount of EGR and reduce pumping loss. The friction loss was also reduced by adopting technologies such as roller lifters on the high-pressure fuel pump plunger and a single roller chain.

Basic improvements were also added to the conventional gasoline engine. For the 1NZ-FE inline 4-cylinder 1.5-liter engine, the variable intake valve timing was optimized and the cooled EGR system was modified to reduce pumping loss. In addition, the compression ratio was raised from 10.5 to 11.0 through improved tumble and other means to further increase fuel efficiency.

2. 2. 3. Fuji Heavy Industries

The FA20, a horizontally-opposed 4-cylinder 2.0-liter engine (Fig. 3) installed on the Toyota 86 and Subaru BRZ, is a newly designed engine that achieves both high power and environmental performance. A square bore and stroke (86 mm × 86 mm) achieves the required amount of air for a power of 100 PS/L, enables compact combustion chambers, and maintains the stiffness balance of the main moving system. The adoption of Fuji Heavy Industries' horizontally-opposed engine technology and Toyota's D-4S system helps this engine to achieve a maximum power of 147 kW (200 PS) and a maximum torque of 205 Nm, while also achieving a fuel economy of 13.4 km/L in the JC08 test cycle and meeting the H17 SULEV emissions standard.

The FA20 (DIT) is a horizontally-opposed 4-cylinder 2.0-liter direct-injection turbocharged engine (Fig. 4) installed on the Legacy B4 and other models. The targets for this engine's design were to make it smaller than the conventional 2.5-liter turbocharged engine (EJ25), while surpassing that engine in terms of both power and environmental performance.

This engine includes direct fuel injection, improved intake and exhaust port shapes, and a twin-scroll turbocharger to improve power performance. In addition, the knock limit was greatly improved by increasing the cooling performance of the cylinder heads, thereby improving the overall performance of the engine. To improve environmental performance, heavy cooled EGR was adopted in the non-turbocharged operation region by enhancing the turbulence intensity of the in-cylinder flow

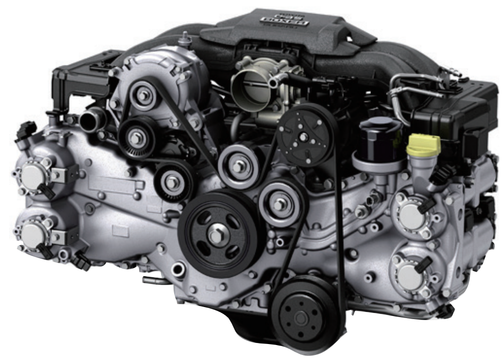

Fig. 3 Fuji Heavy Industries FA20.

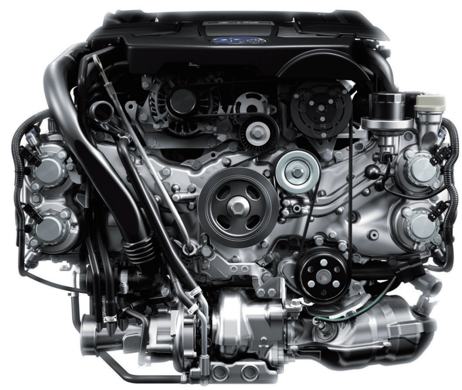

Fig. 4 Fuji Heavy Industries FA20 (DIT).

through the use of a tumble generator valve. In the low load region, pumping loss was reduced by adopting internal EGR used by the variable intake and exhaust valve timing mechanism. An Atkinson cycle with late closing intake valves was also adopted to improve fuel efficiency by increasing the expansion ratio.

2. 2. 4. Nissan

The MRA8DE, an inline 4-cylinder 1.8-liter engine (Fig. 5), was installed on the Sylphy. The bore and stroke on the previous MR18DE engine was 84 mm × 81.1 mm. However, the new model uses a longer stroke of 79.7 mm × 90.1 mm and thereby reducing cooling loss. A variable valve timing mechanism was added to the exhaust side as well as the one on the intake side in the previous engine. This was carried out to reduce pumping loss by applying internal EGR. Other technologies to improve fuel efficiency include diamond-like coatings (DLC) on the valves and beehive valve springs to lower friction loss.

The QR25DE, an inline 4-cylinder 2.5-liter engine, is installed on the Altima in North America. Pumping loss was reduced by adding a variable valve timing mechanism to the exhaust side as well as the one on the intake side in the previous engine. To improve knock resis-

Fig. 5 Nissan MRA8DE.

Fig. 6 Mitsubishi 3A90.

tance and increase the compression ratio from 9.6 to 10.0, the shape of the water jacket was optimized and other technologies were adopted, such as sodium (Na)-filled valves on the exhaust side and highly thermally conductive piston rings. These measures improved the fuel efficiency of the engine and, combined with a new CVT, the Altima achieved a U.S. highway fuel economy label of 38 mpg.

2. 2. 5. Mitsubishi

The 3A90, an inline 3-cylinder 1.0-liter engine (Fig. 6), is installed on the Mirage. This engine is a 3-cylinder version of the 4-cylinder 4A90 model. It adopted friction loss reduction technologies, such as lower valve spring tension and a resin coating for the piston skirt. In addition, the adoption of a lighter weight vehicle body, stop-start system, and CVT helped to achieve a fuel economy of 27.2 km/L in the JC08 test cycle. The 3A92, an inline 3-cylinder 1.2-liter version of this engine with an expanded stroke, has been developed for use in vehicles in

Fig. 7 Mazda PY-VPR.

markets outside of Japan.

The 4J12, an inline 4-cylinder 2.4-liter engine, is installed on the Outlander. This engine is a successor to the previous 4B12 model and is installed with a single overhead camshaft (SOHC) variable valve timing and lift mechanism (MIVEC), the same as on the 4J1 1.8-liter and 2.0-liter engines that have already been launched onto the market.

2. 2. 6. Daihatsu

The Move is installed with the inline 3-cylinder 0.66-liter KF engine. This engine uses combustion control for each cylinder and carries out heat exchange of the engine coolant to promote an increase in the temperature of the CVT lubricating oil. The vehicle speed at which the stop-start system starts to operate was expanded from 7 km/h or less to 9 km/h or less, and the vehicle running resistance was also reduced. These and other improvements helped to achieve a fuel economy of 29.0 km/L in the JC08 test cycle.

2. 2. 7. Suzuki

The Wagon R is installed with the R06A 3-cylinder 0.66-liter engine. The vehicle speed at which the idling stop system starts to operate was expanded from 9 km/h or less to 13 km/h or less. The idling stop time was extended by incorporating a cold storage medium into the HVAC evaporator, and the regenerative braking system was enhanced by adopting a high-power alternator and dedicated lithium ion battery. These and other improvements helped to achieve a fuel economy of 28.8 km/L in the JC08 test cycle.

2. 2. 8. Mazda

The PY-VPR, an inline 4-cylinder 2.5-liter engine (Fig. 7), is installed on the Atenza. This is a new type of engine that uses the SKYACTIV-G concept, which was

Table 2 Main new gasoline engines in the U.S.

Manufacturer	Engine code	Cylinder arrangement and turbocharging	Bore × stroke (mm)	Displacement (L)	Compression ratio	Valve train	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main installation vehicles	Key technologies
Chrysler	Tigershark 2.0	L4	88.0×82.0	1.995	10.2	DOHC 4 V	119/6 400	200/4 600	Dodge Dart	Variable intake and exhaust valve timing, variable displacement oil pump
	Tigershark 2.4	L4	88.0×97.0	2.360	10.0	SOHC 4 V	137/6 250	232/4 800	Dodge Dart	Variable intake valve timing, variable intake valve lift
GM	ECOTEC gen3	L4 T/C	86.0×86.0	1.998	9.5	DOHC 4 V	203 /5 500	353/1 700–5 500	Cadillac ATS	Variable intake valve timing, direct fuel injection, twin-scroll turbocharger, variable displacement oil pump
Ford	EcoBoost	L3 T/C	71.9×82.0	0 .999	10.0	DOHC 4 V	74 /6 000	170 /1 500–4 500	Focus (EU) B-MAX (EU)	Variable intake and exhaust valve timing, cylinder heads with integrated exhaust manifold, direct fuel injection, timing belt drive, stop-start

first introduced in 2011. Combustion is improved by direct fuel injection and optimized shapes for the combustion chambers and pistons. The adoption of a 4-2-1 exhaust manifold promotes scavenging of residual gas in the cylinders, thereby improving the knock limit and increasing the compression ratio to 13.0, that helps to improve fuel efficiency. A double-layer capacitor with low electrical resistance was newly developed and adopted as an electricity storage system to efficiently regenerate braking energy. These technologies helped to achieve a fuel economy of 15.6 km/L in the JC08 test cycle.

3 United States of America

3. 1. Summary

New vehicle sales in the U.S. market were very severely affected by the financial crisis of 2008, reaching rock bottom in 2009. Sales have increased for three consecutive years since 2010, but have not yet recovered to the levels prior to the financial crisis. In 2012, sales of fuel-efficient compact and medium-sized vehicles remained strong due to persistently high gasoline prices. The announcement and launch of new 4-cylinder engines were noted as further confirmation of this trend.

3. 2. Automaker trends

Table 2 shows the main new types of gasoline engines that were sold by U.S. automakers in the U.S. market in 2012. A summary of the new engines is provided below.

Fig. 8 Chrysler Tigershark 2.0-liter engine.

3. 2. 1. Chrysler

The new model Dodge Dart that was developed based on a Fiat chassis is installed with either the 2.0-liter or 2.4-liter versions of the new Tigershark family of inline 4-cylinder engines. The 2.0-liter engine (Fig. 8) has variable intake and exhaust valve timing, a 2-stage variable displacement oil pump, and roller followers, among other features. Pumping and friction loss were both reduced to improve fuel efficiency. The 2.4-liter engine (Fig. 9) is equipped with Fiat's MultiAir hydraulic variable valve timing and lift mechanism on the cylinder head intake side to reduce pumping loss and improve fuel efficiency.

Fig. 9 Chrysler Tigershark 2.4-liter engine.

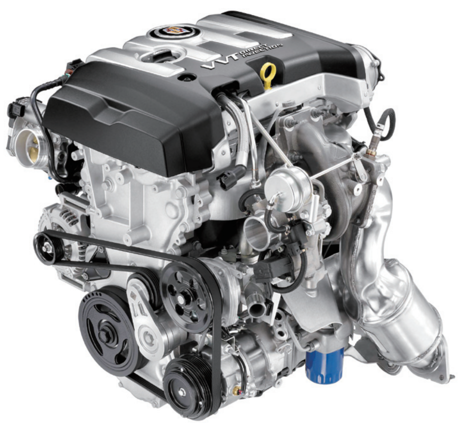

Fig. 10 GM Ecotec.

3. 2. 2. GM

The Cadillac ATS uses an inline 2.0-liter direct fuel injection turbocharged Ecotec engine (Fig. 10). This engine features variable intake valve timing, a twin-scroll turbocharger, and oil jets. The maximum power of the engine is 201 kW.

3. 2. 3. Ford

In addition to the EcoBoost 1.6-liter and 2.0-liter engines that have already been launched, a 3-cylinder 1.0-liter direct injection turbocharged EcoBoost engine (Fig. 11) was introduced on the Focus in Europe.

This engine has the same basic components as the 1.6-liter and 2.0-liter versions, such as direct fuel injection, variable intake and exhaust valve timing, and a turbocharger. However, other unique technologies for the 1.0-liter version were added, such as cylinder heads with an integrated exhaust manifold, a dual cooling system for the heads and the engine block, and a driven timing belt for further improvement of the engine fuel efficiency. The crankshaft counterweight was optimized to suppress engine vibration, allowing the balance shaft to be

Fig. 11 Ford 1.0-liter EcoBoost.

eliminated, despite a 3-cylinder engine. Focus models with an idling stop system achieved CO_2 emissions of 109 g/km in the New European Driving Cycle (NEDC).

4 Europe

4. 1. Summary

The economic recession triggered by the debt problem in Greek was not limited to southern Europe. Spreading throughout the entire euro zone, it caused the vehicle market to fall significantly in 2012. Vehicle sales across Europe fell for the fifth consecutive year.

The main technological trend for engines continues to be downsizing and the majority of new engines that went on sale in 2012 are turbocharged engines that feature direct fuel injection and variable intake and exhaust valve timing mechanisms. Almost all of these engines are also equipped with an stop-start system. Another notable engine trend was the adoption of 3-cylinder 1.0-liter engines for compact vehicles that achieved CO_2 emissions of below 100 g/km in the NEDC.

4. 2. Automaker trends

Table 3 shows the main new types of gasoline engines that were sold by European automakers in Europe in 2012. A summary of the new engines is provided below.

4. 2. 1. Volkswagen (VW)

The next-generation MQB modular vehicle strategy will be adopted for every transverse front-engine front-wheel drive (FF) vehicle released by VW group, from the compact Polo class to the mid-size Passat class. The engines that will comprise this strategy are a 1.0-liter inline 3-cylinder engine and 1.2-liter and 1.4-liter versions of a inline 4-cylinder direct injection turbocharged engine. These engines are all part of the announced EA211 se-

Table 3 Main new gasoline engines in Europe.

Manufacturer	Engine code	Cylinder arrangement and turbocharging	Bore × stroke (mm)	Displacement (L)	Compression ratio	Valve train	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main installation vehicles	Key technologies
VW	EA211 1.0MPI	L3	74.5×76.4	0.999	10.5	DOHC 4 V	55/6 200	95/3 000–4 300	Up!	Variable intake valve timing, cylinder heads with integrated exhaust manifold, timing belt drive, stop-start
	EA211 1.2TSI	L4 T/C	71.0×75.6	1.197	10.5	DOHC 4 V	77/5 000	175/1 550–4 100	Golf	Variable intake and exhaust valve timing, cylinder heads with integrated exhaust manifold, direct fuel injection, variable displacement oil pump, timing belt drive, stop-start
	EA211 1.4TSI	L4 T/C	74.5×80.0	1.395	10.5	DOHC 4 V	103 /4 500–6 000	250/1 500–3 500	Golf	Variable intake and exhaust valve timing, cylinder heads with integrated exhaust manifold, direct fuel injection, variable displacement oil pump, cylinder deactivation, timing belt drive, stop-start
PSA	EB0	L3	71.0×84.1	0.999	11.0	DOHC 4 V	50/6 000	95/3 000	Peugeot 208 Citroën C1	Variable intake and exhaust valve timing, cylinder heads with integrated exhaust manifold, timing belt drive
	EB2	L3	75.0×90.5	1.199	11.0	DOHC 4 V	60/5 750	118/2 750	Peugeot 208 Citroën C1	Variable intake and exhaust valve timing, timing belt drive
Renault	TCe90	L3 T/C	72.2×73.2	0.899	9.5	DOHC 4 V	66/5 000	135/2 500	Clio	Variable intake and exhaust valve timing, direct fuel injection, variable displacement oil pump, stop-start
	TCe115	L4 T/C	72.2×73.2	1.198	10.0	DOHC 4 V	85/4 500	190/2 000–4000	Mégane Scénic	Variable intake and exhaust valve timing, direct fuel injection, variable displacement oil pump, stop-start
Daimler	M270/ M274 (1.6 L)	L4 T/C	83.0×73.7	1.595	10.3	DOHC 4 V	115/5 300	250/1 250–4 000	A-Class B-Class C-Class	Variable intake and exhaust valve timing, variable intake valve lift, direct fuel injection (piezoelectric), multi-spark ignition, variable displacement oil pump, stop-start
	M270 (2.0 L)	L4 T/C	83.0×92.0	1.991	9.8	DOHC 4 V	155/5 500	350/1 200–4 000	B-Class	Variable intake and exhaust valve timing, variable intake valve lift, direct fuel injection (piezoelectric), multi-spark ignition, variable displacement oil pump, stop-start
AUDI	EA888 2.0L TFSI gen3	L4 T/C	82.5×92.8	1.984	9.6	DOHC 4 V	165/4 500–6 250	350/1 500–4 500	Q5	Variable intake and exhaust valve timing, variable exhaust valve lift, cylinder heads with integrated exhaust manifold, direct fuel injection + PFI, TGV (tumble generator valves), twin-scroll turbocharger, stop-start

Fig. 12 Volkswagen inline 3-cylinder 1.0-liter engine.

Fig. 13 Volkswagen 1.4 L-TSI.

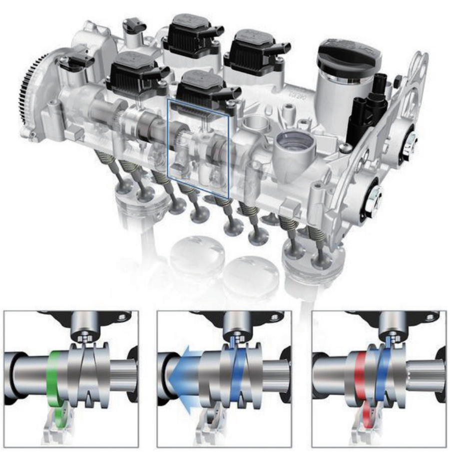

Fig. 14 Volkswagen cylinder deactivation system.

ries.

As a common design element of all the EA211 series engines, the conventional front-facing exhaust was changed to the same rear-facing exhaust layout as on diesel engines. This series also features a standardized 12-degree backward inclination angle for the mounting positions of parts such as the exhaust system, driveshaft, and transmission. The exhaust manifold and cylinder heads are integrated and a dedicated water jacket is also provided. Furthermore, the incorporation of a dual cooling system for the heads and engine block promote warming up to improve fuel efficiency. Numerous friction loss reduction technologies, such as a driven timing belt, roller followers, and deep-groove ball bearing cams (the first cam journal portion) were also adopted. The camshaft is prefabricated with a separate cam lobe shrink-fitted within the cam cover and integrated with the bearing. This reduces the diameter of the cam journal, as well as engine friction loss and weight.

An inline 3-cylinder 1.0-liter engine (Fig. 12) is installed on the Up!. The weight of the connecting rods, pistons, and crank were reduced, the weight distribution was optimized, and vibration was suppressed to eliminate the balance shaft.

The 1.4 L-TSI, an inline 4-cylinder 1.4-liter direct injection turbocharged engine (Fig. 13), is equipped with a cylinder deactivation system (Fig. 14). A variable sleeve and slide mechanism is adopted on the intake and exhaust camshaft of the second and third cylinders. Cylinder deactivation is realized by an actuator that switches between normal and zero-lift cam profiles. Cylinders are deactivated at low loads between 1,250 rpm and 4,000 rpm. This reduced fuel consumption by 0.4 L/100 km in the NEDC, and a VW Golf with this engine achieved CO_2 emissions of 109 g/km in the NEDC.

4. 2. 2. Renault

The TCe115, an inline 4-cylinder 1.2-liter direct injection turbocharged engine (Fig. 15), is installed on the Megane and the Scenic. This is Renault's first downsizing turbocharged engine and will replace the previous inline 4-cylinder 1.6-liter engine. Fuel efficiency was improved by adopting technologies such as intake ports with enhanced tumble, variable intake and exhaust valve timing, a variable displacement oil pump, and a DLC coating on the valve tappet. As a result, the Megane installed with this engine achieved CO_2 emissions of 119 g/km in the NEDC.

The TCe115 serves as the basis for a family of engines, including the TCe90 3-cylinder 0.9-liter direct injection turbocharged engine (Fig. 16) installed on the Clio. A Clio with this engine achieved CO_2 emissions of 99 g/km

Fig. 15 Renault TCe115.

Fig. 16 Renault TCe90.

in the NEDC.

4. 2. 3. PSA Peugeot Citroën (PSA)

Inline 3-cylinder 1.0-liter and 1.2-liter EB series engines are installed on the Citroen C1 and Peugeot 208. Both of these are long stroke engines with a stroke to bore ratio near to 1.2. The adoption of fuel-efficient technologies, such as variable intake and exhaust valve timing, DLC coatings on the piston pins and piston rings, cylinder heads with an integrated exhaust manifold, a driven timing belt, and a dual cooling system for the heads and the engine block, allowed the 1.0-liter and 1.2-liter engines to achieve CO_2 emissions of 99 g/km and 104 g/km, respectively, in the NEDC.

4. 2. 4. Daimler

The Mercedes A-Class, B-Class, and C-Class are installed with the M270 and M274 inline 4-cylinder 1.6-liter direct injection turbocharged engines, or the inline 4-cylinder M270 2.0-liter direct injection turbocharged engine (Fig. 17). An effort was made to use common, modular parts in consideration of the fact that the M270 is a transverse engine and the M274 is a longitudinal engine. The exhaust on the M270 transverse engine faces forward.

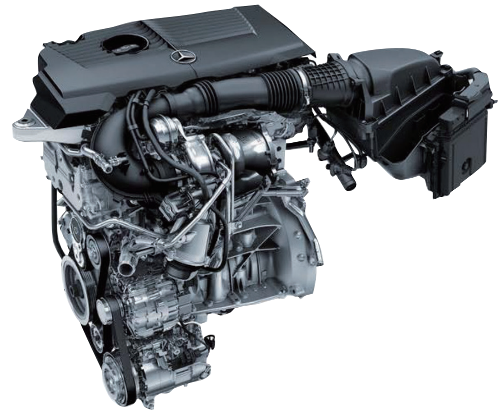

Fig. 17 Daimler M270.

These engines also use the same spray guide-type combustion system with piezoelectric injectors, multi-spark ignition, and stop-start systems as on the V6 and V8 engines that have already been launched. In addition, other technologies, such as turbochargers resistant to heat up to 1,050°C, variable displacement oil pumps, and dual cooling systems for the heads and the engine block, were also adopted to further improve power and fuel efficiency.

4. 2. 5. Audi

The inline 4-cylinder 2.0-liter direct injection turbocharged engine installed on the Q5 is a slightly larger displacement version of the inline 4-cylinder 1.8-liter direct injection turbocharged engine installed on the A6 in 2011. The adoption of both direct and PFI dual fuel injection, cylinder heads with an integrated exhaust manifold, exhaust-side valve lift, variable intake and exhaust valve timing, and a twin-scroll turbocharger with an electric-powered waste gate generate a maximum power of 165 kW and maximum torque of 350 Nm on the Q5.

5 Trends in Research and Development

5. 1. Direct injection gasoline combustion

As the use of smaller turbocharged engines with in-cylinder fuel injection has become more widespread, the occurrence of sudden pre-ignition has become a new problem in addition to knocking. This pre-ignition phenomenon is different from so-called hot-surface ignition, and suspended oil and particulate matter are cited as its causes. However, there are still many unknowns and issues that require further research. Various initiatives have been announced to study the effect of engine oil ignitability and reports, measurements, and analysis will seek to clarify the relevant issues, such as the oxidation mechanism of gasified oil.

5. 2. HCCI combustion

Homogenous charge combustion ignition (HCCI) is a desirable form of engine combustion that can achieve outstanding fuel efficiency and significant reductions in CO_2 emissions through high thermal efficiency. However, despite great expectations, it has yet to be practically adopted due to difficulties in controlling ignition and combustion. Much research is seeking to resolve these issues, such as studies into the ignition reaction mechanism of gasoline and studies to clarify the combustion process through the use of optical measurement.

5. 3. Emissions-related research

European nations have decided to introduce particle number regulations for vehicles installed with direct injection gasoline engines. Consequently, reports have been published about new particulate matter (PM) measurement methods, basic fuel injection concepts, and the use of particulate filters to comply with the regulations. One report verified the effect of an stop-start system in a vehicle with a direct injection engine on particle emissions. This report noted a shift to larger particle diameters due to the stop-start system [6]. Identifying characteristics such as this will be an important aspect of future research.

5. 4. Alternative fuels

A further reduction in CO_2 emissions in the transportation sector will be necessary to promote the transition to a low-carbon society. Consequently, the importance of alternative fuels is also increasing. There has been an increase in the number of reports detailing research into alternative fuels for gasoline engines, such as compressed natural gas (CNG), gasoline blended with ethanol or butanol, and 2,5-dimethylfuran (DMF). This is likely to be an active field of research in the future as well.

5. 5. Initiatives to improve thermal efficiency

Initiatives to examine the heat cycle and to reduce the various different types of loss have intensified as a part of efforts to improve the thermal efficiency of gasoline engines. The aim of these efforts is to reach the theoretical limits of the internal combustion engine. Research focusing on reducing cooling loss from combustion in the expansion stroke has been reported [7][8]. Setting up a thermal insulation within the engine cylinder reduces the heat loss, but also increases the temperature of the gas within the cylinder. Although this may degrade the air intake efficiency and reduce the knock limit, the use of a cylinder wall material with low thermal conductivity and a small heat capacity may reduce the cylinder wall surface temperature during the air intake process and increase the wall temperature only during combustion periods with large thermal loss. Further development of this technology is also expected in the future as one means of reducing cooling loss.

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