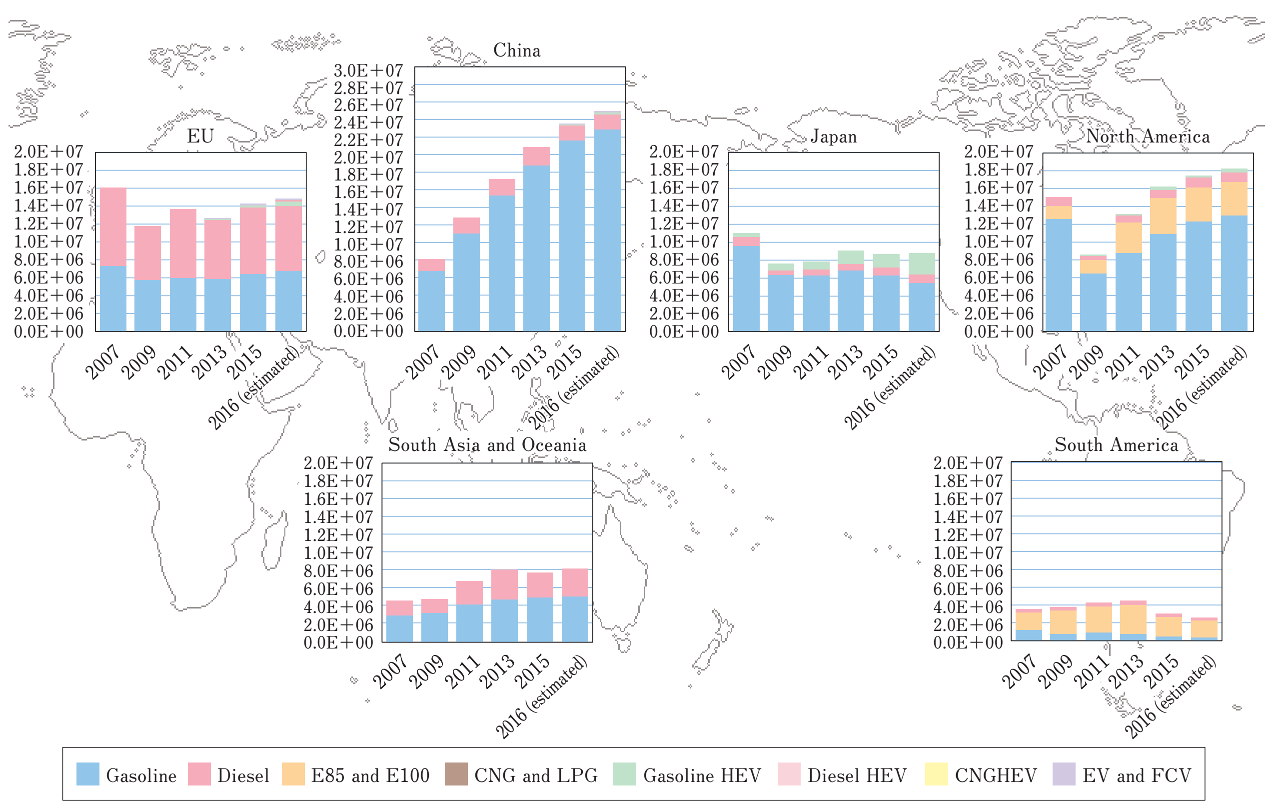
GASOLINE ENGINES

1 Introduction

Global vehicle production in 2015 was 89.68 million vehicles, up 2% from 2014[1]. However, increases and decreases in production varied according to the economic circumstances in each region. Figure 1 shows the powertrain production trends and breakdown of powertrain types in each major global region[2]. In Japan, although total production has remained virtually unchanged, the proportion of hybrid vehicles (HEVs) is increasing. In Europe, total production has also remained flat, with a high percentage of diesel powertrains compared to other regions. In North America, total production has increased and the proportion of vehicles compatible with alcohol-based fuels is relatively high. China is now the world's largest vehicle producer, reflecting continuing increases in production over the last decade. In South America, which is currently suffering from economic recession, total production is falling and the proportion of vehicles compatible with alcohol-based fuels remains high. Production is also relatively stable in South Asia and Oceania, which has the second highest proportion of diesel powertrains after Europe[2].

This article introduces the new gasoline engines that were launched in Japan, North America, and Europe in 2015, and outlines the main gasoline engine research trends.



Source: IHS powertrain production predictions in April 2016

Fig. 1 Powertrain production trends for LDVs in each region.

2 Japan

2. 1. Summary

Vehicle production in Japan in 2015 fell by 9.7% from 2014 to 5.05 million vehicles. This was mainly due to the large 16.6% drop in mini-vehicle sales after a hike in taxes on this segment. Figure 2 shows the breakdown of gasoline engine production in Japan in accordance with displacement, intake system, and fuel injection method. As shown in Fig. 1, HEVs account for a high proportion of vehicle production in Japan. However, in line with trends in Europe, North America, and China, the proportion of direct injection turbocharged engines is also increasing in Japan.

2. 2. Automaker trends

Table 1 shows a list of the main new types of gasoline engines that were sold by Japanese automakers in 2015. Apart from dedicated engines for HEVs, all of the new engines launched in 2015 by Japanese automakers were direct injection turbocharged engines. The following sections describe an outline of the new engines developed by each manufacturer.

2. 2. 1. Toyota Motor Corporation

Toyota launched direct injection turbocharged engines in its NR series covering the 1.2 to 1.5-liter displacement range and its inline 4-cylinder AR series with a displacement of 2 liters or more. The new Auris is installed with the 1.2-liter inline 4-cylinder 8NR-FTS (Fig. 3). This turbocharged engine features a cylinder head integrated with the exhaust manifold and a single-scroll turbocharger, achieve a brake thermal efficiency of 36%. The 2.0-liter inline 4-cylinder 8AR-FTS engine (Fig. 4) applied 4 into 2 exhaust manifold and in-house manufactured twin scroll turbocharger, and optimized with Toyota's unique fan shape spray direct injection and high tumble port, as well as low friction and heat management technologies. As a result, this engine also achieves a brake thermal efficiency of 36%. In addition, the new Prius is installed with the 1.8-liter inline 4-cylinder 2ZR-FXE engine (Fig. 5).

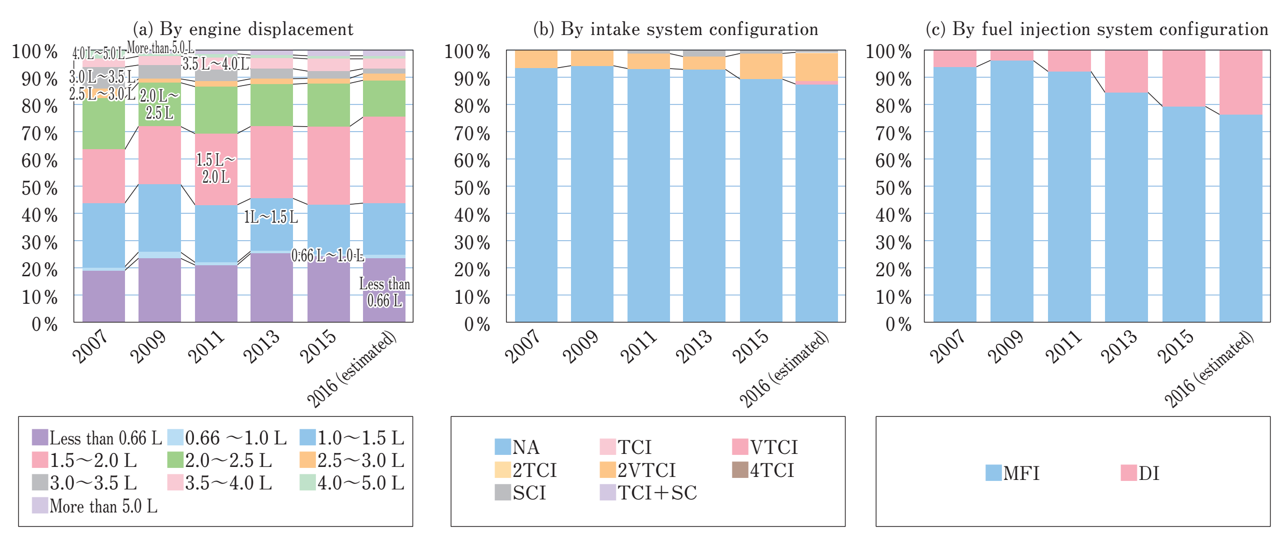
This engine applied following items to improve the thermal efficiency. The cooling loss reduction due to a coolant flow improvement of cylinder block water jacket, many friction reduction items, incrimination of the rate of exhaust gas recirculation (EGR), and etc.

As the result, accomplished the break thermal efficiency up to 40%, even in the port fuel injection.

2. 2. 2. Honda Motor Co., Ltd.

In place of the previous 2.0- and 2.4-liter inline 4-cylinder engines, the latest Step Wagon is now installed with the L15B, a downsize-boosted 1.5-liter inline 4-cylinder engine (Fig. 6).

This engine features sodium-filled exhaust valves compatible with regular gasoline and a new coolant path between the cylinder bores, which enable a high compression ratio of 10.6 and a brake thermal efficiency of 38%. In addition, in place of the previous high-speed naturally aspirated (NA) engine, the Civic Type R has been launched in Japan and Europe installed with the K20C, a 2-liter inline 4-cylinder direct injection turbocharged engine (Fig. 7). This engine features high-tumble ports and variable timing control (VTC) applied to both the intake



Source: IHS global powertrain production predictions in April 2016

Fig. 2 Breakdown of gasoline engine production in Japan.

Table 1 Main new gasoline engines in Japan in 2015.

Manufacturers	Engine model	Cylinder arrange-ment	Bore × stroke (mm)	Displace-ment (L)	Compres-sion ratio	Valve train	Intake system	Fuel injection method	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main installation vehicles	Characteristics
Toyota	8NR-FTS	Inline 4	71.5 × 74.5	1.196	10.0	DOHC 4 V	TCI	DI	85/5 200–5 600	132/1 500–4 000	Auris	Premium gasoline specifications, cylinder head integrated with the exhaust manifold, single scroll turbocharger, brake thermal efficiency=36 %
	8AR-FTS	Inline 4	86 × 86	1.998	10.0	DOHC 4 V	TCI	DI	175/4 800–5 600	350/1 650–4 000	Crown, Lexus IS, Lexus NS	Premium gasoline specifications, cylinder head with an integrated 4 into 2 exhaust manifold, sodium-filled exhaust valves, water-cooled intercooler, brake thermal efficiency=36 %
	2ZR-FXE	Inline 4	80.5 × 88.3	1.797	13.0	DOHC 4 V	NA	PFI	72/5 200	142/3 600	Prius	High-tumble ports, tumble-supporting combustion chamber, expanded cooled EGR flow rate, Atkinson cycle, water jacket spacer, brake thermal efficiency=40 %
Honda	L15B	Inline 4	73 × 89.4	1.496	10.6	DOHC 4 V	TCI	DI	110/5 500	203/1 600–5 000	Step Wagon, Jade RS	Compatible with regular gasoline, coolant path between cylinder bores, sodium-filled exhaust valves, intake and exhaust VTC, electronic wastegate, brake thermal efficiency=38 %
	K20C	Inline 4	86 × 85.9	1.995	9.8	DOHC 4 V	TCI	DI	228/6 500	400/2 500–4 500	Civic Type R	Premium gasoline specifications, exhaust VTEC, intake and exhaust VTC, electronic wastegate, 0 W-20 oil, brake thermal efficiency=36.6 % (NEDC calibrated)
Suzuki	K10C	Inline 3	73 × 79.4	0.996	10.0	DOHC 4 V	TCI	DI	82/6 000	160/1 500–4 000	Baleno	Direct injection turbocharged engine for Japan, China, and India, 10 kg lighter than an 1.6 -liter inline 4 -cylinder NA engine, premium gasoline specifications
Mazda	SKYACTIV G25T	Inline 4	89 × 100	2.488	10.5	DOHC 4 V	TCI	DI	169/5 000	420/2 000	CX-9	Replacement for 3.7 -liter V6 engine for North American market, compatible with regular gasoline, dynamic pressure turbo using bypass valve, cooled EGR

and exhaust camshafts, and with a variable valve lift mechanism (VTEC) adopted on the exhaust side. Other key points of this engine include a cylinder head integrated with the exhaust manifold, a single-scroll turbocharger, cooling channel pistons, and a lightweight crankshaft. And the 0W-20 oil is specified despite the high performance engine. As a result, this engine achieves a maximum power of 228 kW, maximum torque of 400 Nm, and a brake thermal efficiency of 36.6%.

2. 2. 3. Mazda Motor Corporation

Mazda has launched the 2.5-liter inline 4-cylinder SKYACTIV-G 2.5T engine (Fig. 8) to replace the 3.7-liter V6 engine adopted only for SUVs in North America. This engine features a flow control valve locate in the 4-3-1 exhaust manifold, the valve was closed at low speed region, to increase the velocity of the exhaust flow to the turbine wheel of turbocharger, for improving throttle response.

In addition to that, the scavenging effect between No.1 and No.2 cylinder, and No.3 and No.4 cylinder were increasing, then anti-knocking capability were improving by the reduction of residual gas at the low speed high load operating regions even with regular gasoline. Knocking in high-speed high-load regions is improved by cooled EGR.

2. 2. 4. Suzuki Motor Corporation

The Suzuki Baleno is installed with the direct injection turbocharged K10C engine (Fig. 9), which is based on a 1-liter inline 3-cylinder NA engine sold in Europe. This engine aiming the weight and size reduction compared to a 1.6-liter inline 4-cylinder engine with the same performance, without using balancer mechanism 3 cylinder

Fig. 3 Toyota 8NR-FTS engine.

Fig. 4 Toyota 8AR-FTS engine (Lexus NS).

Fig. 5 Toyota 2ZR-FXE engine.

Fig. 6 Honda L15B engine.

Fig. 7 Honda K20C engine.

Fig. 8 Mazda SKYACTIV-G 2.5T engine.

Fig. 9 Suzuki K10C DITC engine.

configuration by applying combination of optimization of engine hardware and engine control. To facilitate its adoption in emerging markets, this engine also features optional specifications such as innovative cooling channels in the cylinder head to prevent injector deposits by controlling the injector temperature, and the elimination of external EGR.

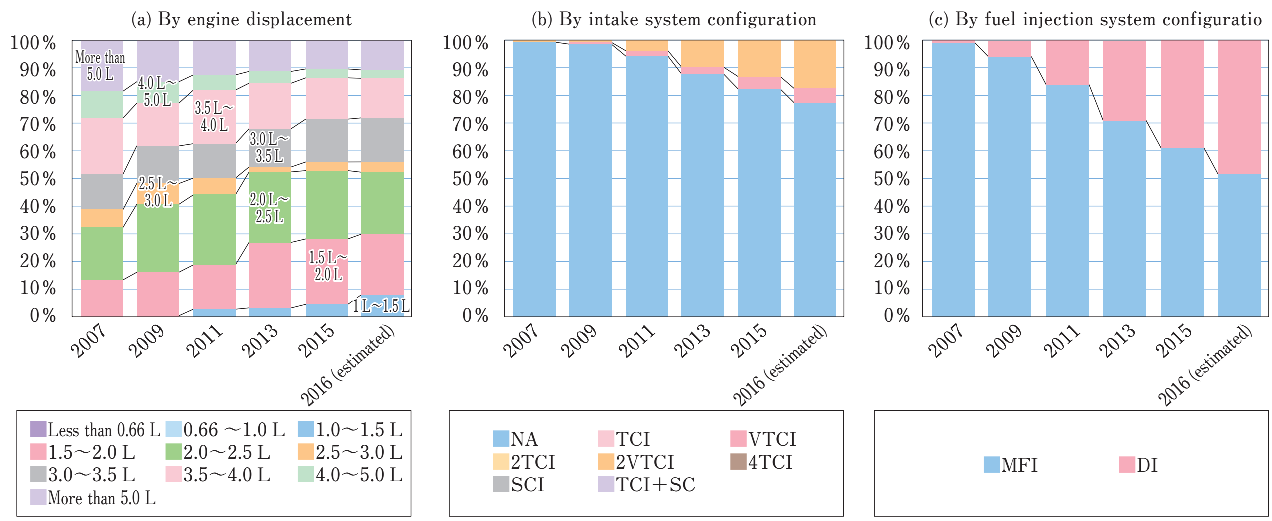
3 North America

3. 1. Summary

In 2015, vehicle sales in the North American market (i.e., the countries that have agreed to the North American Free Trade Agreement (NAFTA)) increased by 6.2% to 20.76 million units[(1)]. Falling gasoline prices affected by the low price of crude oil stimulated a 12.8% increase in light-duty truck (LDT) sales in the United States of America[(4)]. Figure 10 shows the breakdown of gasoline engine production in North America in accordance with displacement, intake system, and fuel injection method. These graphs show a shift toward lower displacement engines and a growing proportion of direct injection turbocharged engines[(2)].

3. 2. Automaker trends

Table 2 shows a list of the main new types of gasoline engines that were sold by North American automakers in 2015. Both GM and Ford launched new high-performance vehicles installed with high-power engines developed under different approaches.



Source: IHS global powertrain production predictions in April 2016

Fig. 10 Breakdown of gasoline engine production in North America.

Table 2 Main new gasoline engines in North America in 2015.

Manufacturers	Engine model	Cylinder arrangement	Bore × stroke (mm)	Displacement (L)	Compression ratio	Valve train	Intake system	Fuel injection method	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main installation vehicles	Characteristics
GM	LGW	V6	86×85.8	2.990	9.8	DOHC 4 V	2TCI	DI	301/5 700	542/2 500–5 100	Cadillac CT6	Cylinder head integrated with the exhaust manifold, low-capacity water-cooled intercooler, 6-4-3 cylinder deactivation, titanium-aluminum alloy compressor, VVT with intermediate position holding mechanism
	LF4	V6	94×85.6	3.546	10.2	DOHC 4 V	2TCI	DI	346/5 850	603/3 500	Cadillac ATS-V	Premium gasoline specifications, titanium-aluminum alloy compressor, sodium-filled exhaust valves, titanium connecting rods, moisture-detecting torque control, intake and exhaust VVT
	LE2	Inline 4	74×81.3	1.399	10.0	DOHC 4 V	TCI	DI	114/5 600	240/2 000–4 000	Chevrolet Cruze	Compatible with regular gasoline, cylinder head integrated with the exhaust manifold, dual-capacity oil pump, intake and exhaust VVT.

3. 2. 1. General Motors (GM)

Launched two high-performance direct injection turbocharged V6 engine variants to its 3-liter range. The Cadillac CT6 is installed with the new designed 3-liter V6 LGW engine (Fig. 11) that features improved throttle response by adopting a exhaust manifold integrated cylinder head, a low-heat capacity compact water-cooled intercooler, and a high response turbocharger with a titanium-aluminum alloy compressor wheel. It also installed a 6-4-3 switching cylinder deactivation system and a variable displacement oil pump. The result is a high-performance engine with a maximum power of 301 kW and maximum torque of 542 Nm, which also achieves excellent fuel economy.

In addition, the high-performance variant of the Cadillac ATS, the ATS-V is installed with the 3.6-liter V6 dual-turbocharger LF4 engine (Fig. 12). The transient response of this turbocharged engine was improved by adopting a titanium-aluminum alloy compressor wheel and a compact water-cooled intercooler with a low thermal capacity, as well as titanium connecting rods to reduce the reciprocating mass of the engine. In combination with knocking countermeasures such as sodium-filled exhaust valves and humidity detecting torque control, this engine achieves a maximum power of 364 kW and maximum torque of 603 Nm.

Table 2 Main new gasoline engines in North America in 2015 (continued).

Manufacturers	Engine model	Cylinder arrange-ment	Bore × stroke (mm)	Displace-ment (L)	Compres-sion ratio	Valve train	Intake system	Fuel injection method	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main installation vehicles	Characteristics
Ford	5.2 Voodoo	V8	94×93	5.163	12.0	DOHC 4 V	NA	PFI	392/7 500	582/4 750	Shelby GT350	Forged steel flat-plane drilled crankshaft, Plasma Transferred Wire Arc (PTWA) cylinder coating, hollow stem intake valves (14 mm valve lift), intake and exhaust VVT

Fig. 11 GM LGW engine.

Fig. 12 GM LF4 engine.

Fig. 13 GM LE2 engine.

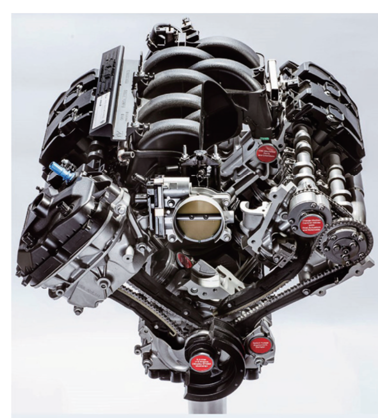


Fig. 14 Ford 5.2 Voodoo engine.

GM has also progressed the innovation of its inline 4-cylinder Ecotec engine series for mass-production vehicles, applied the weight reduction and NV improvement technologies.

The new Chevrolet Cruze is installed with the 1.4-liter inline 4-cylinder LE2 engine (Fig. 13). Using regular gasoline, this engine has a maximum power of 114 kW and maximum torque of 240 Nm, and GM has also announced that it plans to introduce an LE engine that complies with the Euro 6 requirements for compact engines.

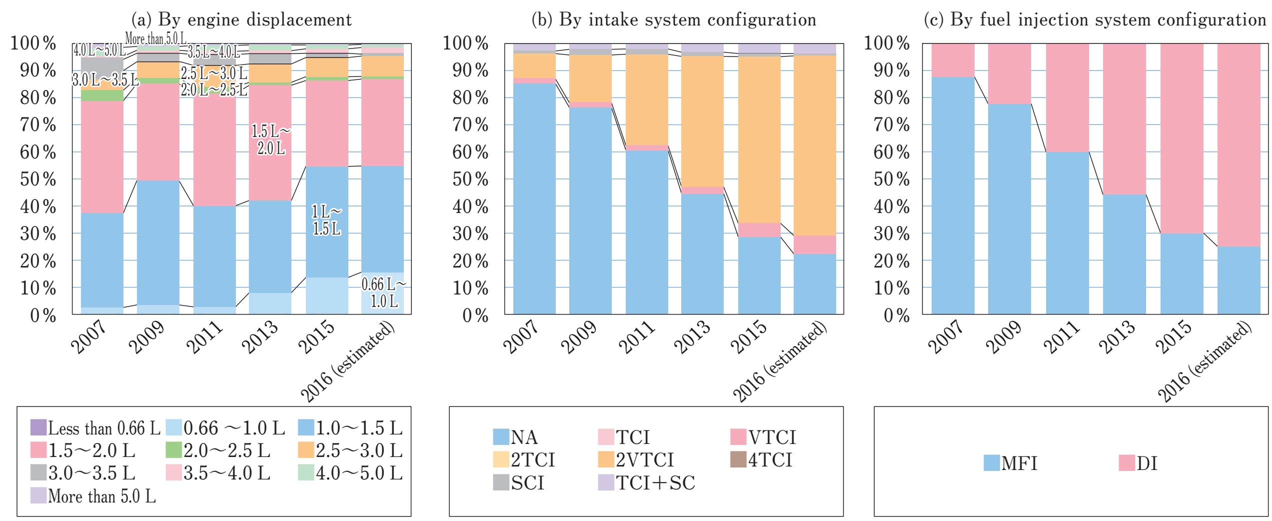
3. 2. 2. Ford

The high-performance Shelby GT350R variant of the Mustang is installed with a 5.2-liter V8 engine (Fig. 14) called the 5.2 Voodoo. This engine features a flat-plane forged steel drilled rankshaft, and an aluminum alloy cylinder bore block using Ford's Plasma Transferred Wire Arc (PTWA) cylinder coating, and weight-reduction measures for the valve train such as a hollow stem intake valves, with a valve lift of 14 mm cam profile, and apply a compression ratio of 12.0. as the result, that engine perfomed a maximum power of 392 kW at 7,000 rpm and maximum torque of 582 Nm at 4,750 rpm even in the 5.163-liter port injection NA engine.

4 Western Europe

4. 1. Summary

In 2015, vehicle sales in the Western European market (17 countries, including the 15 members of the European Union and the European Free Trade Association



Source: IHS global powertrain production predictions in April 2016

Fig. 15 Breakdown of gasoline engine production in Western Europe.

(EFTA)) increased by 9.4% to 15.22 million units. Figure 15 shows the breakdown of gasoline engine production in Western Europe in accordance with displacement, intake system, and fuel injection method. Western Europe has been led the world for a number of years in sales of downsized direct injection turbocharged engines. More than 70% of new vehicles launched in 2015 were installed with these types of engines[2].

In addition, small displacement inline 3-cylinder engines with the same basic structure as 1.3- to 2.0-liter inline 4-cylinder engines started to increase in 2013. In 2015, both VW and Hyundai introduced new 1-liter inline 3-cylinder engines on the market.

4. 2. Automaker trends

Table 3 shows a list of the main new types of gasoline engines for the European market in 2015. All the new engines launched in Western Europe in 2015 were direct injection turbocharged engines. The following sections describe an outline of the new engines developed by each manufacturer.

4. 2. 1. BMW

The 7- and 3-Series are installed with a 3-liter inline 6-cylinder engine (B58, Fig. 16) that is part of BMW's modular engine family with common bore/stroke dimensions, which also includes a 1.5-liter inline 3-cylinder engine (B38) and a 2-liter inline 4-cylinder engine (B48). The B58 engine has a longer stroke than the previous 3-liter inline 6-cylinder N55 engine (diameter of 82 × 94.6 increased from 84 × 89) and a closed deck/deep skirt instead of an open deck/half skirt design. The new engine also features electric arc wire-sprayed cylinder walls. Another key aspect of this engine is the heat management module (HMM) that carries out on-demand control of flow rates between the mechanical water pump, heat exchangers, and engine by opening and closing a rotary valve. Transient control of the intake air mass is performed by an electronic wastegate valve. In addition, the water-cooled intercooler is incorporated into the intake manifold to reduce the volume of the intake system. As a result, this engine achieves a maximum power of 240 kW at between 5,500 and 6,500 rpm and maximum torque of 450 Nm at between 1,380 and 5,000 rpm.

4. 2. 2. Ferrari

From F 40 for the first time turbocharged road engine produced by Ferrari in 30 years, the Ferrari 488 GTB was equipped with a 3.9 L V8 turbocharged F154 CB engine (Figure 17).

The F154CB engine is based on the V8 F154BB engine installed in the Ferrari California, with a flat plane crankshaft instead of a cross plane crankshaft. It also features a twin scroll turbocharger with a ball bearing-supported titanium-aluminum alloy compressor wheel, and the mechanical efficiency of this engine was also improved through the measures such as adopting roller finger followers in the valve train. as the results, that engine ensures the same transient characteristics as an NA engine. As a result, the F154CB engine achieves a maximum power of 493 kW up to its maximum engine speed of 8,000 rpm and maximum torque of 760 Nm from 3,000 rpm.

Table 3 Main new gasoline engines in Western Europe in 2015.

Manufacturers	Engine model	Cylinder arrange-ment	Bore × stroke (mm)	Displace-ment (L)	Compres-sion ratio	Valve train	Intake system	Fuel injection method	Maximum power (kW/rpm)	Maximum torque (Nm/rpm)	Main installation vehicles	Characteristics
BMW	B58	Inline 6	82 × 94.6	2.997	11	DOHC 4 V	TCI	DI	240/5 500–6 500	450/1 380–5 000	340i, 735i	Common bore/stroke with inline 3-cylinder 1.5-liter, inline 4-cylinder 2-liter engines, closed deck cylinder block, electric arc wire-sprayed cylinder walls, water-cooled intercooler, heat management module, intake VVL, intake and exhaust VVT
Ferrari	F154CB	V8	86.5 × 83	3.902	9.4	DOHC 4 V	2TCI	DI	493/8 000	760/3 000	488 GTB	Flat plane crankshaft, dry sump, cast and welded exhaust manifold, titanium-aluminum alloy compressor, water-cooled dual-scroll turbocharger, intake and exhaust VVT
Porsche		Boxer 6	91 × 76.4	2.981	10	DOHC 4 V	2TCI	DI	309/6 500	500/1 700–5 000	911	Plasma-transferred iron cylinder liners, plastic oil pan, intake and exhaust VVT, intake VVL, electronically controlled wastegate
VW	EA211 1.0 TSI	Inline 3	74.5 × 76.4	0.999	10.5	DOHC 4 V	TCI	DI	85/5 000–5 500	200/2 000–3 500	Polo TSI, Golf L4	Common bore pitch with inline 4-cylinder 1.4-liter engine, cylinder head integrated with the exhaust manifold, dual-circuit cooling for engine and transfer case (T/C) with water-cooled intercooler, intake VVT
Hyundai	Kappa	Inline 3	71 × 84	0.998	10	DOHC 4 V	TCI	DI	88 /6 000	172 /1 500–4 000	i20	Euro 6c compliant, common bore pitch with inline 4-cylinder 1.4-liter engine, cylinder head integrated with the exhaust manifold, separate temperature control cooling for cylinder head and block, electronically controlled wastegate, Intelligent Stop and Go (ISG) system

4. 2. 3. Porsche

The 2016 911 Carrera, which is the base model of the 911 series, is installed with a 3-liter 6-cylinder direct injection turbocharged boxer engine (Fig. 18). In NA specifications, power characteristics differ depending on whether the engine has a displacement of 3.4 liters (Carrera) or 3.8 liters (Carrera S). However, this new engine shares a wide range of common specifications on each engine, such as an aluminum block with plasma-transferred iron cylinder liners, bore/stroke dimensions of 91 × 76.4 mm, a compression ratio of 10.0, and weight-reduction technologies such as a plastic oil pan. The performance differences between the Carrera and Carrera S are determined by the size of the turbocharger (compressor diameter: 49 or 51 mm) and the supercharging pressure (0.9 or 1.1 bar). The Carrera S achieves a maximum power of 309 kW and a maximum torque of 500 Nm.

4. 2. 4. VW

In 2015, despite being shaken by the diesel emissions scandal, but gasoline engine technologies of VW group are doing various efforts by combining a wide range of displacement and various electric power trains. The Polo and Golf were installed with the 1-liter inline 3-cylinder 1.0 TSI engine (Fig. 19). This engine is part of the new generation EA211 series of 1.4-liter inline 4-cylinder modular engines. This engine features a dual-circuit cooling design consisting of a high-temperature system that cools the cylinder head and other parts using a mechanical water pump, and a low-temperature system that cools the intercooler and turbocharger using an electric water pump.

4. 2. 5. Hyundai

In 2015, the Hyundai i20 was installed with a 1-liter inline 3-cylinder direct injection turbocharged engine (Fig. 20) that was developed at the Hyundai Motor Europe Technical Center. This is an inline 3-cylinder modular engine that shares the same basic framework as the 1.4-liter inline 4-cylinder Kappa engine. It features a dual-circuit cooling system that cools the cylinder head inte-

Fig. 16 BMW B58 engine.

Fig. 17 Ferrari F154CB engine.

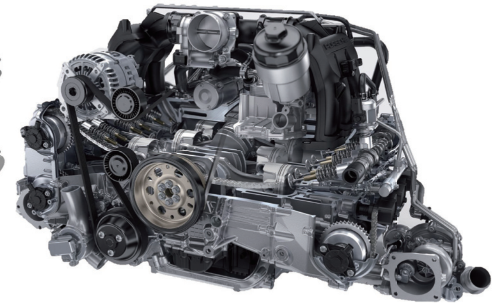


Fig. 18 Porsche Boxer 6 3.0-liter turbocharger.

Fig. 19 VW EA211 1.0 TSI engine.

Fig. 20 Hyundai Kappa 1.0-liter T-GDI engine.

grated with the exhaust manifold to a lower temperature than the engine block. This enables faster warm-up of the exhaust catalyst and improves real-world fuel economy. This engine achieves power of 88 kW at 6,000 rpm and torque of 172 Nm at between 1,500 and 4,000 rpm, while satisfying the Euro 6c emissions standards.

5 Research Trends

5. 1. Japan

In 2014, nine Japanese automakers and two research institutions established the Research Association of Automotive Internal Combustion Engines (AICE). The aim of AICE is to encourage cooperation between automakers and share research requirements to help further improve fuel economy, reduce emissions, and resolve issues related to combustion technologies and emissions treatment systems. Under this framework, the participating automakers can carry out joint research projects with universities and use the results to accelerate development in each company. Since then, a committee of supporting members was formed that has been joined by 58 companies (as of February 2016) and its activities are continuing(6).

In addition, the Cross-Ministerial Strategic Innovation Promotion Program (SIP) was introduced in 2014 to eliminate government red tape and strengthen cooperation between industry, academia, and the government with the objective of helping to revitalize the Japanese economy. Under the SIP, a government-industry-academia research organization has been set up to develop basic technologies capable of reducing CO_2 emissions by 30%. This organization has begun the Innovative Combustion Technology program to help raise the brake thermal efficiency of internal combustion engines up to 50% ahead of the global trend. The members of AICE and the SIP Innovative Combustion Technology program are collaborating as part of this government-industry-academia approach to research technical fields related to gasoline combustion, diesel combustion, loss reduction, and controls. The 2015 research results have already begun to be released in various forms. Figure 21 shows the scenario put forward by the gasoline combustion team for increasing the brake thermal efficiency of gasoline engines to 50% by utilizing a super lean burn approach(7).

5. 2. The U.S.

The Department of Energy (DOE) has established a target to reduce vehicle fuel consumption by 30% from current levels to 2030. Based on this target, research

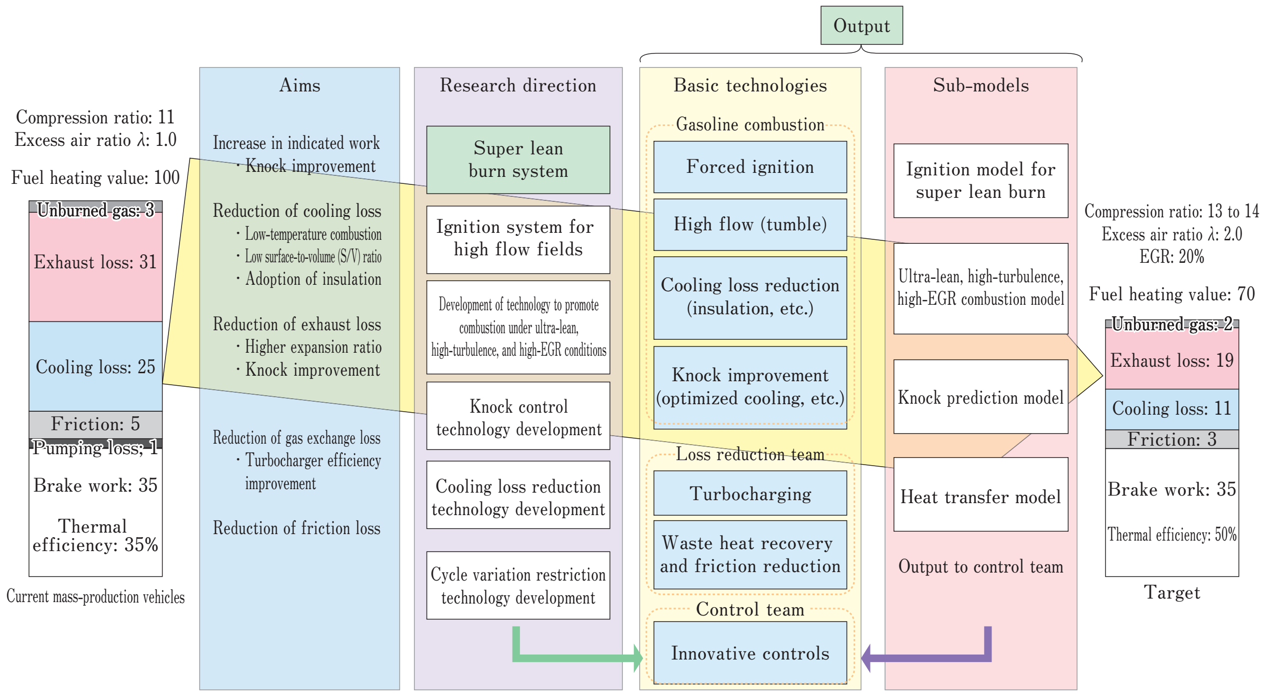


Fig. 21 Scenario for achieving thermal efficiency of 50% under SIP super lean burn project.

projects into engine improvements and domestically produced new biofuels were started in 2015. In 2016, a budget of around 3 billion dollars has been allotted to various projects including those related to advanced compression ignition (ACI) engines and the properties of fuels that can be used in both spark ignition (SI) and ACI engines.

5. 3. Europe

In the seven-year period from 2014 to 2020, the European Union (EU) has allotted a total budget of around 80 billion euros (around 10 trillion yen) to enhance Europe's international competitiveness in various scientific and technical fields under the Horizontal 2020 framework program for research and innovation. This is the seventh phase (FP7) of the existing framework program. Under this program framework, the Social Challenges project in the transportation sector has a budget of 29.7 billion euros (around 3.7 trillion yen), the Smart, Green and Integrated Transport project that includes internal combustion engines has a budget of 227.4 billion yen, the Technologies for Low-Emission Powertrains project has a budget of 5.7 billion yen over two years from 2014, and the Green Vehicle project has a budget of 25.8 billion yen over two years from 2016. Research is currently under way in all these fields.

Reference

(1) International Organization of Motor Vehicle Manufacturers 2015-1
http://www.oica.net/category/production-statistics/

(2) HIS Light Vehicle Powertrain Forecast, 2016 April

(3) Japan Automobile Dealers Association Statistics
http://www.jada.or.jp/contents/data/index.html

(4) Mark Lines Vehicle Sales Data base
https://www.marklines.com/en/vehicle_sales/search

(5) Public information materials and WEB sight of each OEM

(6) The Research association of Automotive Internal Combustion Engines (AICE)
http://www.aice.or.jp/

(7) Cross-ministerial Strategic Innovation Promotion Program WEB site
http://www.jst.go.jp/sip/k01.html

(8) US DOE RFIDE-FOA-0001460: Co-Optimization of Fuels and Engines, Dec. 16/2015
https://eere-exchange.energy.gov/Default.aspx#FoaIdf1c91182-d5c9-41bc-990e-93515d538cc1

(9) EU Horizon 2020 WEB site, and Horizon 2020 Smart Green Integrated Transportation WEB site
https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020

http://ec.europa.eu/programmes/horizon2020/en/
h2020-section/smart-green-and-integrated-transport