Environmentally Friendly High-efficiency Engine Systems

Environmental regulations for vehicles are becoming stricter all over the world. To reduce CO_2 emissions, technologies for clean combustion and better fuel economy in the real world are required to increase the thermal efficiency and exhaust purification performance of engines. Hitachi Automotive Systems, Ltd. is developing not only engine components, but also low fuel consumption powertrain systems that utilize outside-world information, which include autonomous driving technologies that are expected to become widespread in the future. This article describes measures taken in collaboration with overseas facilities for increasing engine efficiency, as well as the details of specific technology developments related to improving thermal efficiency.

Takuya Shiraishi, Dr. Eng.
Yoshinori Ichinosawa
Yoichi Anzo
Yoshihito Yasukawa

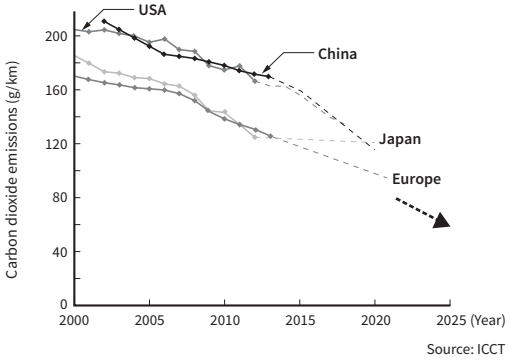
1. Introduction

The development of vehicles for reducing environmental burden is required on a global scale. Further stricter regulations are being studied for future implementation, which will result in the urgent need for the development of environmental technologies (see **Figure 1**). For example, although the electrification of vehicles will be effective for reducing greenhouse gas CO_2 emissions to 75 g/km or less, the development of technologies that increase the thermal efficiency of engines will also need to be continued. Further, technologies are required not only for clearing the regulation standards under specific test environments, but also for improving fuel economy and reducing exhaust gas under various conditions close to actual driving conditions.

Hitachi Automotive Systems, Ltd. is developing high-efficiency engine/transmission systems, low fuel consumption powertrains (energy management) and electrically powered systems in order to comply with these stricter CO_2 regulations. This article describes

Figure 1 — Carbon Dioxide Emission Regulation Trends for Passenger Vehicles

CO_2 regulations in Europe are driving worldwide regulations, and are scheduled to be strengthened to 95 g/km in 2020, and to 75 g/km (provisional) in 2025.



ICCT: The International Council on Clean Transportation

the high-efficiency engine systems and the developed technologies.

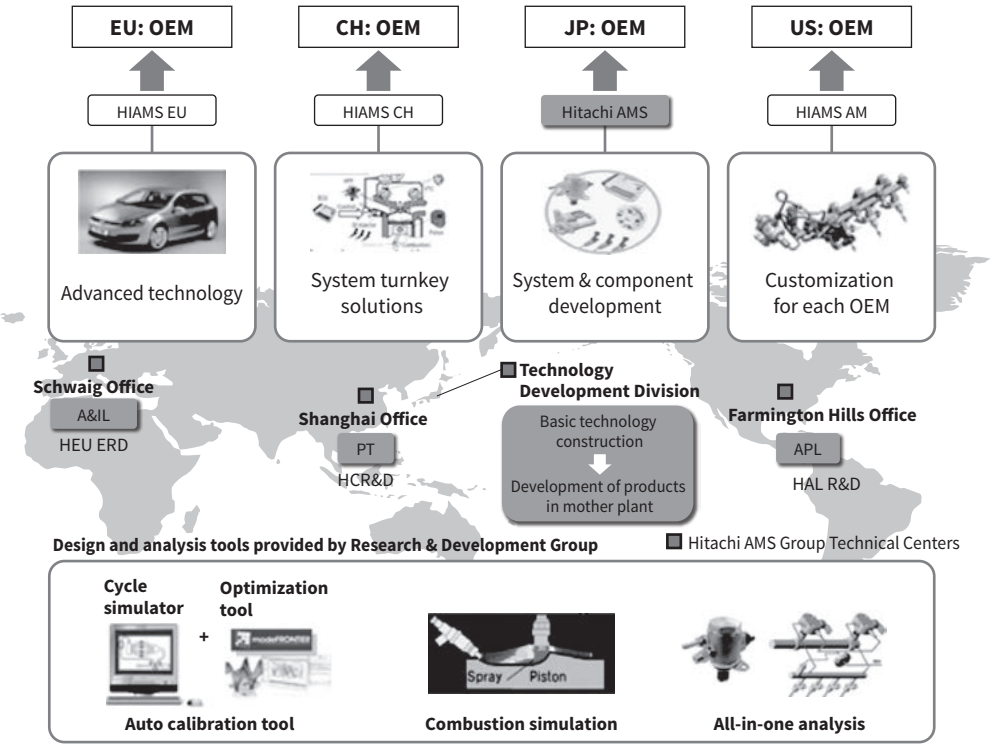
In order to increase the thermal efficiency of engines, Hitachi Automotive Systems is developing a fuel system based on direct injection of gasoline (DIG) technology that achieve a high compression ratio and diluted combustion [exhaust gas recirculation (EGR) combustion, lean combustion], high energy ignition system, and highly responsive electronic valve timing control (VTC). Hitachi Automotive Systems is participating in the joint research frameworks of the Research Association of Automotive Internal Combustion Engines (AICE) and Forschungsvereinigung Verbrennungskraftmaschinen e.V. (FVV) conducted at the national level in Japan and Europe, and collaborates with the Research & Development Group at Hitachi, Ltd. to identify the latest technologies and conduct research and development activities to incorporate these into products. One of these activities is global research, and an overview of that activity is described in the next section.

2. Development of Technologies Global Environmental Regulation Compliance

Vehicles are used in every region of the world and the environmental regulations are different in each region. Therefore, efficient information collection and research and development are necessary to supply products and propose technologies in a timely manner. To promote this, Hitachi Automotive Systems has established technical centers in the core markets of Europe, the USA, and China, and is conducting global research activities known as "Global One Team (GOT) activities" that include overseas Research and Development (R&D) members (see **Figure 2**).

GOT activities are defined as a collaborative framework that promotes contributions from domestic and overseas R&D facilities and local businesses. The system and mission have been clarified for information exchange and technology development, which had previously been performed individually at each

Figure 2 — Structure of Overseas Technical Centers and Overseas R&D Facilities
Business conditions of each facility are shared, including with research laboratory members, to develop technologies close to customers.



OEM: original equipment manufacturer HIAMS EU: Hitachi Automotive Systems Europe GmbH HIAMS CH: Hitachi Automotive Systems (China) Ltd.
Hitachi AMS: Hitachi Automotive Systems, Ltd. HIAMS AM: Hitachi Automotive Systems Americas, Inc. A&IL: Automotive & Industry Lab. APL: Automotive Products Research Lab.
HEU: Hitachi Europe Ltd. ERD: European R&D Centre PT: Product Technology Lab. HCR&D: Hitachi (China) R&D Corporation HAL: Hitachi America, Ltd.

facility. Activities have been developed so that information exchange meetings are held periodically and technology development is conducted by setting joint development themes and dividing the work between the facilities. GOT activities in the engine field are conducted according to the following policies.

(1) Mutual sharing of information and deployment of technology between divisions in domestic and overseas technical centers

(2) Sharing of business conditions at each facility (including with research laboratory members)

(3) Development of technology at each facility (close to customers)

(4) Sharing of each workgroup's issues and risk management

The next section describes examples of advanced technologies developed through engine GOT activities.

3. Engine Systems for Environmental Regulation Compliance

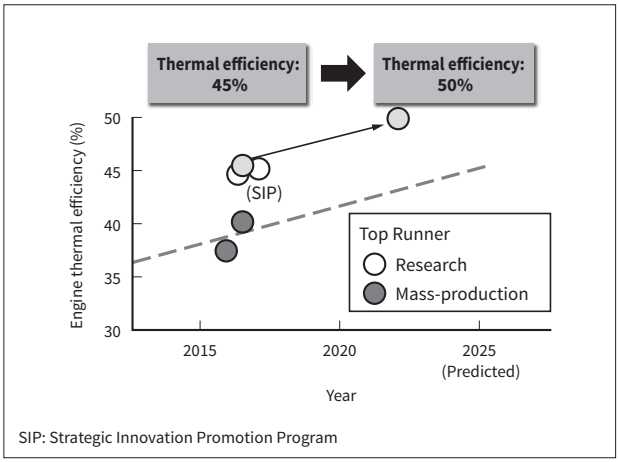
3. 1
High-efficiency Engine Systems

To reduce CO_2 (improve fuel economy) as described at the beginning of this article, the SIP national project in Japan is leading research and development to increase the thermal efficiency of engines. The maximum thermal efficiency in currently mass-produced vehicles is approximately 40%[(1)]. At the research level, the SIP has reported other research results that have achieved over 45% thermal efficiency[(2), (3)] (see **Figure 3**).

Hitachi Automotive Systems is conducting development with a thermal efficiency target of 50% for

Figure 3 — Benchmarks for Engine Thermal Efficiency

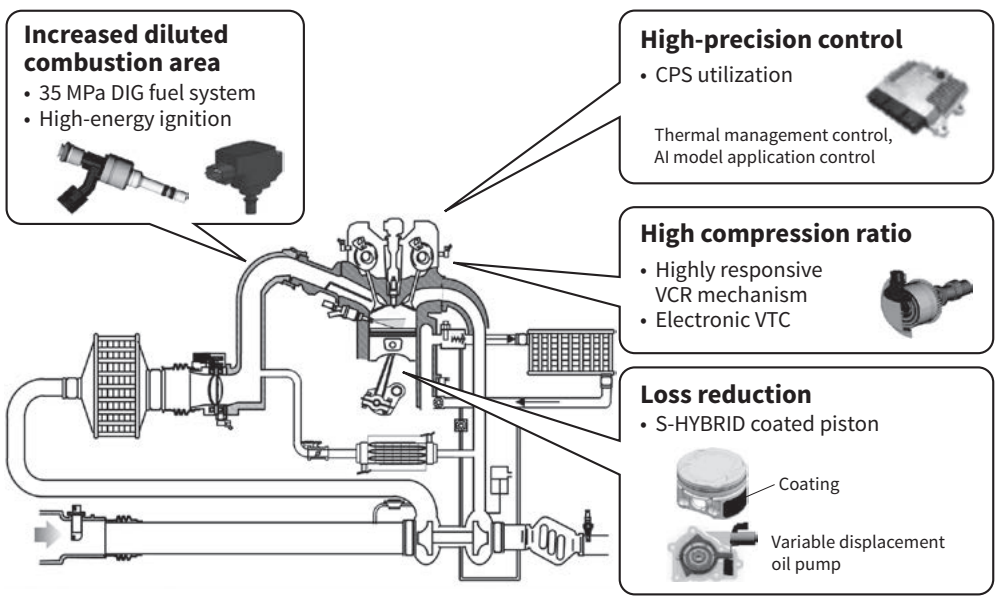
The thermal efficiency of mass-produced engines is approximately 40%, and technology has been developed at the R&D level for thermal efficiency of over 45%. To comply with stricter fuel consumption regulations in the future, R&D is being conducted to develop high-efficiency engine systems that achieve a thermal efficiency of 50%.



SIP: Strategic Innovation Promotion Program

Figure 4 — Lineup of System Products for Achieving 50% Engine Thermal Efficiency

A higher compression ratio, diluted combustion, and reduced loss are important for increasing thermal efficiency. Hitachi Automotive Systems is developing combustion control technologies and system products that achieve this.



DIG: direct injection gasoline CPS: cylinder pressure sensing VCR: variable compression ratio VTC: valve timing control AI: artificial intelligence

gasoline engines. A higher compression ratio, diluted combustion, and reduced loss are important for increasing the thermal efficiency. To achieve these, Hitachi Automotive Systems is developing combustion control technologies and system products (see **Figure 4**).

Engine knock at high engine loads is an issue when trying to raise the compression ratio. Knocking has been restricted by using a highly responsive variable compression ratio (VCR) mechanism and an electronic VTC that quickly changes the compression ratio.

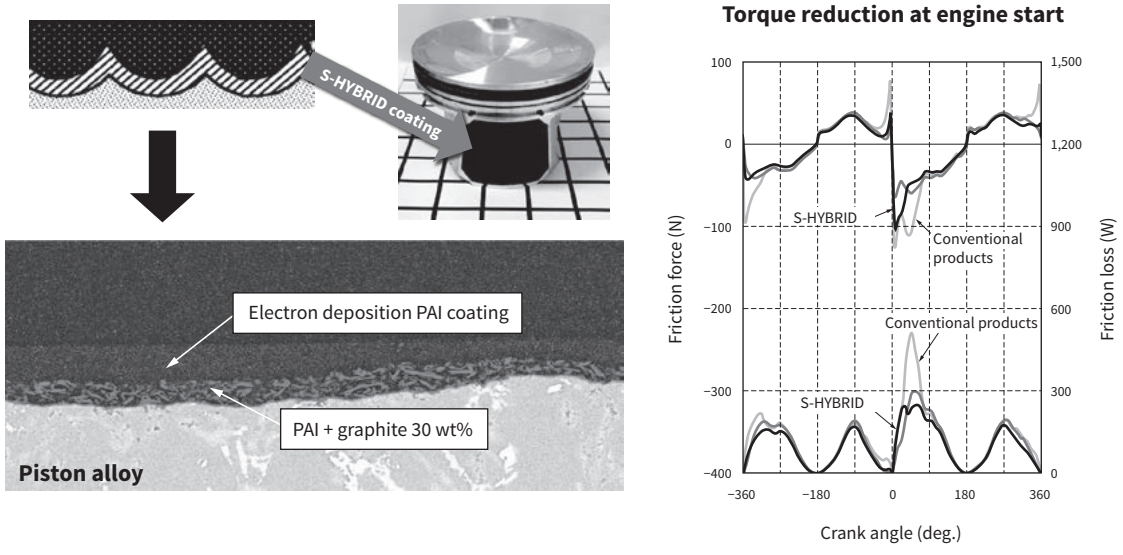
Regarding diluted combustion, pump loss reduction technology using homogeneous lean combustion has been developed. In homogeneous lean combustion, the tumble air motion and fuel spray must be thoroughly mixed in order to form a homogenous air-fuel mixture in the combustion chamber. To do this, a DIG fuel system has been developed with a fuel pressure of 35 MPa that is highly effective for fuel spray atomization. Because the combustion speed becomes slower in diluted combustion, the tumble air motion is strengthened to promote flame propagation. However, another issue is that when the tumble air motion is strong, the ignition spark can be blown and extinguished by the motion. To address this, Hitachi Automotive Systems Hanshin, Ltd. developed a new type of high-energy ignition coil that increases the ignition energy to 120 mJ from the previous level of 60 mJ. The use of this ignition coil enables stable combustion even under diluted combustion conditions with strong tumble air motion.

In terms of combustion control, cylinder pressure sensing (CPS) control is being developed to detect and control combustion fluctuations and address the issue of balancing combustion stability and NO_X emissions. Also, in anticipation of further performance advances in the microprocessors used in electronic control units (ECU), advance development is also being conducted for control that applies artificial intelligence (AI) models.

Regarding loss reduction, technology is being developed to reduce piston friction and cooling loss from the pistons. The piston system accounts for 30% to 50% of mechanical loss in the engine; therefore, reducing frictional force between the piston skirt and the cylinder bore is a critical issue. Because friction loss generated at the piston skirt is known to account for a large proportion of loss under fluid lubrication conditions, a new coating method[4] was developed that reduces the surface roughness of the skirt. This S-HYBRID coating is an original technology of Hitachi Automotive Systems (see **Figure 5**). Normally,

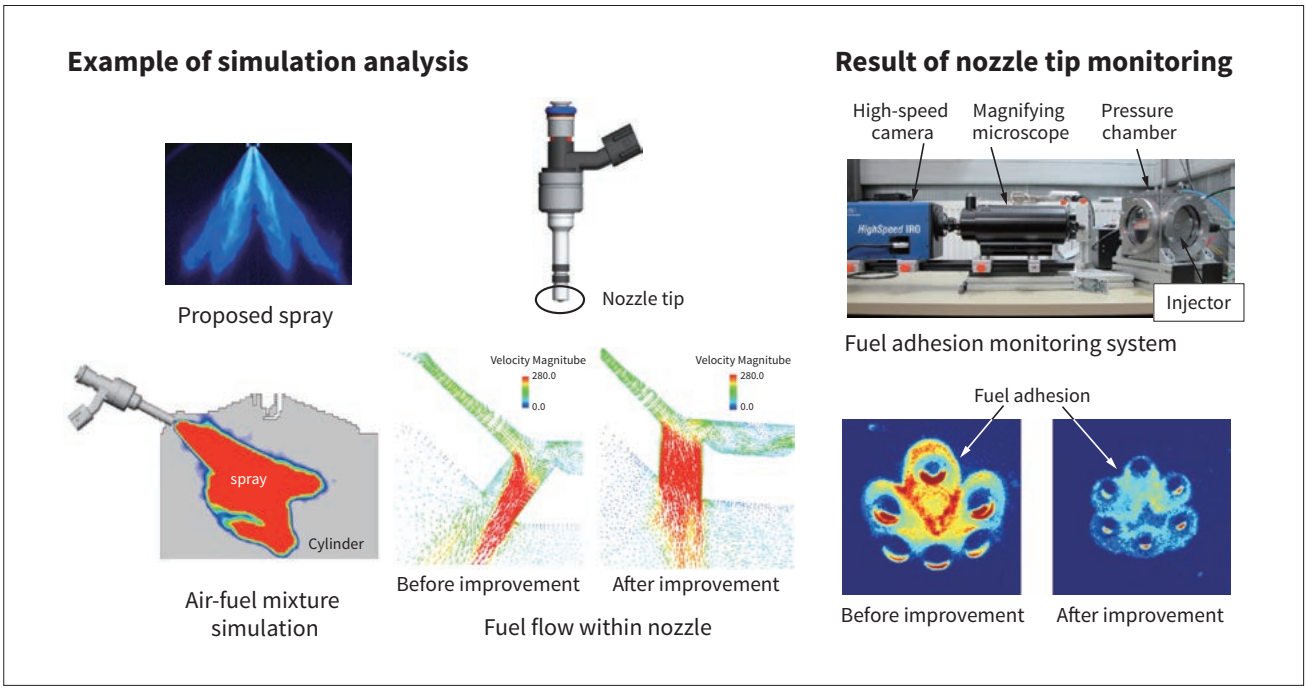
Figure 5 — S-HYBRID Coated Piston

This has a two-layer coating structure. The role of the upper layer is to wear quickly in the beginning to smooth the surface of the piston skirt.



PAI: polyamide imide

Figure 6 — Analysis Technology Supporting Low-emission Systems
Technology for monitoring the nozzle tip and simulations of the fuel flow inside the nozzle were used to develop technology that reduces particulate matter.



the skirt has bumps with an approximate depth of 10 μm, known as "striations." However, the S-HYBRID coating has a two-layer coating structure. The role of the upper layer is to wear quickly in the beginning to smooth the surface of the piston skirt. This reduces piston friction under all operating conditions, with a 14% reduction of friction loss [friction mean effective pressure (FMEP)] confirmed under engine start conditions.

The most common type of engine oil pump varies the discharge amount according to the rotation of the crankshaft. However, the hydraulic pressure required by hydraulically driven auxiliary devices varies greatly according to the operating conditions. For this reason, the variable displacement oil pump with a mechanism independently developed by Hitachi Automotive Systems reduces friction with an on-demand system that controls the hydraulic pressure, reducing it to the required level.

Also, with the goal of constructing lean combustion technology that surpasses SIP's "Innovative Combustion Technology," advance development of elemental technology is being conducted through joint research with domestic and overseas universities and research institutions.

3. 2
Low Emission (Low Particulate Number) Systems

In addition to restricting CO_2 emissions, compliance with exhaust gas regulations is also an urgent task. In particular, countermeasures for particulate number/particulate matter (PN/PM) are important for DIG. In response, Hitachi Automotive Systems is developing a DIG fuel system that reduces the PM in exhaust gas.

PN/PM is generated as particulate matter when fuel that does not vaporize adheres inside the combustion chamber, and when the air-fuel mixture is unevenly distributed. For this reason, Hitachi Automotive Systems used simulations to analyze the process by which the fuel spray injected from the injector and the air flowing in from the intake port form the air-fuel mixture inside the combustion chamber, and is developing a fuel injection control method that creates a uniform air-fuel mixture with low fuel adhesion. It discovered that reducing the amount of fuel adhering to the injector tip is highly effective for limiting PM emission[5].

Using technology for monitoring the injector nozzle tip and simulations of the fuel flow inside the nozzle, it has constructed technology that reduces PM by 90% compared to conventional systems (see **Figure 6**).

4. Conclusions

This article has described the progress of activities and developments toward increasing the thermal efficiency and reducing the exhaust gas of combustion engines, in order to comply with the 2025 CO_2 emission regulations, and in the context of the sudden trend toward the electrification of vehicles.

Hitachi Automotive Systems will continue to provide advanced systems that comply with environmental regulations by developing both component and control technologies.

References

1) T. Toda et al., "The New Inline 4 Cylinder 2.5L Gasoline Engine with Toyota New Global Architecture Concept," 38th International Vienna Motor Symposium 2017 (Apr. 2017).
2) T. Tomoda, "Strategies for Powertrain Development in the Era of Electric Mobility," Forum of 2017 JSAE Annual Congress (Spring) "Powertrain for Passenger Vehicles after 2030," (May 2017) in Japanese.
3) Cross-ministerial Strategic Innovation Promotion Program Website, Innovative Combustion Technology, http://www.jst.go.jp/sip/k01.html#RESUL0054 in Japanese.
4) M. Sasaki et al., "Development of Low Friction Solid Film Lubricant for Piston (5) —Analysis of Piston Friction Coated Smooth Double Layer Solid Film Lubricant on Skirt at Firing Engine—," Proceedings of 2017 JSAE Annual Congress (Spring) (May 2017) in Japanese.
5) T. Itaya et al., "Study of a Particle Number Reduction Method using a Flow Analysis of the Fuel Injector," Proceedings of 2017 JSAE Annual Congress (Spring) (May 2017) in Japanese.

Authors

Takuya Shiraishi, Dr. Eng.
Powertrain Technology Development Department, Advanced Development Center, Technology Development Division, Hitachi Automotive Systems, Ltd. *Current work and research:* Advanced development of engine powertrain systems. *Society memberships*: Society of Automotive Engineers of Japan, Inc. (JSAE) and the Combustion Society of Japan.

Yoshinori Ichinosawa
Engine Components & Control Brake Division, Engine & Chassis Division, Hitachi Automotive Systems, Ltd. *Current work and research:* Development of engine mechanical components. *Society memberships*: JSAE.

Yoichi Anzo
Ignition Coil Design Department, Design Development Division, Hitachi Automotive Systems Hanshin, Ltd. *Current work and research:* Development and manufacturing of ignition coils. *Society memberships*: JSAE.

Yoshihito Yasukawa
System Control Research Department, Center for Technology Innovation – Controls, Research & Development Group, Hitachi, Ltd. *Current work and research:* Research and development of engine powertrain systems and components. *Society memberships*: JSAE, The Japan Society of Mechanical Engineers (JSME), and the Institute for Liquid Atomization and Spray Systems – Japan (ILASS-Japan).