FEATURED ARTICLES

# Environmentally Compatible Technologies for a Car Society that Coexists with the Earth

In 2016, the Paris Agreement that was enacted specified international targets for reducing greenhouse gases ($CO_2$). In this context, proposals for preserving the global environment include next-generation vehicles such as electric and hybrid electric vehicles, improving the fuel economy of vehicles themselves through lighter designs and other measures, using alternative fuels, and improving traffic flows.
Hitachi is developing and expanding $CO_2$ reduction systems based on high-efficiency engines, high-efficiency electric systems, and energy management, as well as core technologies that support higher quality products. In addition, group companies are collaborating to develop various products based on metallic, magnetic, and lightweight materials, and processing and evaluation technologies, as well as to develop analysis and modeling technologies.
Hitachi will continue to comprehensively utilize technologies, starting from core and material technologies, and extending to system construction, to develop technologies that are compatible with environmental regulations and contribute to preserving the global environment.

Overview

# Considerations for Global and Urban Environments in the Automotive Field

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## 1. Introduction

Preserving the global environment is an urgent issue for the world today. The Paris Agreement was adopted at the 21st UN Conference of the Parties (COP 21) to the UN Framework Convention on Climate Change held in 2015, with the aim of restricting the rise of global average temperatures. The goal is to restrict (reduce) greenhouse gases to a certain level. Reduction targets were set, including targets for industry, and roadmaps for $CO_2$ reduction were also proposed in the transportation (automotive) field.

Hitachi Automotive Systems, Ltd. is developing technologies for improving the quality of $CO_2$ reduction systems and the products that support them. The company is also collaborating with Hitachi, Ltd.'s Research & Development Group, Hitachi Metals, Ltd., and Hitachi Chemical Co., Ltd., to develop high-quality products based on core technologies for materials, processing, and analysis.

## 2. Efforts to Preserve the Global Environment

In the Paris Agreement (COP 21), all participating countries voluntarily decided their targets for reducing greenhouse gases. This is different from the Kyoto Protocol (COP 3), which set uniform reduction goals.

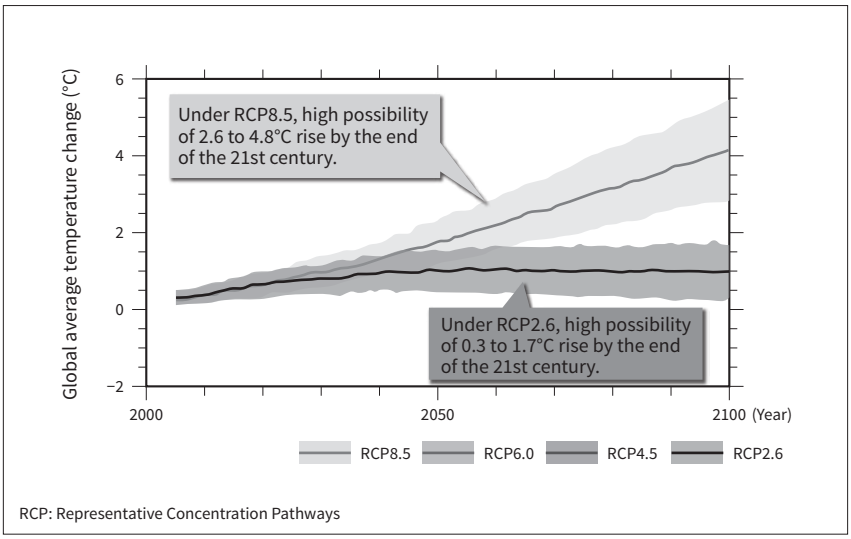
### 2. 1 Restriction of Rising Average Temperatures[1]

The Paris Agreement aims to restrict climate change and the rise in average temperatures on a global scale to preserve the global environment. Four scenarios for stabilizing greenhouse gas emissions known as Representative Concentration Pathways (RCP) have been adopted, and temperature rises are predicted based on these scenarios (see **Figure 1**).

Rising temperatures pose high risks such as rising sea levels. Other risks include effects on organisms, crops, and ecosystems, and extreme weather events such as droughts and floods.

**Figure 1 — Predicted Future Average Temperatures**[1]

The aim is to restrict climate change and rising average temperatures on a global scale to preserve the global environment. Four scenarios for stabilizing greenhouse gas emissions known as RCP have been adopted, and temperature rises are predicted based on these scenarios.




RCP: Representative Concentration Pathways

### 2. 2

### Greenhouse Gas ($CO_2$) Reduction Commitments per Country[2]

Each country proposed voluntary greenhouse gas ($CO_2$) reduction targets to apply from 2020 (see **Table 1**). Each country selected its own concepts for emission reduction and specified a base year and reduction amount. Quantifiable numbers were also specified, such as values per unit of gross domestic product (GDP), and reduction amounts based on predicted emissions according to current emission trends (Business as Usual: BAU). For example, Japan aims to reduce emissions 26% by 2030 relative to 2013. 150 countries and regions, including countries in Europe, Asia, and Africa, submitted targets. Periodic evaluation of results, such as the progress toward target achievement, is under consideration as a future measure.

## 3. Roadmap for $CO_2$ Reduction in Vehicles

Total $CO_2$ emissions in Japan are 1,265 million tons (2014), of which the transportation sector accounts for 17.2%. To successfully reduce emissions, measures must be implemented in both the industrial and household sectors. Applicable technologies have been proposed by the Japan Automobile Manufacturers Association.

### 3. 1

### Proposals for $CO_2$ Reduction Technologies[3]

The Japan Automobile Manufacturers Association has proposed $CO_2$ reduction methods for the transportation sector from the perspective of four categories (see **Figure 2**). Measures for improving the fuel economy

**Table 1 — Greenhouse Gas Reduction Targets per Country**[2]

In the Paris Agreement, each country proposed voluntary greenhouse gas reduction targets to apply from 2020. 150 countries and regions, including countries from Europe, Asia, and Africa, submitted targets. Periodic evaluation of results, such as the progress toward target achievement, is under consideration as a future measure.

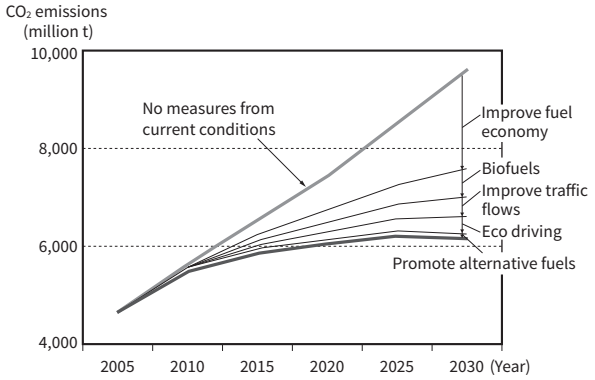
| | Intended Nationally Determined Contributions from 2020 |
|---|---|
| **Japan** | -26% by 2030 (relative to 2013) |
| **28 EU countries** | -40% by 2030 (relative to 1990) |
| **USA** | -26% to -28% by 2025 (relative to 2005) (withdrawal from agreement announced by current government) |
| **Switzerland** | -50% by 2030 (relative to 1990) (-35% by 2025) |
| **Russia** | -25% to -30% by 2030 (relative to 1990) |
| **China** | -60% to -65% of $CO_2$ emissions per unit of GDP (relative to 2005) ($CO_2$ emissions peak reached around 2030) |
| **South Korea** | -37% by 2030 relative to BAU |
| **India** | -33% to -35% of GHG emissions per unit of GDP by 2030 (relative to 2005) |
| **South Africa** | 614 million t $CO_2$ by 2030 (annual average) |

BAU: Business as Usual GDP: gross domestic product GHG: greenhouse gas EU: European Union

**Figure 2 — Proposals by Japan Automobile Manufacturers Association for Vehicle $CO_2$ Reduction Technologies[3]**

The Japan Automobile Manufacturers Association has proposed $CO_2$ reduction methods for the transportation sector from the perspective of four categories. The proposals consist of measures for improving the fuel economy of the vehicle itself, promoting biofuels, improving traffic flows, and driving efficiency tools to assist drivers.

| Category | Measure |
|---|---|
| Improve fuel economy of vehicles themselves | Set fuel economy standards, make vehicles lighter, promote measures for next-generation vehicles and vehicles with low $CO_2$ emissions |
| Fuel diversification | Expand promotion of biofuels, etc. |
| Improve traffic flows | Traffic measures, urban plans |
| Efficient use | Driving efficiency, fuel consumption meters, and other support tools |




of vehicles themselves include making vehicles lighter and introducing technologies such as next-generation vehicles. Other proposals include promoting biofuels, improving traffic flows, and driving efficiency tools to assist drivers.

### 3. 2
### Predictions of Future Production Volumes by Vehicle Type[4]

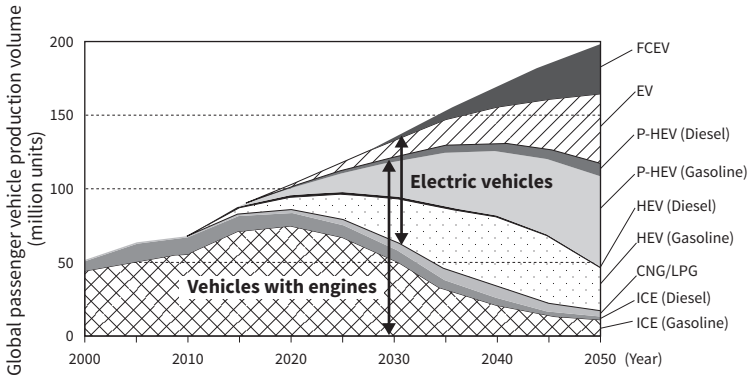
Future production volumes by vehicle type, including next-generation vehicles, have been predicted by the International Energy Agency (IEA) (see **Figure 3**). By 2030, the electric vehicle types of hybrid electric vehicles (HEV) and electric vehicles (EV) are expected to account for about half of the volume, which means this trend will accelerate sharply from now. However, even including HEV, vehicles equipped with engines will still account for about 90% of the volume, therefore it will be necessary to improve engines also.

## 4. Hitachi Automotive Systems Efforts

This section describes the development of systems by Hitachi Automotive Systems that reduce $CO_2$ emissions and core technologies that will support high-quality products.

**Figure 3 — Prediction of Future Production Volume by Vehicle Type[4]**

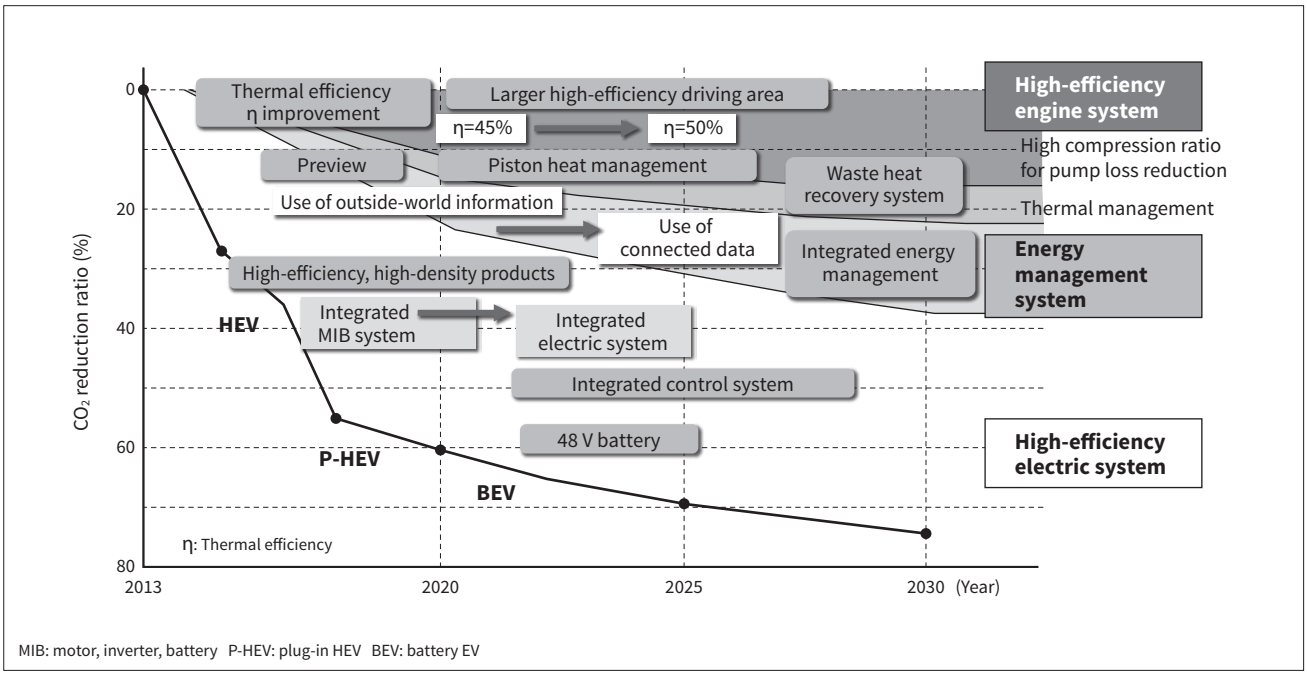
The International Energy Agency (IEA) has predicted future production volume by vehicle type, including next-generation vehicles. By 2030, electric vehicles, including HEVs, are expected to account for about half of the volume, which means this trend will accelerate sharply in the future. However, even including HEVs, vehicles equipped with engines will still account for about 90% of the volume, therefore engine improvements will be required also.




ICE: internal combustion engine CNG: compressed natural gas LPG: liquefied petroleum gas
HEV: hybrid electric vehicle P-HEV: plug-in HEV EV: electric vehicle FCEV: fuel cell EV

**Figure 4 — Development of Powertrain Systems with Low $CO_2$ Emissions**

Hitachi Automotive Systems is developing a powertrain system that reduces $CO_2$ emissions. System technologies and products are being developed in three areas: high efficiency engine systems, high efficiency electric systems, and energy management systems. By 2030, the aim is to reduce $CO_2$ emissions by 70% or more relative to 2013.




**4. 1**

## Development of $CO_2$ Reduction Systems

Hitachi Automotive Systems is developing a powertrain system that reduces $CO_2$ emissions (see **Figure 4**). System technologies and products are being developed in three areas: high-efficiency engine systems, high-efficiency electric systems, and energy management systems. By 2030, the aim is to reduce $CO_2$ emissions by 70% or more relative to 2013.

The high-efficiency engine systems improve thermal efficiency (η) by 45% to 50% through pump loss reduction, high-compression-ratio engine control systems, and thermal management systems. The key technologies for reducing pump loss are combustion and control technologies such as exhaust gas recirculation (EGR) and lean-burn systems. In terms of thermal management systems, the company is developing technologies for the effective use of piston heat, engine heat, and exhaust heat.

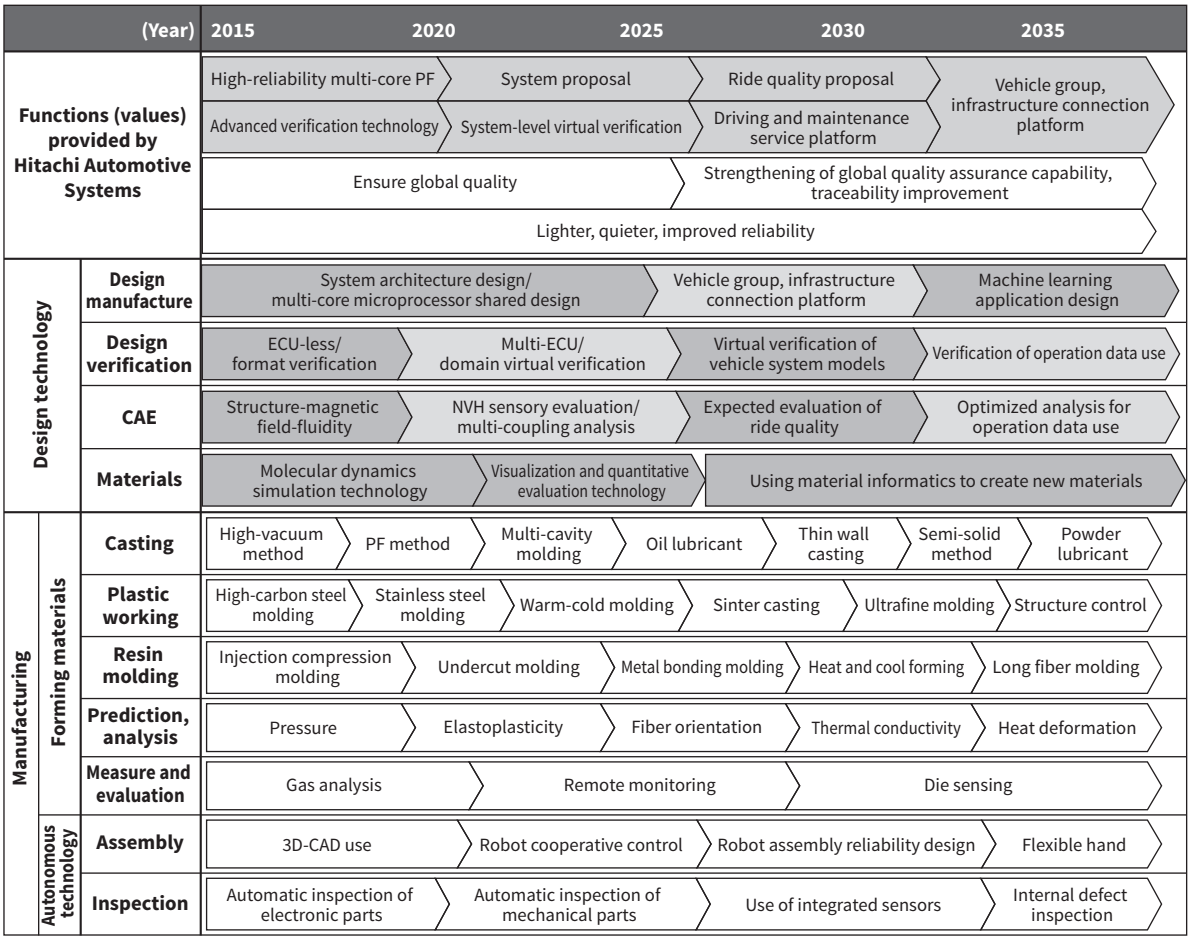
Energy management systems achieve powertrain operation with low fuel consumption by using outside-world information such as previews. In engine vehicles, $CO_2$ emissions are reduced by stopping the engine while driving and decelerating, and coasting via inertia. In the future, $CO_2$ emissions will be further reduced by advanced control of the powertrain using Big Data such as traffic flow information, a wide range of signals, signs, and detailed topographical information. This integrated energy management system will form a base technology that is applicable to both engine vehicles and electric vehicles.

Regarding high-efficiency electric systems, Hitachi Automotive Systems is developing technologies for increasing the efficiency and density of MIB (Motor, Inverter, Battery) products. The aim is to improve efficiency with an integrated MIB system that achieves the optimum specifications and control from the perspective of each component of the MIB system. To further reduce $CO_2$ emissions, optimum energy (drive, regeneration) management under driving conditions, and environments is also being developed. Additionally, Hitachi Automotive Systems is developing an integrated energy management system that is combined with an autonomous driving system, which will become an important system in the future.

To construct a $CO_2$ reduction system, it is essential to combine these three areas and to integrate them with autonomous driving technologies. Hitachi Automotive Systems is developing a total system that will create synergies.

**Figure 5 — Technologies for Improving Product Quality at Hitachi Automotive Systems**

Hitachi Automotive Systems is developing core technologies for design and manufacturing that support systems and products, to improve the performance and quality of products.




PF: pore free die casting CAE: computer-aided engineering ECU: electronic control unit NVH: noise, vibration, harshness CAD: computer-aided design

## 4. 2
## Core Technologies that Support High-quality Products

Hitachi Automotive Systems is also developing core technologies that support environmentally compatible products and high-quality products (see **Figure 5**).

(1) High-efficiency Design Technologies

To meet high safety and quality requirements, Hitachi Automotive Systems is advancing core design technologies that support design and development. It is promoting the development of efficient products by applying simulation technologies starting from the development stage in all kinds of fields, including hardware, software, and materials.

The scope of verification for electronic control units (ECU) that have built-in software has increased significantly. To support this, Hitachi Automotive Systems is constructing virtual verification environments and providing highly reliable systems that reduce the re-work required due to verification in upstream design processes, and perform verification linked to multiple ECUs and simulations linked with external environments. In addition, analytically driven design utilizing three-dimensional computer-aided engineering (CAE) technology is being promoted. Hitachi Automotive Systems is accelerating the front-loading of development by utilizing three-dimensional CAE tools in various physical domains such as structure, magnetic fields, fluids, and sounds, and predicting product performance from the early stages of development and design.

In terms of material technology, analytically driven material technologies are being developed to improve the competitiveness of core products. Predicting

performance using analysis between specification determination and trial evaluation, makes it possible to conduct thorough evaluations before trial production to improve quality and performance, and to shorten development times.

(2) Manufacturing Technologies

As product globalization progresses, so does the demand for local production and local consumption. To stay ahead of global competitors, Hitachi Automotive Systems is developing manufacturing technologies focusing on the following two areas.

(a) Developing differentiated production methods that blend forming materials and mold technologies, aiming to be the best in the industry in terms of forming material technologies.

(b) Developing autonomous technologies aiming to be the global standard, and to achieve stable quality.

To strengthen the forming materials used in the vertically integrated business, a pore free (PF) die casting method, which reduces internal defects, a high-vacuum method, and a semi-solid method for more even texture and higher strength are being developed for casting. This makes it possible to replace existing products with lighter and stronger ones. In terms of plastic working, Hitachi Automotive Systems is seeking to implement process-less work, to establish processing technologies for difficult-to-form materials (such as stainless steel), and to develop technologies that ensure high accuracy. To ensure stable quality on a global scale, collaborative control of robots aimed at improving automation rates, and assembly reliability-design technology aimed at reducing the difficulty of automated assembly are being developed for assembly. For inspections, the goal is to completely automate the visual inspections that were previously conducted by humans.

## 5. Collaboration Between Hitachi Groups

This section describes the high-quality products and supporting technologies of Hitachi Metals and Hitachi Chemical, and the collaborative development between Hitachi Automotive Systems and the Research & Development Group of Hitachi, Ltd.

### 5. 1
### Hitachi Metals Efforts

The three main product fields of Hitachi Metals are automotive, industrial infrastructure, and electronics. Of these, there is particular focus on the automotive field, which accounts for about 50% of total sales. Examples of the Hitachi Metals' core technologies and product technologies in the automotive field are shown on the left side of **Figure 6**. Previously, the main products in this field were metal parts and various cast parts for internal combustion engines, such as piston rings and continuously variable transmission (CVT) belts.

However, Hitachi Metals also provides various metal components for core electric parts such as motors, inverters, and batteries, and is developing products that support next-generation vehicles such as HEVs and EVs, the market for which is expected to grow in the future. For the metal parts of motors, Hitachi Metals is developing products based on neodymium (Nd) magnets and rectangular enameled wires. Heavy rare-earth elements such as dysprosium (Dy) and terbium (Tb) can be added to Nd magnets to improve heat resistance, but this may cause risks due to uneven resource distribution. By optimizing the magnet structure, Hitachi Metals is developing heavy rare-earth magnets that significantly reduce the amount of heavy rare-earth elements used, and magnets that do not use any heavy rare-earth elements.

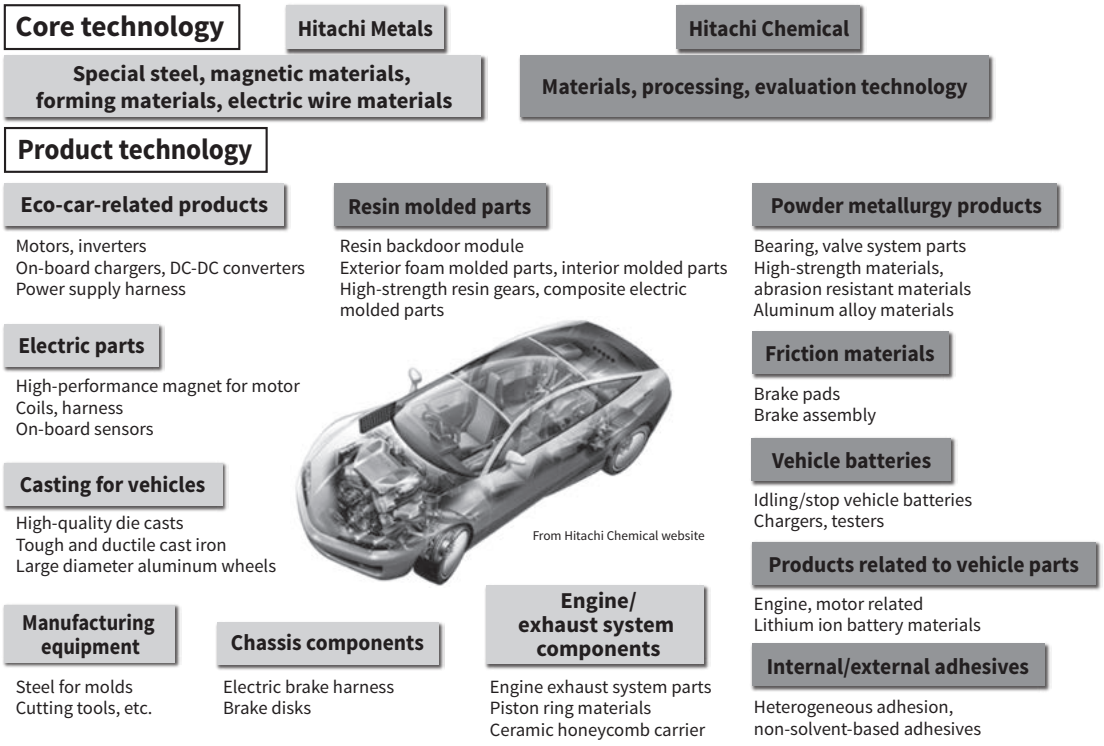
In addition, Hitachi Metals has started mass-production of high-performance pure copper (HiFC) for reducing the resistance of coils. By combining this with thick coating technology for high heat resistance and low dielectric constant sheathing, a high-performance rectangular enameled wire has been produced. This is being applied to drive motors that require a small size and high reliability.

Hitachi Metals has developed low-loss amorphous metal and nanocrystalline metal materials as metal materials for inverters. In addition to high-performance ferrite materials, Hitachi Metals is commercializing various soft magnetic parts that support next-generation high-frequency switching, and is developing new materials to further improve performance.

As a high-strength, low-resistance current collector for next-generation silicon (Si) negative electrode

**Figure 6 — Collaboration between Hitachi Groups**

Hitachi Metals and Hitachi Chemical are also developing various products based on metallic, magnetic, and lightweight materials, and core technologies such as processing and evaluation technologies.




DC: direct current

lithium-ion batteries, three-layer cladding made of copper (Cu) and nickel-niobium (Ni-Nb) is being commercialized using independently developed metal processing technology.

The trend toward electric vehicles is expected to continue accelerating in the future, and the development of new materials that achieve further performance improvements is required. However, the use of electric vehicles alone is not enough to comply with the environmental regulations. The development of new materials and parts for improving the efficiency of internal combustion engines and reducing vehicle weights will also be essential. In the future, Hitachi Metals will continue to contribute to preserving the global environment through next-generation metal material technologies.

## 5. 2
## Hitachi Chemical Efforts

Hitachi Chemical is developing technologies and products that contribute to various fuel economy improvements, such as lighter vehicle weights and engine improvements that support $CO_2$ emission reductions (see the right side of **Figure 6**).

For lighter vehicle weights, Hitachi Chemical is developing distinctive resin molded parts that apply independently developed material design, mold design, and molding technologies, exemplified by resin backdoor modules and resin gears. Their parts have been adopted in many vehicles. Particularly notable was the world's first* development and practical application in 2016 of injection foam molding technology for exterior resin molded parts. By using a sponge-like foam inside the resin molded parts, the weight was reduced by about 30% while maintaining the same rigidity as conventional products. For the design, by forming a solid resin layer with the same performance as conventional products, Hitachi Chemical succeeded in meeting the required specifications for exterior vehicle parts that could not previously be achieved using injection foam molding. Exterior resin molded parts

* Based on July 2016 research by Hitachi Chemical[5].

that use this technology have already been adopted for vehicles sold by two Japanese manufacturers, and increased adoption is expected in the future for the rapidly growing EV/HEV market.

In terms of engine improvements, powder metallurgy products are being adopted to help downsize supercharged engines. In recent years, downsizing vehicle engines by installing a supercharger has become more widespread to reduce the engine displacement, fuel consumption, and exhaust emissions while maintaining the same power and performance as a conventional engine. By utilizing the high flexibility of material designs in powder metallurgy, Hitachi Chemical has developed high-strength materials with excellent abrasion resistance even in the high temperature environments of superchargers, which reach 700°C or higher. Powder metallurgy products using these materials have been adopted by several supercharger manufacturers, and further adoption is expected in the future as downsizing of supercharged engines becomes more widespread.

Through the technologies and products described above and future technological developments, Hitachi Chemical will continue to contribute to society by helping to develop an automotive industry that is compatible with environmental regulations.

### 5. 3
### Collaboration with the Research & Development Group

Hitachi Automotive Systems is conducting development in collaboration with the Research & Development Group of Hitachi, Ltd. In the powertrain field, they are conducting engine combustion analysis, model-based development of electric systems, and development of related products based on material technologies.

(1) Engine Combustion Analysis

Analysis technology developed by the Research & Development Group is being applied to the development of combustion technology, which is key to the engine system. The parts specifications for achieving optimal combustion, such as injectors, ignition coils, and pistons, are determined from the perspective of fuel economy, exhaust, and output. This enables systems and products to be proposed in advance during the engine development stages at automobile manufacturers, which contributes significantly to business expansion.

(2) Model-based Development of Electric Systems

When developing electric systems such as motors, inverters, and batteries, it is important to propose the optimal specifications for the automobile manufacturer's requirements (efficiency, output). Development is linked to a simulator that constructs models of these products and performs analysis up to system performance. This enables not only the specifications to be determined, but also compliance with inverter control, which significantly reduces the development time.

(3) Material Technologies

To expand business, it is important to propose products that can support global fuels. To do this, it is necessary to identify fuels and the constituents that affect (corrode, erode) fuel system components, to select materials with excellent durability, and to apply them to products. The Research & Development Group is contributing significantly to product design by developing test methods and durability prediction technologies that take into account the selection of fuel constituents and usage conditions.

## 6. Conclusions

Together with other Hitachi Group companies, Hitachi Automotive Systems is developing systems and products to reduce $CO_2$ emissions. A wide range of product fields are covered, and synergies between the different technologies are required. In the powertrain field as well, these technologies need to be combined with autonomous driving technologies and chassis technologies, therefore a total system for these needs to be developed. On the other hand, higher quality for the products that support this system is also important. Hitachi Automotive Systems is developing and improving design technologies and manufacturing technologies for the future that support advanced systems and products.

Hitachi Automotive Systems will continue utilizing all technologies, from core technologies to technologies for entire systems, to meet the needs of society for preserving the global environment.

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