# Innovative Combustion Technology

## The Plan for the Rising Sun Engine Initiative to Save the World

## Innovative Combustion Technology from Japan; the Trump Card to Save the Global Environment

Cars provide indispensable support to industry, society and our personal lives, getting us from place to place quickly and comfortably. At the same time, the impact of vehicles on the global environment calls for improvements in drivability, safety and greater environmental performance. Innovative combustion technology (The Plan for the Rising Sun Engine Initiative to Save the World) aims to dramatically improve internal combustion thermal efficiency up to a maximum of 50 percent, reducing the impact of combustion engines on the environment. This cooperative research and development project between industry, academia and government will also contribute to the development of Japan's practical engineering capacity and the nation's ability to compete.


Program Director

**Masanori Sugiyama**

Toyota Motor Corporation


**Profile**

Mr. Sugiyama joined Toyota Motors in 1984. He took over as project manager for new V6 engine development in 2002, and was subsequently named project general manager for renovation promotion of engine development in 2003. In 2007, Mr. Sugiyama took over as General Manager, New Engine Development Division. Mr. Sugiyama was named Executive General Manager, Field General Manager, Engine Engineering Field in 2013 and, in 2016, he was named Executive General Manager for Power Train Company and Field General Manager for Advanced Power Train Engineering Field. In 2017, he was named General Manager for Advanced Development Power Train Company and Executive General Manager for Higashifuji Technical Center. In 2018, he was named Executive Adviser for Frontier Reserch Center. In 2019, he was appointed to his present position.

## Research and Development Topics

### 1. Research to improve gasoline engine thermal efficiency

Work towards elemental technologies for super lean burn, high boosted combustion, as well as combustion under high EGR volume,leading to thermal efficiency of up to 50 percent in comparison to the initial maximum of 39 percent.

### 2. Research to improve diesel engine thermal efficiency

Develop elemental technologies such as fast and quiet combustion and clean low temperature combustion that lead to thermal efficiency of up to 50 percent in comparison to the initial maximum of 43 percent.

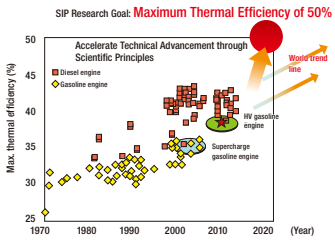
### 3. Shared research for gasoline and diesel engines

Develop foundational technologies shared between gasoline and diesel engines, including modeling and control technologies for combustion, research into combustion analysis tools, and research into various types of loss reduction.

•SPORT HYBRID i-MMD 2.0L DOHC i-VTEC

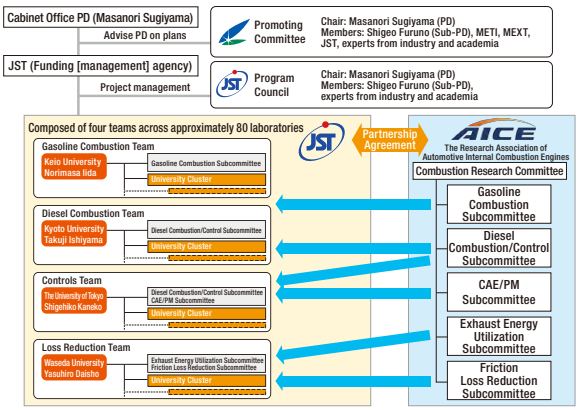
(Source: Honda R&D Co., Ltd.)

•Changes in the Thermal Efficiency of Automotive Internal Combustion Engines and SIP Goals




## Implementation Structure

As an expert in research management, the Japan Science and Technology Agency (JST) oversees the program as a whole. Approximately 80 participating laboratories and public research institutions have been divided into four teams covering the research fields of gasoline combustion, diesel combustion, control, and loss reduction, each led by a leader university. The Research Association of Automotive Internal Combustion Engines (AICE) has entered into a partnership agreement with JST to support each research team, creating a research and development framework that brings together industry, academia and government agencies.



## Exit Strategies

### Maintenance and development of open laboratory and HINOCA after SIP

Provide society with the latest technology and development tools to improve thermal efficiency and reduce $CO_2$ by maintaining and developing full-scale empirical research infrastructure (open laboratory) and a development tool (HINOCA) that evolve by incorporating the results at domestic universities.
Leverage these results to improve fuel efficiency for the Japanese auto industry, strengthening the industry's competitive advantage and contributing to lower global $CO_2$ levels.

### Create a structure for sustainable multi-industry, multi-academic collaboration

A successful industry-academia cooperative research relationship will communicate common needs from industry, mutual understanding through personnel exchange between industry and academia, grow the management capabilities of leader universities, and empirical research at the leader universities. This new cooperative scheme will serve as a model to other industries, leading to a new development process that will contribute to a stronger Japan. Japan's Ministry of Economy, Trade and Industry (METI) and Ministry of Education, Culture, Sports, Science and Technology (MEXT) work together to study policies to create a sustainable multi-industry, multi-academic cooperative research relationship that contributes to Japan's industrial competitiveness.

### Construction of research result database

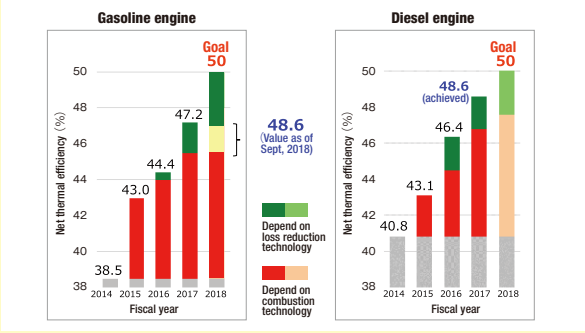
Summarizing the research results, and making it a database. By combining research use at academia of the database and development and use at industry, it will lead to the development of this technical field even after SIP.

## Progress to Date

### Building a research system to challenge with All Japan

Cross-linking and fusion of research fields occurred through industry-academia collaboration centered on open laboratories, and exchanges of knowledge among researchers became active. Four research and development bases capable of actual machine testing are in place and fully operational. Two facility providers are planning cooperation even after SIP.

●Achievement status of thermal efficiency (as of September 2018)

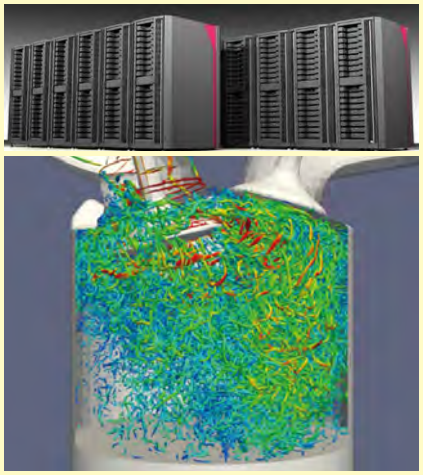



●Research system of All Japan with research and development bases


### Unveiling the HINOCA Rising Sun Software

Although automotive engines are widespread, surprisingly little is known about the many unresolved issues surrounding heat flow phenomena associated with combustion. It is the mission of HINOCA to unravel these issues and model them numerically to build highly versatile, Japanese- made 3D simulation code for engine combustion.
HINOCA has also been released to engineers at automakers. Together with relevant researchers and with members of the CAE/PM Subcommittee at the Research Association of Automotive Internal Combustion Engines (AICE), collaborative efforts are being made to increase the accuracy of modeling by using super computers to represent actual engines. It is expected that this technology will be broadly adaptable, from basic research to development, including for elucidating the turbulent vortex structure generated inside engines.

● Visualization of turbulent vortex structure using Japan Aerospace Exploration Agency's (JAXA) supercomputer



Program Director **Masanori Sugiyama** Interview

# Expectations for Deepened Multi-industry, Multi-Academic Collaborations and for Invigorated Automotive Engineering

**While electrification of the automobile continues, more than half of all vehicles are expected to still be using internal combustion engines 30 years from now. This program continues to make progress in improving the thermal efficiency of automotive internal combustion engines by combining specialized knowledge of control, combustion and loss reduction.**

## Sparking an Exchange of Knowledge Among Researchers

It is time for the final fiscal year as industry-academia-government collaborative research which has been set an ambitious goal for achieving a thermal efficiency of 50 percent for gasoline and diesel engines. With approximately 80 laboratories and public research institutions participating, the scale of this joint research is unparalleled. Program Director Masanori Sugiyama sees a positive outcome from the deepening cooperation. “To meet the needs considered by AICE (The Research association of Automotive Internal Combustion Engines), we would like to bring it closer to the height that we can not reach if we do it by industry alone by gathering the scientific power of academia. For that purpose, discussions frequently occur between industry and academia, and very good results have come out.”

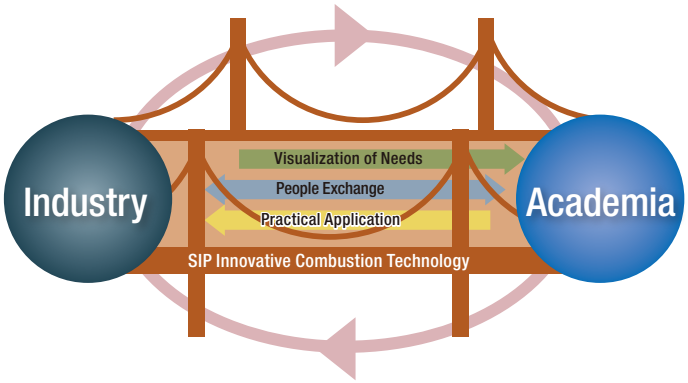
To achieve these program goals, it is essential now to form new scientific theories, rather than reasoning by analogy based on past engine development experience and results. To this end, program researchers are combining a number of research fields, including chemical reactivity and basic combustion. Based on these results, research teams their work together to build larger integrated models. Academic research tends to build deep into a particular field, having limited interchange with other fields. Through this joint research, however, a number of research fields have been cross-linked and integrated, encouraging active exchange of researcher knowledge.

## Progress Through Open Innovation

Under this program, open labs have been established at the four leader universities, equipped with state-of-the-art laboratory equipment and serving as forums for experiments, discussions and data-sharing among industry and academic researchers. The Keio University SIP Engine Laboratory in the Ono Sokki Technical Center was the first such open lab. This center is home to more than 100 registered researchers and student participants.

Mr. Sugiyama spoke of his expectations for developing human resources, saying, “I believe that the following are major achievements. Researchers at the university of the same thought conducted experiments at the open laboratories, and the results demonstrated there led to research outcomes. Not only can university researchers gather and discuss various subjects but also people from enterprises can enter there, human exchanges progressed, which led to promotion of research.”

•Creation of Sustainable “Multi-Industry, Multi-Academy” Collaboration




Industry ⇒ Academia: Visualize Common Needs in Industry

Academia ⇒ Industry: Provide Basic Knowledge

Academia ⇔ Industry: Sustained Exchanges in Human Resources/Needs/Seeds

Universities throughout Japan
Companies at the Edge of their Individual Potential

United!

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A research environment that promotes this kind of open innovation leads to steady results. “Both Gasoline Combustion Team and Diesel Combustion Team need to raise their thermal efficiency of 1-2% for the demonstration of the achievement of a thermal efficiency of 50%. In the past four years, the efficiency improvement of about 7 to 8% was seen, so I think that we will be able to produce some good result in this final year, if we go at this pace. ” The Loss Reduction Team has developed a technology in which low-friction materials are used to form a hardened surface on the engine piston, while the Control Team and Gasoline Combustion Team are collaborating to develop HINOCA, software for the three-dimensional simulation of engine combustion. Another of the goals of this program is to develop standards from unique Japanese control models and analysis software, leading to future reductions in development costs.

## Innovating Practical Engineering Research

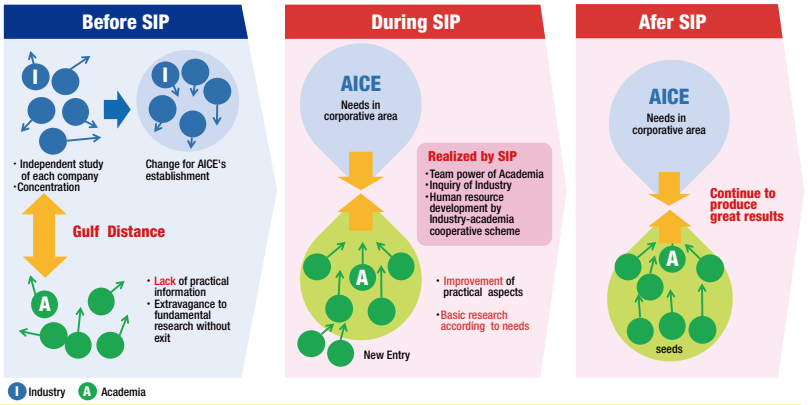
Thus far, this program has achieved its target efficiencies each year. However, we will need to strengthen the cycle of exploring, pursuing and verifying new ideas.

It took researchers 40 years of effort to finally raise the thermal efficiency of internal combustion engines from 30 percent to 40 percent. To gain another 10 percent in a span of five years is certainly a lofty goal.

To break through this wall, program participants are engaged in the scientific approach mentioned earlier. From the scientific elucidation of the phenomenon occurring in the engine by the power of "academia", the result of generic model is created. By utilizing this outcome by "industry", it will lead to sophistication and speedup of technology development. This is an important element for achieving Society 5.0 as provided under the 5th Science and Technology Basic Plan, as well as an important initiative leading to highly competitive manufacturing for Japan.

“In terms of securing international competitiveness in research and development, we aim to further develop internal combustion engines and to win the position outstanding in this field.” (Sugiyama) Research and development bases that can carry out actual machine tests up to now have been developed in four locations nationwide, and facilities will be continued even after SIP. In addition, a sustainable industry-academia collaborative system is being constructed in order to continue the industry-academia collaboration that is realized by the centripetal force of SIP. This program continues to evolve with industry-academia collaboration unique to Japan with strength of basic research and teamwork.

• Relationship between industry and academia that changed before and after SIP




**Industry-academia, which was disjointed, united by the centripetal force of SIP, to create research results and human resource development.**

**We do not let "the end of SIP = the end of industry-academia collaboration".**
**So we have started a new approach.**

**From now on, the internal combustion engine will lead the way towards zero $CO_2$ and zero emissions, as a result, I hope to be able to create a society where everyone is truly enjoyable and able to live conveniently with a smile.**