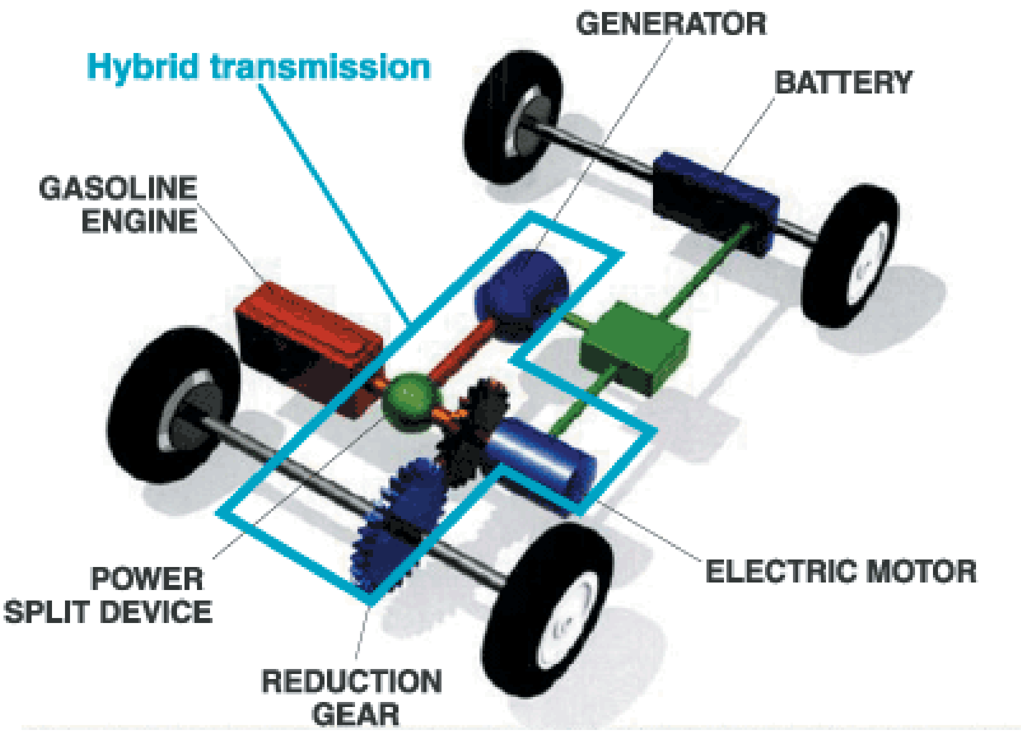
Hybrid Transmission

A hybrid transmission that uses Toyota's original power split device



Hybrid Transmission

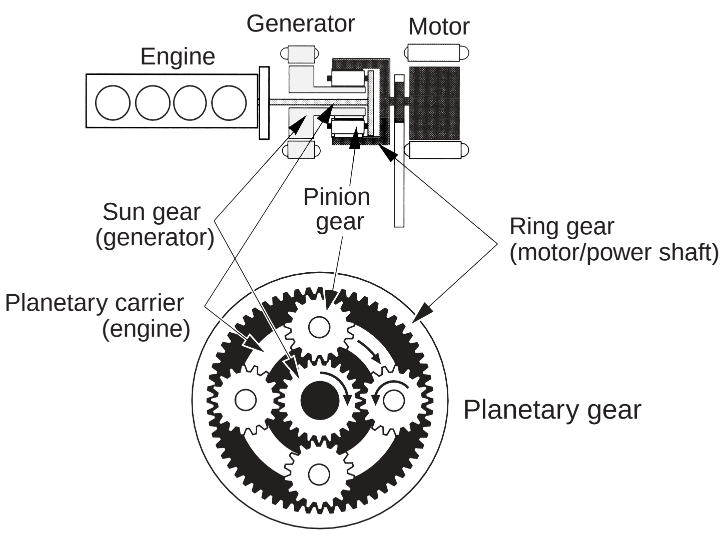
The hybrid transmission consists of the power split device, the generator, the electric motor and the reduction gears, etc. The power from the engine is split into two by the power split device. One of the output shafts is connected to the motor and the wheels while the other is connected to the generator. In this way, the motive power from the engine is transmitted through two routes, i.e., a mechanical route and an electrical route.

An electronically controlled continuously variable transmission is also provided, which can change speed while continuously varying the rpm of the engine and the rpm of the generator and the electric motor (in relation to vehicle speed).

THS II also reduces friction loss by about 30% by using ball bearings in the transmission and low-friction.

Power Split Device

The power split device uses a planetary gear. The rotational shaft of the planetary carrier inside the gear mechanism is directly linked to the engine, and transmits the motive power to the outer ring gear and the inner sun gear via pinion gears. The rotational shaft of the ring gear is directly linked to the motor and transmits the drive force to the wheels, while the rotational shaft of the sun gear is directly linked to the generator.



Actions of the Engine, the Generator and the Motor

1) WHEN THE VEHICLE IS AT REST

The engine, the generator and the motor are stopped.

2) DURING START-UP

The vehicle starts moving using only the motor drive.

3) DURING ACCELERATION FROM START

The generator, which also has the function of an engine starter, rotates the sun gear and starts the engine. Once the engine has started, the generator begins generating electricity, which is used for charging the battery and supplied to the motor for driving the vehicle.

4) DURING NORMAL DRIVING

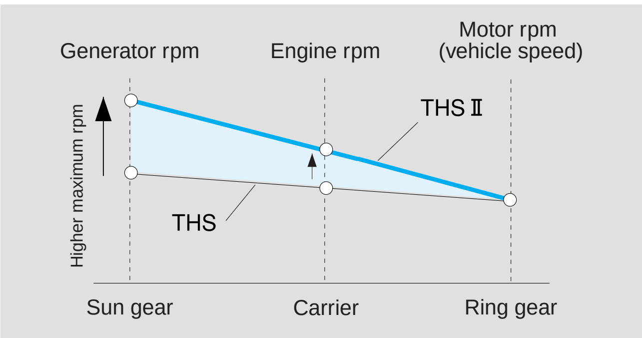
For the most part, the engine is used for driving. Electricity generation is basically not necessary.

5) DURING ACCELERATION

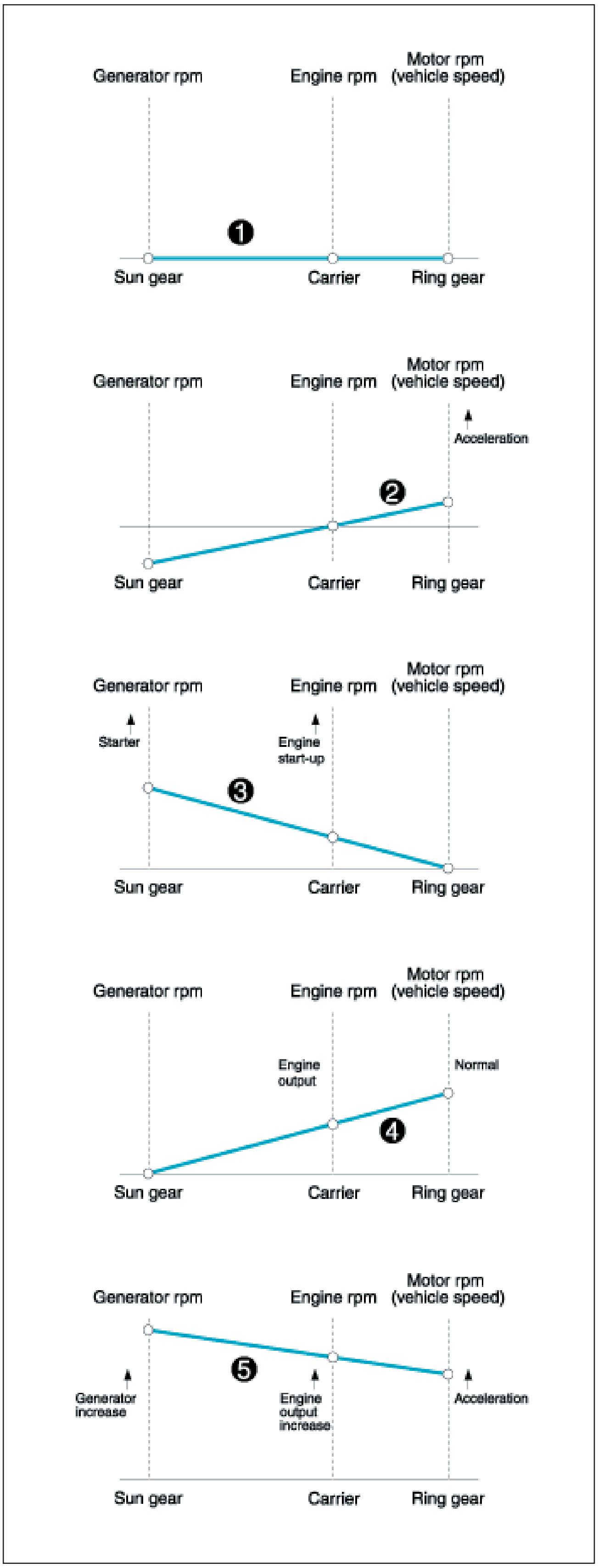
During acceleration from the normal driving state, the engine rpm is increased and, at the same time, the generator begins generating electricity. Using this electricity and electricity from the battery, the motor adds its driving power, augmenting the acceleration.

Output Enhancement Based on High-Speed Rotation of the Generator

Because the maximum possible rpm of the generator has been increased, it can draw on higher engine rpm, thereby producing higher output. As a result, the amount of electricity created by the generator is increased, and this increased amount feeds the motor, thus leading to an increase in driving power.



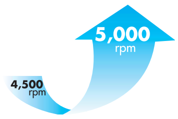
Colinear graphing of planetary gear relationships



A linear relationship always exists between rotations per minute of the various gears on the vertical axis.

Engine

The methodical pursuit of fuel efficiency improvement



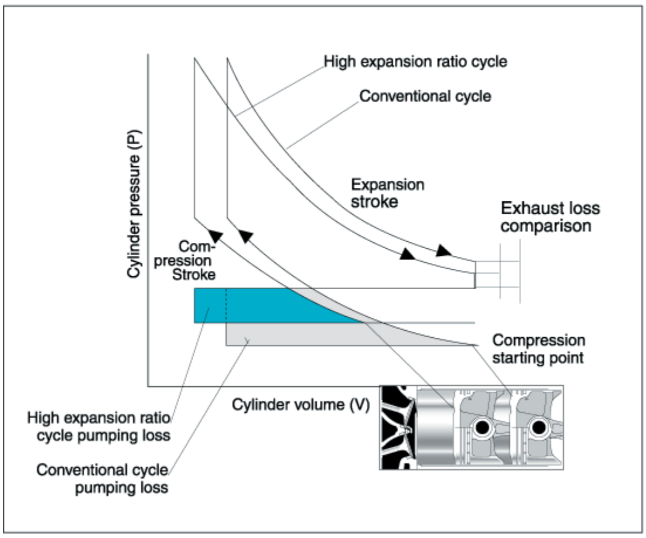
Using an engine that synergistically works with motor output and achieving high-efficiency operation and comfortable cruising through the synergistic effect of high-torque motor output

High-Expansion Ratio Cycle

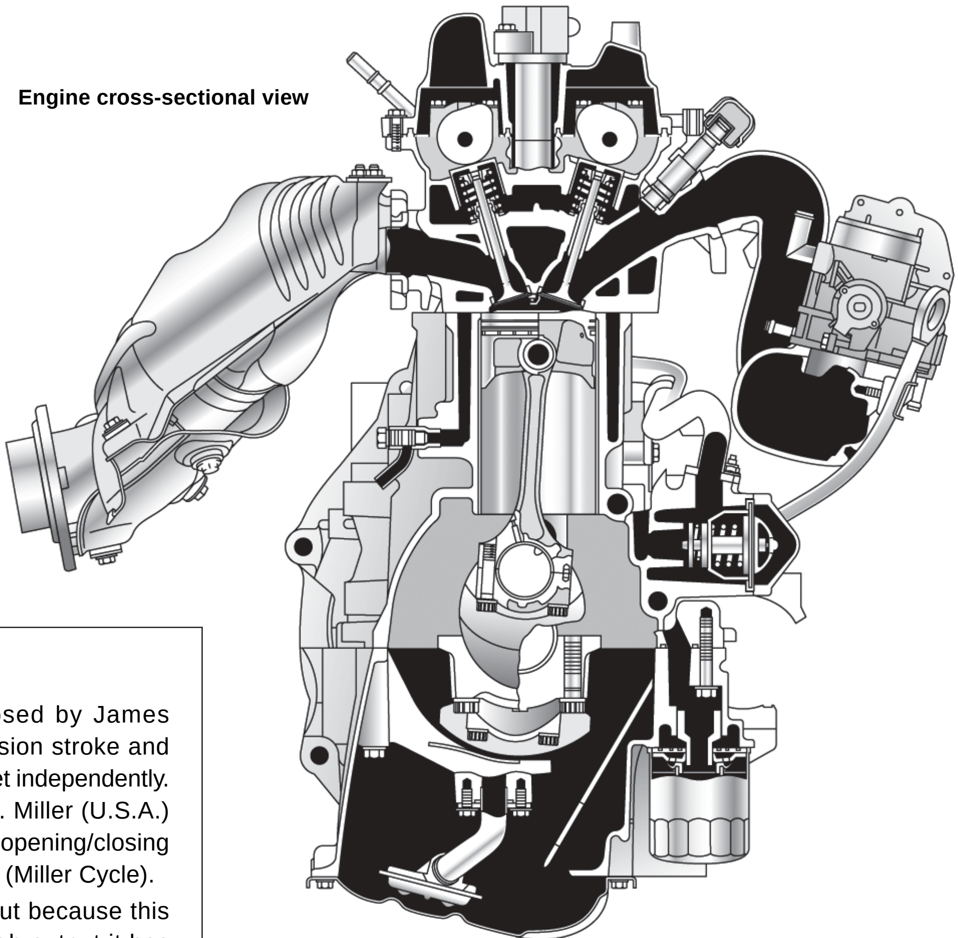
A 1.5-liter engine is used, which achieves high efficiency by using the Atkinson Cycle, one of the most heat-efficient, high-expansion ratio cycles. Because the expansion ratio ((expansion stroke volume + combustion chamber volume)/ combustion chamber volume) is increased by reducing the volume of the combustion chamber and the chamber is evacuated only after the explosion force has sufficiently fallen, this engine can extract all of the explosion energy.

*1 Expansion ratio: (expansion stroke volume + combustion chamber volume)/combustion chamber volume
*2 Compression ratio (compression stroke volume + combustion chamber volume)/combustion chamber volume

High expansion ratio conceptual diagram



Engine cross-sectional view



ATKINSON CYCLE

A heat cycle engine proposed by James Atkinson (U.K.) in which compression stroke and expansion stroke duration can be set independently. Subsequent improvement by R. H. Miller (U.S.A.) allowed adjustment of intake valve opening/closing timing to enable a practical system (Miller Cycle).

Thermal efficiency is high, but because this engine does not easily provide high output it has virtually no practical application unless used with a supercharger.

In conventional engines, because the compression stroke volume and the expansion stroke volume are nearly identical, the compression ratio ((compression stroke volume + combustion chamber volume)/combustion chamber volume) and the expansion ratio are basically identical. Consequently, trying to increase the expansion ratio also increases the compression ratio, resulting in unavoidable knocking and placing a limit on increases in the expansion ratio. To get around this problem, the timing for closing the intake valve is delayed, and in the initial stage of the compression stroke (when the piston begins to ascend), part of the air that has entered the cylinder is returned to the intake manifold, in effect delaying the start of compression. In this way, the expansion ratio is increased without increasing the actual compression ratio. Since this method can increase the throttle valve opening, it can reduce the intake pipe negative pressure during partial load, thus reducing intake loss.

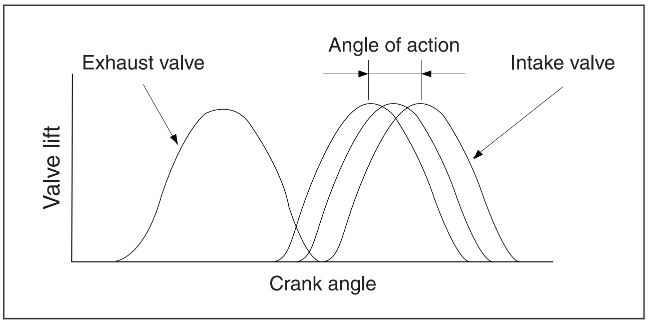
High Functionality

VVT-i (Variable Valve Timing-intelligent) is used to carefully adjust the intake valve timing according to operating conditions, always obtaining maximum efficiency. Additionally, the use of an oblique squish compact combustion chamber ensures rapid flame propagation throughout the entire combustion chamber. High thermal efficiency, coupled with reductions in both the size and weight of the engine body through the use of an aluminum alloy cylinder block, and a compact intake manifold, etc., help improve the fuel efficiency.

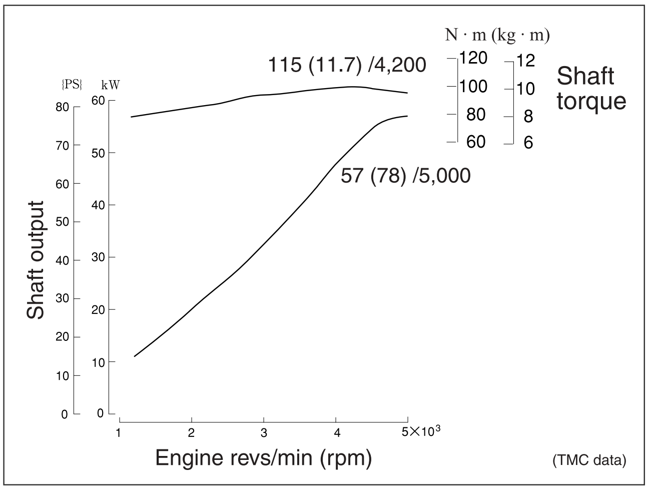
Output Improvement

The engine's top revolution rate has been increased from the 4,500 rpm in conventional engines to 5,000 rpm, thereby improving output. Moving parts are lighter, piston rings have lower tension and the valve spring load is smaller, resulting in reduced friction loss. Furthermore, the increase of 500 rpm produces faster generator rotation, increasing the driving force during acceleration and further improving fuel efficiency.

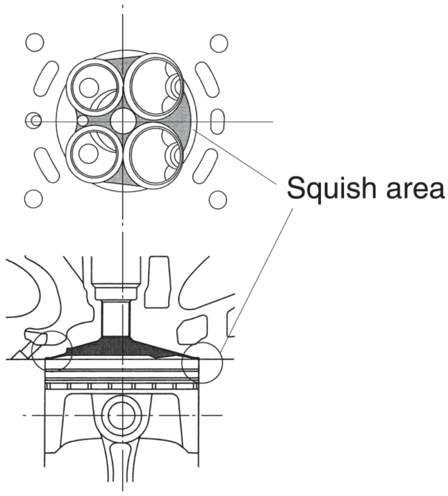
VVT-i valve timing (conceptual diagram)



Performance curve



Combustion chamber shape

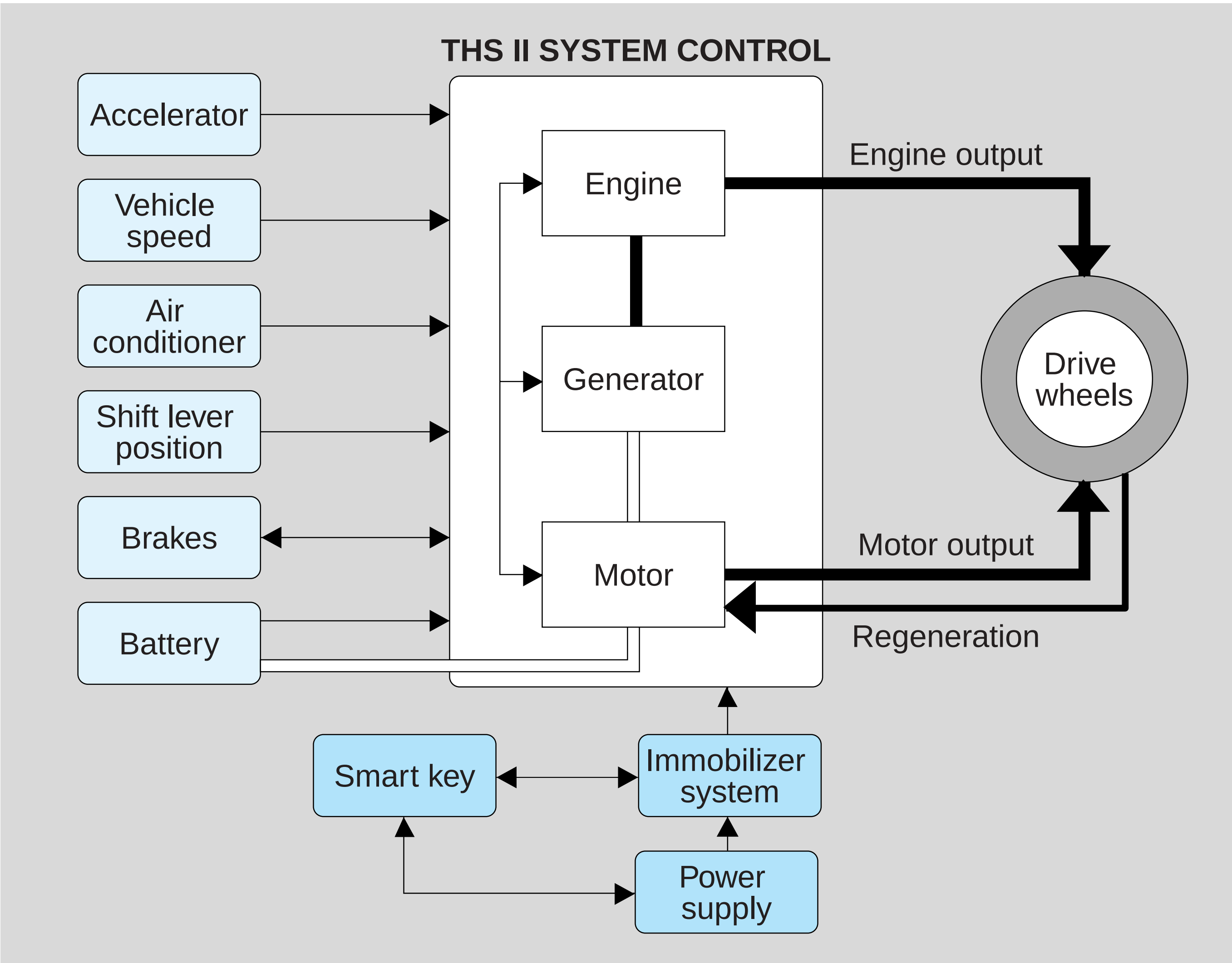


System Control

Precise real-time control — sensing the driver's intentions

The system control of THS II maintains the vehicle at its maximum operating efficiency by managing the energy used by the entire vehicle, which includes the energy for moving the vehicle as well as the energy used for auxiliary devices, such as the air-conditioner, heaters, headlights and navigation system. The system control monitors the requirements and operating states of hybrid system components, such as the engine, which is the source of energy for the entire hybrid vehicle; the generator, which acts as the starter for the engine and converts the energy from the engine into electricity; the motor, which generates the drive power for running the vehicle using the electrical energy from the battery; and the battery, which stores the electrical energy generated through power generation by the motor during deceleration. It also receives braking information being sent via the vehicle's control network, as well as instructions from the driver, such as the throttle opening and shift lever position. In other words, the system control of THS II monitors these various energy consumption statuses of the vehicle in real time and provides precise and fast integrated control so that the vehicle can be operated safely and comfortably at the highest possible efficiency.

System control (conceptual diagram)



System Start-up and Stop

Like modern jet planes, THS II hybrid vehicles use by-wire control, in which the driver's instructions are converted into electrical signals (through wires) to be used in integrated control. In by-wire control, system reliability is the highest control priority. When a smart key sends information indicating that the driver has gotten inside the vehicle, the system power supply is turned on.

First, whether or not the hybrid computer itself is functioning normally is monitored, and an operational check is performed before the ignition button is pressed.

When the ignition button is pressed, the system checks whether or not various sensors, the engine, the motor, the generator and the battery are functioning normally. Then, the switches for the components in the high-voltage system, such as the motor, the generator and the battery, are turned on, making the vehicle ready to run. This is the start-up control sequence. When the driver presses the ignition button again before leaving the vehicle, the components in the high-voltage system are disconnected and, after confirming that such systems are turned off, the hybrid computer shuts down.

Safety checks are also being carried out while the vehicle is moving, and, based on various types of information such as changes in driving conditions, the system controls the vehicle so that it can operate in an emergency mode in the unlikely event of failure in the hybrid system or lack of fuel.

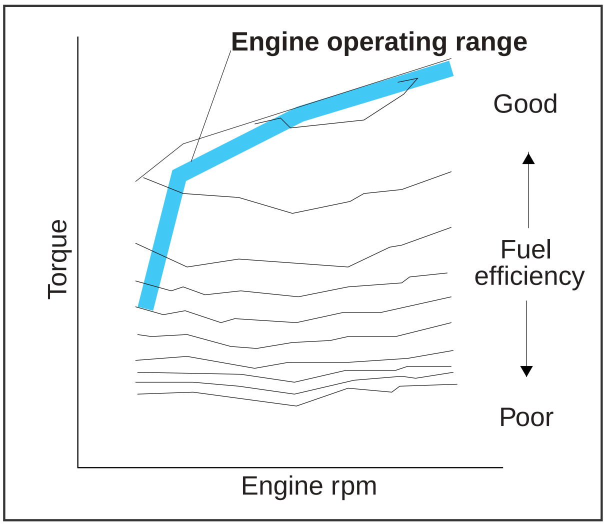
Engine Power Control

Engine power control is the basic control mechanism of THS II for always minimizing the energy consumption of the entire vehicle.

Based on the vehicle's operating state, how far the driver has depressed the acceleration pedal and the status signals from the battery computer, energy management control determines whether to stop the engine and run the vehicle using the electric motor only or to start the engine and run the vehicle using engine power.

When first started, the vehicle begins to operate using the motor unless the temperature is low or the battery charge is low. To run the vehicle using engine power, the engine is first started by the generator and at the same time, the system calculates the energy required by the entire vehicle. It then calculates the running condition that will produce the highest efficiency for producing this energy and sends an rpm instruction to the engine. The generator then controls the engine revolution to that rpm. The power from the engine is controlled by taking into account the direct driving power, the motor driving power from electrical generation, the power needed by the auxiliary equipment and the charging requirement of the battery. By optimizing this engine power control, THS II has advanced energy management for the entire vehicle and has achieved improved fuel efficiency.

Engine operating range

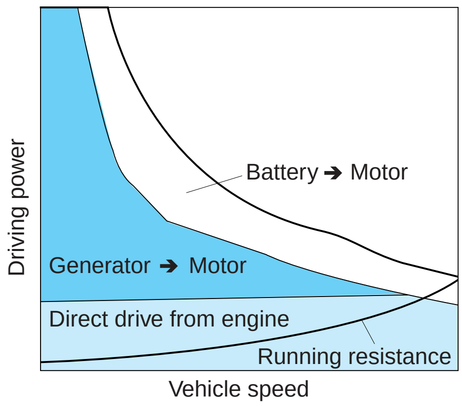


Driving Control

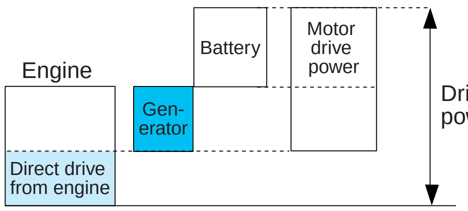
The driving power of a vehicle with THS II is expressed as the combination of the direct engine driving power and the motor's driving power. The slower the vehicle's speed, the more the maximum driving power is derived from the motor's driving power. By increasing the generator rpm, THS II has made it possible to use the engine's maximum power starting at slower speeds than was possible with the current THS. It has also made it possible to significantly increase the maximum drive power by using a high-voltage, high-output motor that successfully improves power performance. Because the engine has no transmission and uses a combination of the direct driving power from the engine and the motor's driving power derived from electrical conversion, it can control the driving power by seamlessly responding to the driver's requirements, all the way from low to high speeds and from cruising with a low power requirement to full-throttle acceleration. (This is known as torque-on-demand.)

Additionally, the time required to start the engine during acceleration from motor-only drive has been reduced by 40%, greatly improving the acceleration response. In order to eliminate shock during engine start-up, the generator also precisely controls the stopping position of the engine's crank. To ensure that the vehicle's driving power is not affected even when a large load is applied, e.g., when the air-conditioner is turned on, precise driving power correction control is carried out, achieving smooth and seamless driving performance.

Driving power performance



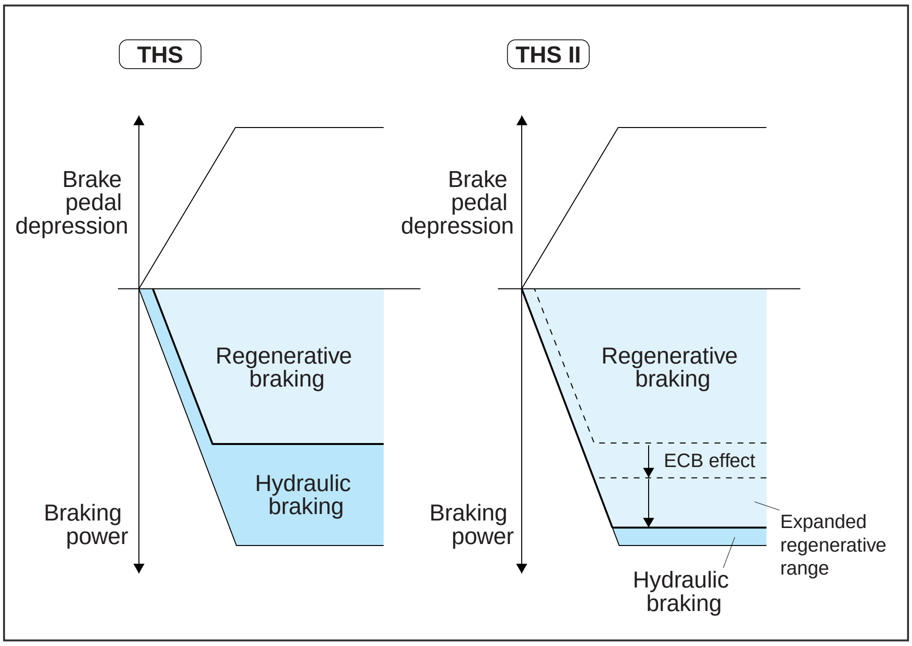
THS II drive power (conceptual diagram)



Regenerative-brake Control

In THS II, the newly developed Electronically Controlled Braking System (ECB) controls the coordination between the hydraulic brake of the ECB and the regenerative brake and preferentially uses the regenerative brake; it also uses a high-output battery and increases the amount of energy that can be recovered and the range in which it can be recovered. The system increases overall efficiency and, thus, fuel economy.

Improved regenerative braking



THS II's Torque-on-Demand Control

Torque-on-Demand ensures that driving power is provided faithfully according to the driver's wishes under any driving conditions. THS II has further expanded this concept and has added an enhanced driver assist function, which ensures safe driving.

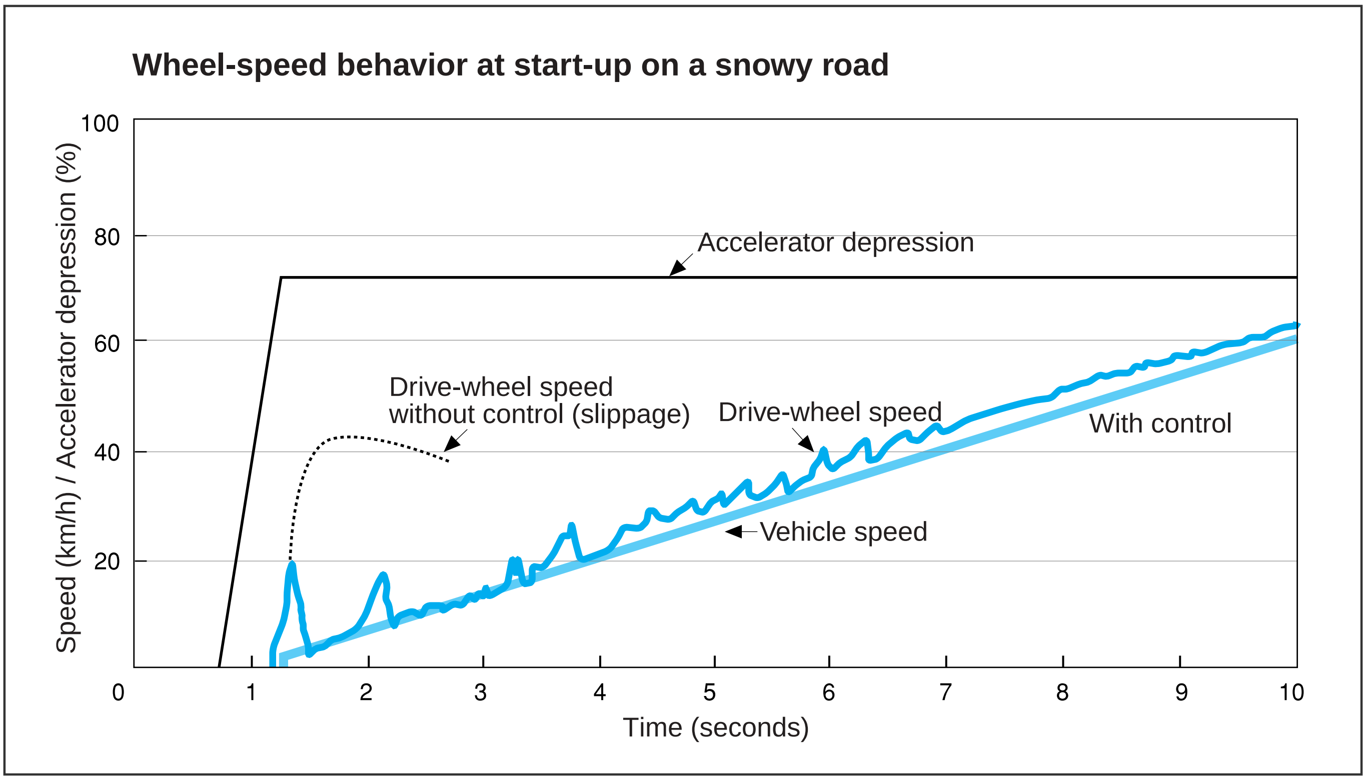
1) MOTOR TRACTION CONTROL

In THS, the engine, the generator, the motor and the wheels are linked together via the power split device. Furthermore, most of the engine power is converted into electrical energy by the generator, and the high-output and high-response motor drive the vehicle. Consequently, when the vehicle's driving power changes abruptly, e.g., wheel slippage on icy or other slippery surfaces and wheel locking during braking, a protection control similar to that used in conventional traction control is used to prevent abrupt voltage fluctuation and revolution increase of the planetary gear in the power split device. In THS II, we have advanced the parts protection function further and achieved the world's first motor traction control by utilizing the characteristics of a high-output, high-response motor. The goal of the motor traction control is to restore traction when wheel slippage on a snowy road is detected, for example, and inform the driver of the slipping situation. The basic requirement for safe vehicle operation is firm traction between the tires and the road surface. Motor traction control helps the driver maintain this state.

2) UPHILL ASSIST CONTROL

This is another driver assist function that is unique to the high-output motor THS II. This function prevents the vehicle from sliding downward when the brake is released during startup on a steep slope. Because the motor has a highly sensitive revolution sensor, it responsively senses the angle of the slope and the vehicle's descent and ensures safety by increasing the motor's torque.

Motor traction control



Output Enhancement

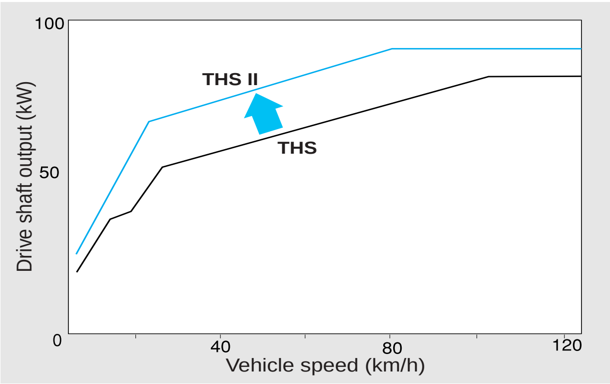
Raising output through acceleration and environmental performance compatibility

Acceleration Performance

INCREASED OUTPUT

Increasing the motor performance and raising the control voltage to 500V have improved the maximum output of the motor by 1.5 times from 33kW to 50kW. Coupled with this improvement, an increase in the maximum revolution of the generator from 6,500 to 10,000 rpm has increased the electrical power supplied to the motor at low to medium speeds, thereby increasing the motor output, and significantly boosted the system output, which also includes the engine's direct driving power. Furthermore, in the high-speed range, the engine, which is capable of faster revolutions and higher output, has boosted the system output.

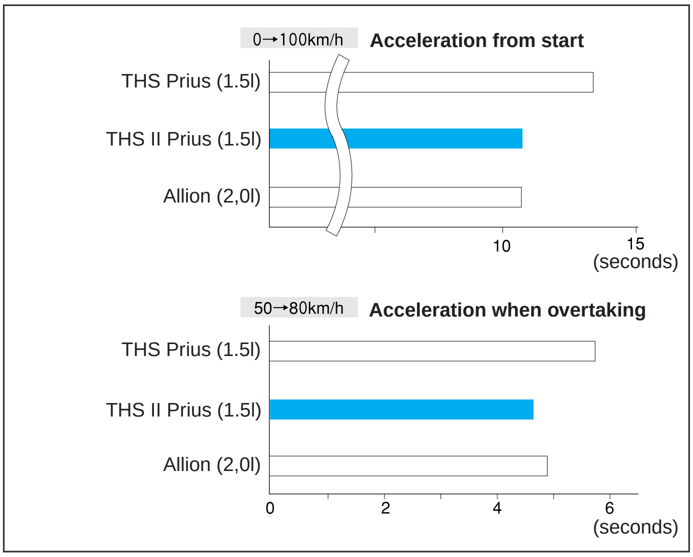
System output comparison **(TMC data)**



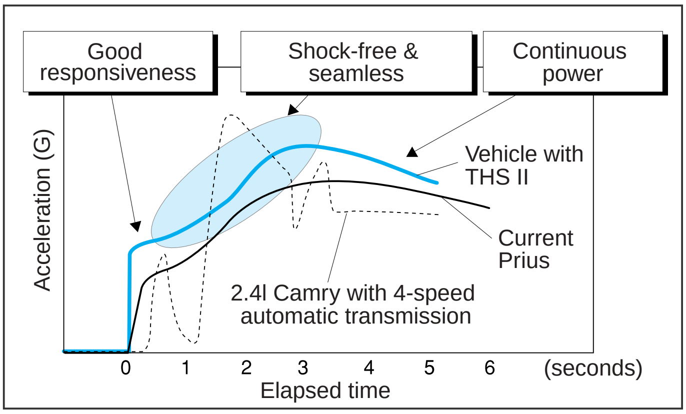
BETTER ACCELERATION PERFORMANCE

Especially as a result of improvements in output in the low to medium speed range, both at-start acceleration performance and overtaking acceleration performance have drastically improved. A performance level that exceeds that of a 2.0-liter gasoline engine vehicle has been achieved. High response and smooth acceleration based on the high-output motor have been improved, further advancing the hybrid driving experience.

Acceleration performance **(TMC data)**



Acceleration sensation 50km/h -> 80km/h



Improved Environmental Performance

OVERALL EFFICIENCY

THS II has achieved higher efficiency by improving hybrid energy management control and making improvements to the regenerative coordinated brake control, both of which are designed to improve the energy efficiency of the entire vehicle.

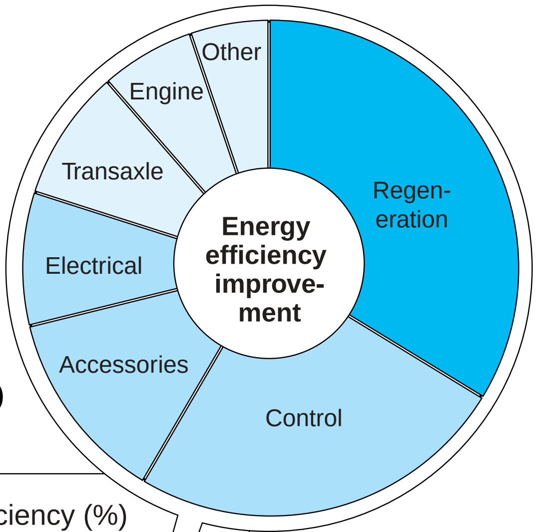
When compared in terms of overall efficiency (well-to-wheel efficiency), which indicates the efficiency of the entire process starting from the fuel manufacturing process, to the driving of a vehicle using that fuel, THS II's efficiency is striking. Its overall efficiency value has reached a level that exceeds even that of an FCHV (fuel cell hybrid vehicle), which is highly efficient, representing one step closer to creation of the ultimate eco-car.

Through technology such as that found in THS II, Toyota is working on development to the next step, including how such technology may apply to FCHVs, with an aim toward achieving even better efficiency.

EMISSIONS

According to Toyota's in-house measurements, the emission level from a vehicle with THS II meets the Ultra-Low Emissions Level in Japan, as well as the planned zero-emission (ATPZEV) regulations in California, which are considered to be strictest in the world, and Europe's next-generation regulations (EURO IV).

Contribution to energy efficiency



Fuel efficiency(%) x Vehicle efficiency(%) = Overall efficiency(%)

Overall efficiency

	Fuel efficiency (well-to-tank) (%)	Vehicle efficiency (tank-to-wheel) (%)	Overall efficiency (%) (well-to-wheel)
Recent gasoline car	88	16	14%
Prius (before improvement)	88	28	25%
Prius (after improvement)		32	28%
Prius with THS II		37	32%
Toyota FCHV	58 Natural gas-H2	50	29%
FCHV (target)	70	60	42%

Note: The Japanese-market Prius was upgraded in August 2002.

In-house Development and Production

Leading the hybrid evolution through in-house development and production

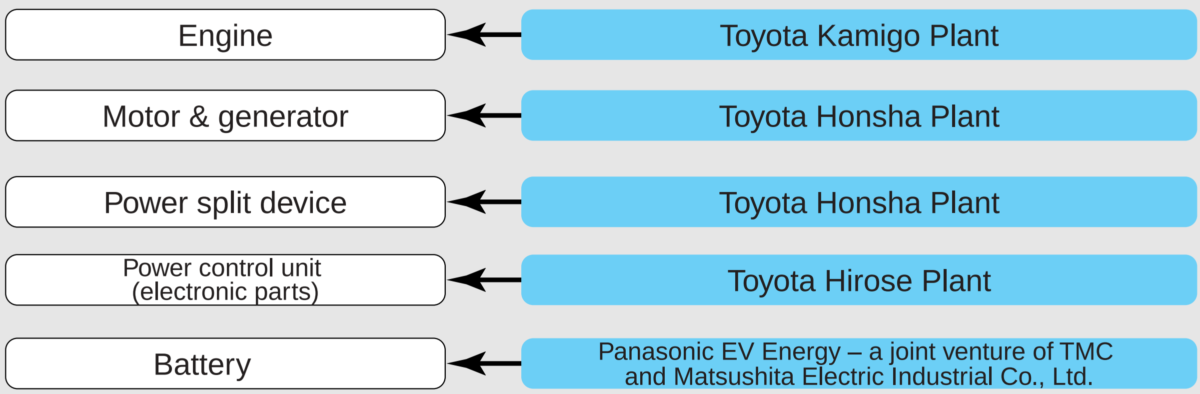
Production Technology

Based on Toyota's corporate philosophy of internally developing core technologies, we have positioned the engine and the power split device, which form the basis of THS II, as well as electrical and electronic parts such as the generator and the power control unit, as the core units essential to the new system and have developed and are producing these core parts in-house.

By undertaking the development and production of motors and electronic parts in-house, which was unheard of for an automaker, Toyota brought the world's first hybrid vehicle to market and plans to play a leading role in the evolution of hybrid vehicles.

For example, in terms of production technology, we are working on improving the insulation performance of motors that run on high voltage, developing semiconductor transistor (IGBT) technology that supports large inverter output and improving soldering technologies to increase heat dissipation. The accumulation of these technologies is what has made THS II possible.

SOURCES OF MAJOR COMPONENTS



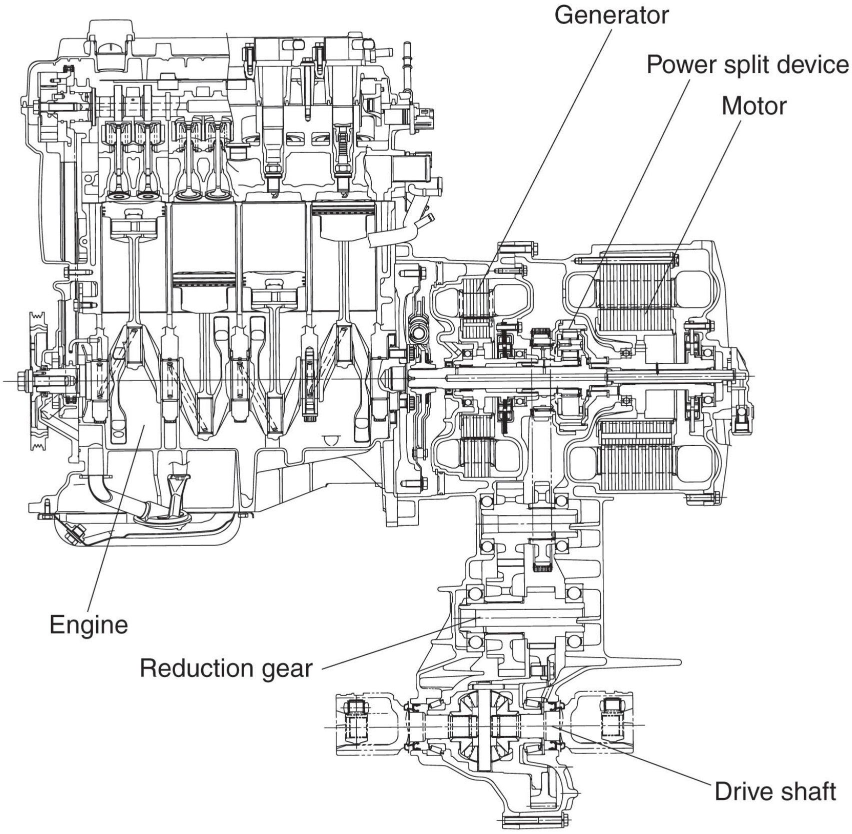
Specifications of New Hybrid System

Specifications of new hybrid system

	Item	THS II	THS
Engine	Type	1.5 L gasoline (high-expansion ratio cycle)	←
	Maximum output in kw (Ps)/rpm	57 (78)/5,000	53 (72)/4,500
	Maximum torque in N-m (kg m)/rpm	115 (11.7)/4,200	115 (11.7)/4,200
Motor	Type	Synchronous AC motor	←
	Maximum output in kw (Ps)/rpm	50 (68)/1,200-1,540	33 (45)/1,040-5,600
	Maximum torque in N-m (kg m)/rpm	400(40.8)/0-1,200	350(35.7)/0-400
System*	Maximum output in kW (Ps)/vehicle speed km/h	82(113)/85 or higher	74 (101)/120 or higher
	Output at 85km/h in kW (PS)	82 (113)	65 (88)
	Maximum torque in N-m (kg m)/vehicle speed km/h	478(48.7)/22 or lower	421 (42.9)/11 or lower
	Torque at 22km/h in N-m (kg m)	478 (48.7)	378 (38.5)
Battery	Type	Nickel-metal hydride	←

*Maximum combined engine and hybrid battery output and torque constantly available within a specified vehicle speed range (Toyota in-house testing)

Cross-sectional view



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