TOYOTA

TOYOTA MOTOR CORPORATION AUSTRALIA LIMITED
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Mr Rob Hansen
Research Director
Impact of Petrol Pricing Select Committee
Parliament House
Brisbane QLD 4000

10 February 2006

Dear Mr Hansen,

Submission to Queensland Parliamentary Select Committee on the Impact of Petrol Pricing

I am writing in response to Mr Andrew Fraser MP's letter of January 19 to Toyota's President Ted Okada alerting us to the work of his Committee and inviting Toyota to make a submission. Your letter specifically requested our views on:

1) the current fuel efficiency labelling scheme and
2) Initiatives by our company to reduce the fuel cost of vehicles that are available in Australia.
3) Manufacture of small cars in Australia

I will attempt to address these issues in the following paragraphs, but first I would like to give a little background on Toyota Australia

A. Toyota Australia Profile

Toyota Australia has been producing cars in Australia for more than four decades and in 1995 commissioned a new state of the art plant in Altona Victoria at a cost of $420 million. This is now the base for all Toyota Australia vehicle manufacturing operations and will produce our new model Camry and new 6 cylinder Aurion vehicles, which are to be introduced later this year

Toyota Australia's total sales revenue from domestically produced and imported products reached $7.4 billion in 2005. 110,000 vehicles were manufactured locally with a value of $2.5 billion, making the company one of Australia's largest manufacturing enterprises.

Toyota Australia is Australia's largest vehicle exporter. Around 69,000 vehicles were exported to 23 overseas destinations and together with parts and accessories earned more than $1 3 billion in export revenue.

Domestic manufacturing relies on an extensive local supplier base, with 84 first tier local component suppliers plus general suppliers earning $2.1 billion per annum from goods and services supplied to Toyota

Toyota employs 4,500 staff Australia wide, including over 3,300 in manufacturing, with an annual payroll of $380 million.

Toyota continues to make major investments in production, largely linked to new model cycles In the lead up to 2002, $350 million was spent bringing to market a new model Camry and production of a new 4 cylinder engine. Toyota is now in the final stages of spending over $400 million in preparation for the next generation Camry and the Aurion 6 cylinder cars scheduled for release in 2006, and also to increase plant capacity from 110,000 to 140,000 units p.a.

Toyota Australia's head office is based in a new purpose built facility in Port Melbourne

In addition to its Melbourne facilities, Toyota Australia maintains a comprehensive sales and marketing and parts distribution operation in Sydney employing 500 people, as well as sales and distribution operations in all mainland states.

In terms of sales to the end customer, Toyota has around 220 dealerships Australia wide with employment of around 11,500 staff.

Toyota is currently No.1 in the domestic market with a market share of over 20%. The product range covers market sectors from family sedans and four wheel drives to luxury vehicles and small hatches to small buses. A large range of imported passenger, 4WD and commercial vehicles complement locally produced Camry vehicles.

B. Current Fuel Efficiency labeling scheme.

As you may be aware the current fuel efficiency testing scheme is determined by Australian Design Rule 81/01 which in turn is based on the equivalent UN-ECE regulation (R101).

As such it represents international best practice and we would not support any suggestion of a unique Australian regulation for fuel efficiency testing which moved us away from the international standard.

The results of these tests are affixed to the window to assist consumers by providing information on fuel usage and CO2 emissions

In addition further information is available to consumers through a Federal Government website www.greenvehicleguide.gov.au, which was developed in cooperation with the automotive industry. This index rates all vehicles based on fuel consumption and emission performance categorisation We are very pleased to note that the Toyota Prius is the top rating vehicle in this index.

We believe that the combination of internationally harmonised testing criteria, vehicle labelling and the Green Vehicle Guide ensures that the consumer is well informed on fuel efficiency of the vehicle they are considering buying.

C. Initiatives by Toyota to reduce the fuel cost of vehicles;

(a) Hybrid technology

Toyota Australia is very appreciative of the role of Q Fleet in the pilot introduction of the initial six Prius into the Queensland government fleet. The Hybrid Prius is now well established in the Australian market. Its combination of petrol and electric motors, regenerative braking and other breakthrough technologies creates a saving of nearly 50% in fuel usage and carbon dioxide emissions.

We are launching two more hybrid models this year under the Lexus brand

Although the Prius is well received in the market place and provides significant reduction in fuel use and emissions, volumes sold in Australia are still very low. Prius sold 1,423 units nationwide in 2005.

Some overseas governments choose to provide some incentives to encourage consumer choice of environmentally friendly technology. For example we understand a tax credit of up to US$3,400 is available in the USA, some USA states provide priority access to transit lanes, and the City of London offers exemptions from the congestion tax.

As hybrid sales uptake is still very low, these sorts of initiatives can be introduced with minimal budget impact, while still making a very positive statement to potential purchasers, confirming the social responsibility motivation which often drives the choice of a hybrid vehicle.

For your information and understanding, I am attaching copies of the Toyota Technical Review. The first two articles give a good summary of hybrid development while many of the other articles cover other aspects of research into hybrid technology.

(b) Other initiatives:
Toyota is the only manufacturer of four cylinder vehicles in Australia, and the forthcoming new model Camry will be powered exclusively by our locally produced 2.4 litre VVTI four cylinder engine.

The Toyota Camry offers similar space to a large six vehicle but offers significant fuel consumption savings. We believe this car provides a major opportunity for government, fleet and private buyers to reduce their cost of motoring while still maintaining the key attributes of a traditional six cylinder car.

Governments could take more of a leadership role in this area by purchasing more four cylinder cars. We welcome the announcements in this regard late last year by the Queensland Government. Not only does a move to four cylinder vehicles reduce fuel use by government, but the private motorist will also benefit as ex government fleet vehicles are passed down as used vehicles

Also Toyota continues to be on the leading edge in the mass adoption of fuel saving technologies such as variable valve timing (VVTi) and Direct Injection Diesel technology as well as innovations in vehicle packaging, which increases the space and facilities offered to the motorist without increasing the vehicle footprint or fuel consumption.

D. Manufacture of small cars in Australia

As you may be aware, Australian manufacturers including Toyota have manufactured small cars in Australia in the past. However with the opening up of the Australian market, production of low priced small vehicles became non viable.

With some exceptions, owners of small cars are only prepared to pay very low prices, and small cars are now being increasingly built in low cost locations such as Thailand, Korea and China

It is our view that any manufacturer would struggle to build small cars in Australia and still be price competitive with vehicles from these locations.

We acknowledge that there is a market for premium priced small cars, but these represent only very small volumes and would not justify local manufacture.

E. Further information

If you require further comment, please contact me (details below).

Thank you for the opportunity to make comments on issues of interest to the Select Committee.

Yours sincerely,

J. A. Egan

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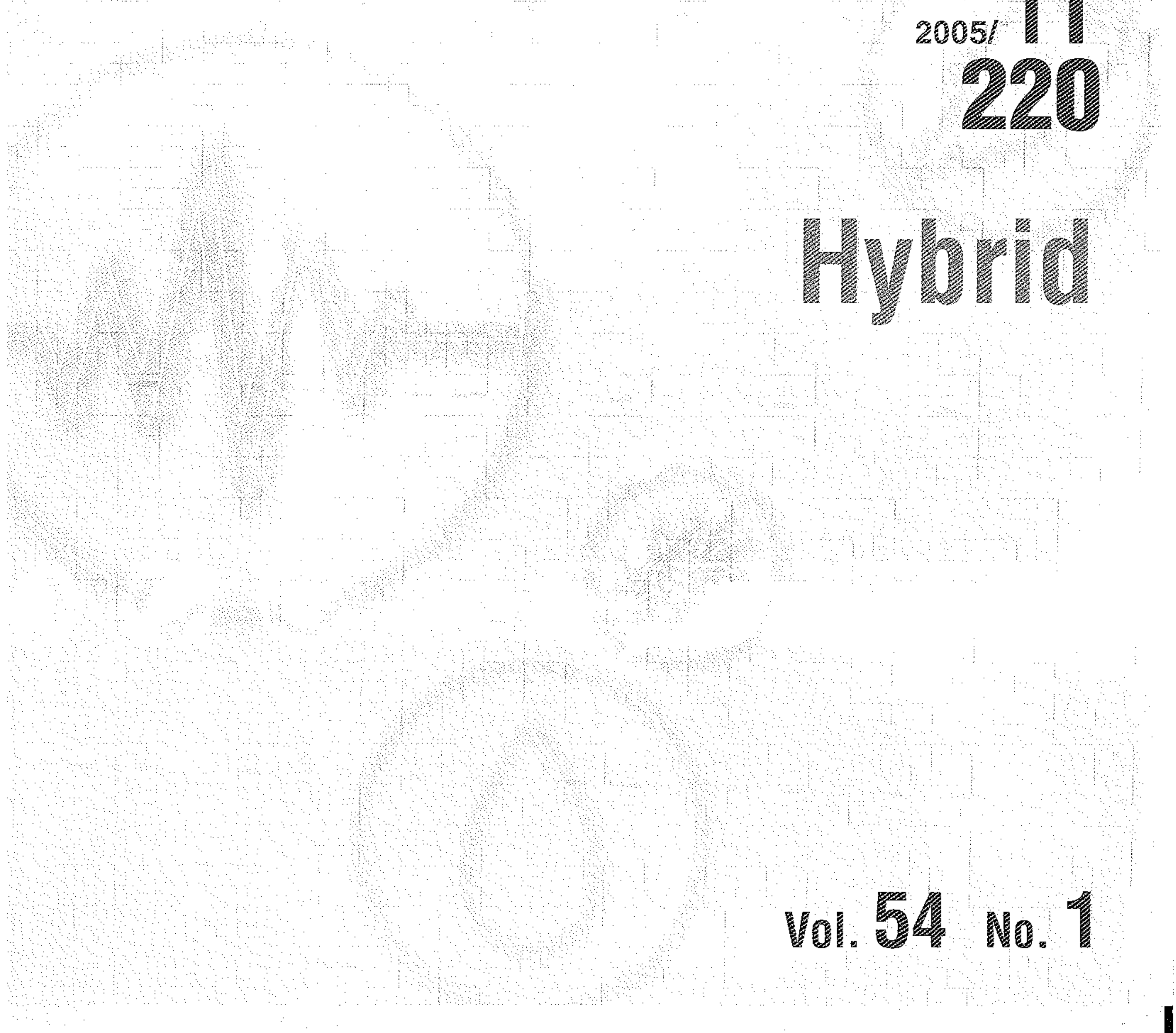
Hybrid



Vol. 54 No. 1

Preface

The 21st Century: The Age of the Hybrid

M. Takimoto

Masatami Takimoto,
Executive Vice President, Member of the Board

1. Today for Tomorrow—What We Must Do Now for Future Generations

Since the Industrial Revolution, human beings have consumed enormous quantities of coal, petroleum, and other fossil fuels in their pursuit of comfort and convenience. But as a consequence, enormous quantities of carbon dioxide and other greenhouse gases have been generated, bringing with them the problems of global warming and large-scale climate change. The Kyoto Protocol came into effect on February 16 of this year, and it will require more truly effective action than ever before to put a halt to global warming, mainly through the reduction of CO_2 emissions.

It must also be noted that the production of petroleum, on which today's affluent society was built, is expected to peak in the next few decades. Not only must we manage this limited resource carefully, but we must also convert to alternative energy sources that are easy to use and have lower environmental impact.

In essence, it is vital that our generation stops the increase in atmospheric CO_2 concentrations right now, for the sake of future generations in the decades to come. We must build a society capable of sustainable development by constructing infrastructure systems to use new energy resources that are clean and safe, alongside the limited amounts of petroleum available.

2. The Age of the Hybrid Powertrain

Shifting our focus to the automotive realm, petroleum is still essential for automobiles, and CO_2 emissions are therefore hard to avoid. But that is exactly the reason why, while we must develop cars that consume less fuel and make every effort to reduce CO_2 emissions, we must also prepare for an age of energy alternatives to petroleum.

It is therefore time for hybrid powertrain technology to assume a leading role. The Toyota Hybrid System (THS) realizes low fuel consumption and low CO_2 emissions by reducing energy loss as far as possible. This is achieved by recovering the energy that would otherwise be wasted during deceleration, and by stopping needless engine idling when the vehicle is stopped. Moreover, by reutilizing the recovered energy for acceleration, the system realizes a synergy effect. In other words, the system simultaneously achieves exemplary environmental performance (low NOx and particulate matter levels) and excellent acceleration performance superior to a conventional car. The THS is truly the ultimate high-efficiency powertrain system.

We believe the hybrid system is a core technology for the future It can be applied not only to gasoline engines, but also to diesel engines, natural gas engines, and synthetic liquid fuel engines. It can also be used with fuel cell vehicles, which are expected to become the cars of the future This is why we want to improve and develop the system further, and promote its wider use throughout the world as a gift to future generations.

3. The Age of Hybrid Energy

It is believed that the exploitation period of petroleum can be extended through further evolution of extraction technology, but sooner or later, the supply of low-cost, high-quality petroleum will be exhausted. The world will then enter the so-called hybrid energy age, when primary energy resources such as oil shale, natural gas, coal, biomass, sunlight, water power, wind power, and nuclear power will be used to make a variety of secondary energy resources, such as ethanol, hydrogen, and electricity, as well as synthetic fuels like gas-to-liquid (GTL) and biomass-to-liquid (BTL). The optimum combination of these secondary resources will then be used in industry, homes and transportation.

A number of issues in the sequence from primary energy to secondary energy to industry, homes, and transportation must be addressed in a thoroughgoing and comprehensive manner if the optimum system is to be established. As well as straightforward economic considerations, these include reducing CO_2 generated by the manufacture and consumption of secondary energy, ensuring global supply capacity and energy security, and prioritizing the use of resources according to their energy density and the ease of establishing a refueling infrastructure. Therefore, research into hybrid energy is needed now more than ever before. The key element for this research will be collaborative thinking, not just between the automobile and energy industries, but also from the combined perspectives of government, academia, and industry at large.

The effort to realize our dream of making safe, enjoyable cars that do not emit exhaust gas and CO_2 will open the way to the optimum energy solution. Let us approach this task from a variety of perspectives, so that we can build a society capable of sustainable development for future generations.

The Present and Future of Hybrid Technology

Takehisa Yaegashi
Power Train Development Group

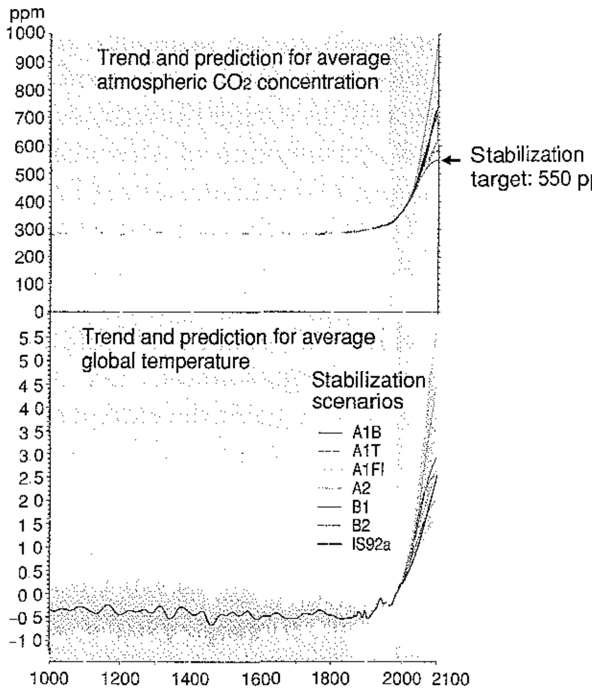
1. Introduction

Almost eight years have passed since the launch of the Prius, the world's first production hybrid vehicle and the first step toward realization of sustainable mobility, which is a concept that aims to address the issues of global warming, dwindling petroleum resources, and air pollution. At Toyota Motor Corporation, we view these environmental issues as the most important business challenges for a car manufacturer, and we have been quick to initiate efforts to mass produce hybrids as practical yet environmentally friendly vehicles. Starting with the Prius, Toyota has applied hybrid technology to various categories of vehicles including minivans, and is striving to further develop the technology. In September 2003, Toyota succeeded in developing a next-generation hybrid system under the Hybrid Synergy Drive concept, which aims to create vehicles that have a high level of environmental performance as well as being fun to drive. This new technology was installed in the Prius, which was subsequently released onto the market. 2005 has seen the launch of the RX400h, powered by a version of this next-generation hybrid technology updated for use in a luxury V6-engined SUV. As for other car makers, last year Honda added the Accord V6 Hybrid to the Insight and Civic Hybrid, and Ford introduced the Escape SUV hybrid. This spate of releases indicates that the hybrid system has entered the popularization stage as an environmentally sound power train.

This article describes present and future trends for environmental and resource related issues that are relevant to vehicles. It also presents an overview of Toyota's past efforts and future perspectives on hybrid technology, which is positioned as a core technology for future vehicles.

2. Vehicles and Issues Related to the Environment and Resources

Emissions of CO_2 and other greenhouse gases that are generated by human activities are having a profound impact on global warming and associated global climate change. In the same year as the launch of the first Prius, the Third Conference of the Parties to the United Nations Framework Convention on Climate Change (COP3) was held in Kyoto to discuss global efforts to counter climate change. As a result, a medium-term action plan called the Kyoto Protocol was drafted. Although the US refusal to ratify the protocol cast dark clouds over its future, the protocol finally came into effect after being ratified by Russia this year. **Fig. 1** shows data presented in the third assessment report of the Intergovernmental Panel on Climate Change (IPCC) published in June 2001.[1] It shows the changes that have been observed in mean atmospheric CO_2 concentration and average global temperature up to the current point in time, and the predictions for CO_2 concentration and temperature increase based on various scenarios for curbing global warming.



Source: IPCC Third Assessment Report

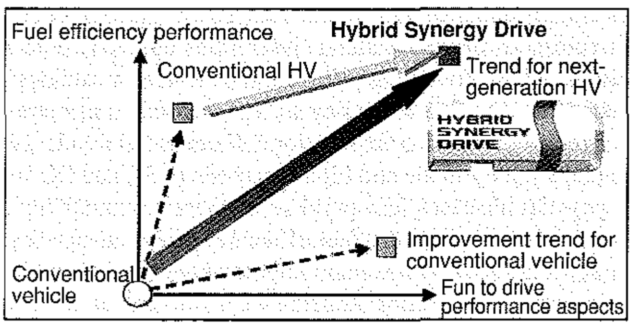
Fig. 1 Trends for Atmospheric CO_2 Concentration and Average Ground Temperature

Atmospheric CO_2 concentration has increased from around 280 ppm in the pre-Industrial Revolution era to around 380 ppm at present. If energy consumption continues as it is, CO_2 concentration will approach 1,000 ppm in the year 2100, increasing concern that climate change will become more serious. Internationally, various scenarios for reducing CO_2 emissions in transportation and other sectors are being studied with the aim of stabilizing CO_2 concentration at 550 ppm. The burning of coal, petroleum, and other fossil fuels accounts for most CO_2 emissions. In particular, the CO_2 emissions from transportation that mainly uses oil for fuel accounts for at least 20% of the total. In the future, increased motorization in countries like China, India, and Russia will rapidly increase the total number of vehicles owned in the world, and further boost CO_2 emissions. It has been predicted that extraction of the world's petroleum reserves will peak around the year 2040, which means that the problems surrounding exhaustion of this resource are fast approaching. Therefore, popularization of vehicles that emit less CO_2 and consume less fuel is becoming an urgent issue. At the same time, it is also important to clean exhaust emissions to prevent air pollution.

It is clear that the impending challenges cannot be met by mere extension of conventional technologies. Greater expectations are being placed on the shoulders of hybrid and fuel cell vehicles.

3. Hybrid Synergy Drive

No matter how low the CO_2 emissions or how clean the exhaust gas of a vehicle, it cannot expect to gain popularity among drivers if it is inferior to conventional vehicles in terms of running performance, driving range, user-friendliness, and price. After the Prius, Toyota introduced a variety of hybrid vehicles, including the Crown Mild Hybrid, and the Estima Hybrid. Subsequent developmental efforts have produced a synergy between the engine and the electric power train. This has enabled improvements in both the environmental performance of hybrid vehicles and so-called "fun to drive" performance aspects such as running performance. Consequently, the idea of simultaneously achieving high levels of both environmental and fun to drive performance aspects was adopted as the direction for the next generation of hybrid vehicles. This was encapsulated by the Hybrid Synergy Drive concept, which became the catalyst for a further acceleration in development efforts (**Fig. 2**).



Simultaneous achievement of environmental performance and exciting driving experience

Fig. 2 Hybrid Synergy Drive

4. Hybrid Systems and Improvements in Environmental Performance

This section discusses how the functions and configuration of a hybrid system contribute to reducing CO_2 emissions and fuel consumption.

A hybrid system is defined as a system in which two or more types of power units with different working principles are operated in combination. Configurations of power units where the internal combustion engine is used with either an electric or a hydraulic motor have been implemented commercially. The currently mainstream configuration is the electric system, thanks to dramatic advances in electric motor, battery, and control technology as a result of the development of electric vehicles. The most significant feature of the hybrid system is the installation of high-power and high-capacity batteries as a rechargeable energy buffer in the driving force transmission path to create a circulation route for efficient use of energy. This enables part of the energy to run the vehicle to be temporarily stored in the battery for later use (**Fig. 3**).

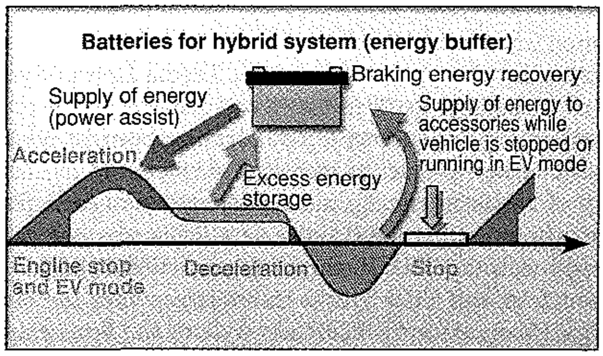


Fig. 3 Features of Hybrid System (Energy Storage)

4.1 Hybrid systems and improvements in fuel efficiency

This section describes how the introduction of the hybrid system has improved fuel efficiency. The key ways in which this has been accomplished include optimizing and increasing the efficiency of the engine, motor, and other individual components, in addition to combinations of the following four factors.

(1) Engine operation is stopped and the vehicle is put into EV mode when parked or running at low speeds where engine efficiency is low.
(2) The use of a continuously variable transmission (CVT) function enables the engine to be operated at optimum efficiency.
(3) High efficiency engines, such as high expansion ratio engines, are used. These engines have been designed to operate at maximum efficiency in the hybrid use region, on the assumption that battery power assist can be obtained for acceleration during high-speed driving where considerable driving power is necessary.

(4) The electric motor is operated as a generator, and the kinetic energy of the vehicle, which would otherwise be released into the air during deceleration, is converted into electricity and stored in the battery. The energy is reused as the driving energy described in points 1 and 3 (electric regenerative braking)

The rate of improvement depends on the mechanism of the hybrid system and to what degree the functions described above are performed. Particularly, a hybrid system that is able to stop engine operation and run the vehicle under EV mode during driving is often called a "strong hybrid" or a "full hybrid" to distinguish it from other simplified hybrid systems

The Prius was positioned to be the leading environmentally friendly car. When its hybrid system was selected, a basic goal was set to achieve the ultimate in fuel efficiency performance while maintaining the equivalent running performance and utility space of a conventional vehicle. Naturally, this meant that a lightweight and compact system that could be installed in a small passenger car was required for commercial implementation. A system was subsequently selected from nearly 100 different types of hybrid systems, but this system did not fit the available definitions of conventional hybrid systems. Thus, a new definition was created, called the "series/parallel hybrid." This is the strong hybrid type in the various Toyota Hybrid Systems (THS). In addition, the THS uses a brake system that is capable of performing regenerative cooperative control with the hydraulic brakes in order to increase the amount of regenerated energy of the electric regenerative braking described in point 4 above. In September 2003, the new Prius was put on sale equipped with the THS II, the next-generation hybrid system evolved from the THS hybrid technology under the Hybrid Synergy Drive concept. The body style of the Prius was also totally renewed to expand the interior capacity of the vehicle. As a result, the Prius was classed as a mid-size vehicle instead of as a compact. In March of this year, the RX400h was launched with a high-power version of the THS II that incorporates further improved technologies to meet the needs of V6-engined SUVs. The technical details of the high-power version of the THS II are described elsewhere in this Toyota Technological Review. The optimization of fuel efficiency by the hybrid system has already been described above. In addition, the system in the Prius and the RX400h that performs regenerative cooperative control with the hydraulic brakes includes the Electronically Controlled Brake System (ECB) that was previously adopted in the Estima Hybrid. ECB has a high degree of controllability and less brake drag, thereby enabling an increase in regeneration efficiency and making a significant contribution to improving fuel efficiency. Furthermore, the secondary battery in hybrid vehicles is used as an energy buffer to optimize running efficiency, and to supply power to the heater, air conditioner, and other accessories via a DC-DC converter. Energy optimization from the perspective of total vehicle energy consumption (i.e., the sum of the energy required for running both the vehicle and accessories) is also a key point for the improvement in fuel efficiency. The regeneration and fuel efficiency of the new Prius was also improved by the adoption of an aerodynamic body with a coefficient of drag (CD) of 0.26, and by reducing losses in the drive system. Taking these steps to optimize the energy efficiency and specifications of the entire vehicle enables hybrids to realize a considerable improvement in fuel efficiency performance over conventional vehicles. **Fig. 4** shows the fuel efficiency improvement effect achieved by the hybrid functions described in points 1 to 4, in terms of engine efficiency and operating characteristics.

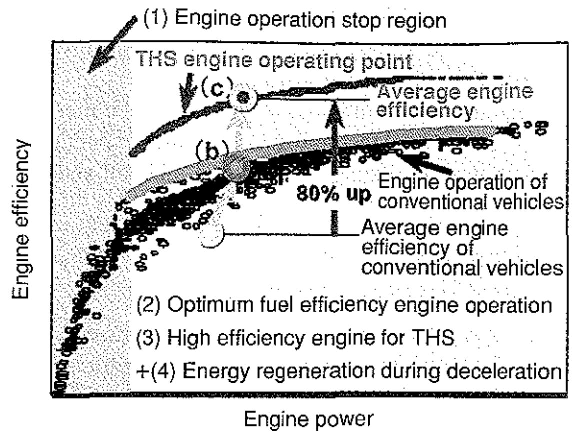


Fig. 4 Improvement in Fuel Efficiency by Introduction of Hybrid System

4.2 Fuel efficiency performance of hybrid vehicles

(1) Official fuel efficiency

The fuel efficiency performance of a vehicle varies according to specifications such as weight, and various driving patterns such as city driving in congestion, suburban driving, highway driving, uphill/downhill driving, and at various levels of acceleration. The operations of the driver and the ambient temperature can also affect fuel efficiency. From the perspective of reducing levels of CO_2 emissions and fuel consumption, it is important to enhance the actual fuel consumption reduction effect across all driving patterns, operations and environmental conditions. The official fuel efficiency indicated in catalogs and the like is determined according to test methods and notations that differ from location to location. Examples include 10-15 mode (Japan), city mode and highway mode (US), and EU mode (Europe). In all cases, the purpose of these test methods and notations is to compare the fuel efficiency potential of vehicles under set conditions that exclude impacts from the differences in driving pattern, operation and the environment as described above

Fig. 5 [2] compares the Japan-certified fuel efficiency (10-15 mode) of hybrid vehicles and conventional vehicles. Hybrid vehicles have achieved a dramatic fuel efficiency improvement in comparison with conventional vehicles. The improvement rates of strong hybrids such as the Prius and RX400h are particularly high. Furthermore, hybrid vehicles equipped with the THS II have achieved a considerable improvement in fuel efficiency over conventional vehicles in each of the different official fuel efficiency test driving modes in Japan, the US, and Europe These vehicles have among the best fuel efficiency performance of any vehicles in the world.

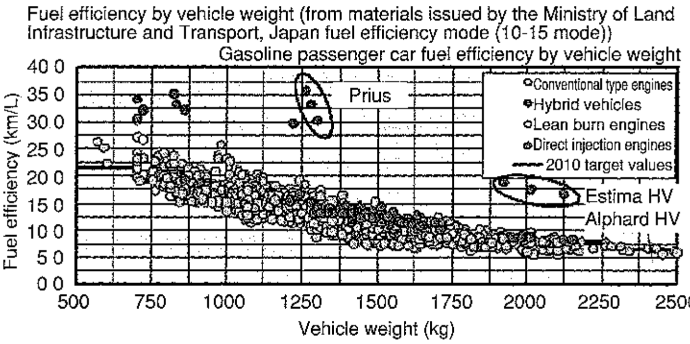


Fig. 5 Official Fuel Efficiency Performance of Hybrid Vehicles

(2) On-road fuel efficiency

In order to reduce fuel consumption and CO_2 emissions in the on-road environment, it is important to understand and improve the vehicle's fuel efficiency performance in various driving patterns, operations, and atmospheric environments One of the aims of the THS II was to improve fuel efficiency in various driving environments that are not evaluated in the official tests, as well as those in the official tests. As shown in Section **4.1**, functions such as engine stop, EV mode operation and energy regeneration during deceleration are some of the factors that have enabled hybrid systems to improve fuel efficiency considerably in city driving where there are many intersections and traffic lights, frequent stops and longer periods of low-speed driving In highway driving where engine-stop operation and deceleration occur less frequently, improved fuel efficiency performance is achieved by capitalizing on the functions of strong hybrid vehicles These include the adoption of high efficiency engines in combination with the electric power assist function during acceleration, optimum engine efficiency operation using CVT functionality, and precise power control for accessories. Fuel consumption during air conditioner operation is a factor not evaluated in official tests, but it has a significant impact on actual on-road fuel efficiency. Starting with the new Prius, hybrids have used an electric air conditioner driven by a high efficiency inverter to make use of the high voltage of the hybrid system, instead of a conventional engine-driven air conditioner. The new air conditioner does not just improve air conditioning capacity while the engine is stopped. It also enables a dramatic improvement in fuel efficiency while in use by operating under precise optimum efficiency conditions according to various cooling demands (**Fig. 6**).

Fig. 7 [3] shows a comparison of the monthly average fuel efficiency trends for old and new models of the Prius, as reported by users in Japan The user fuel efficiency report shows that the new Prius achieves the same improvement in fuel efficiency over the previous models as seen in the official fuel efficiency tests

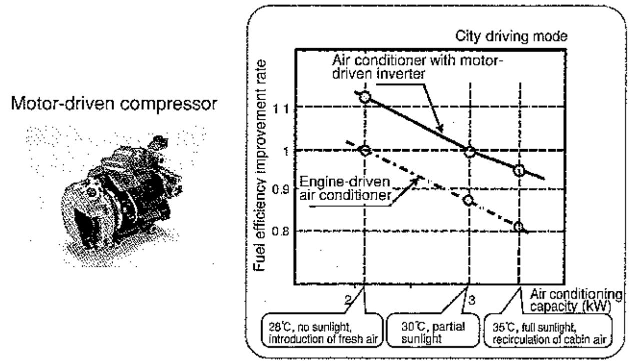
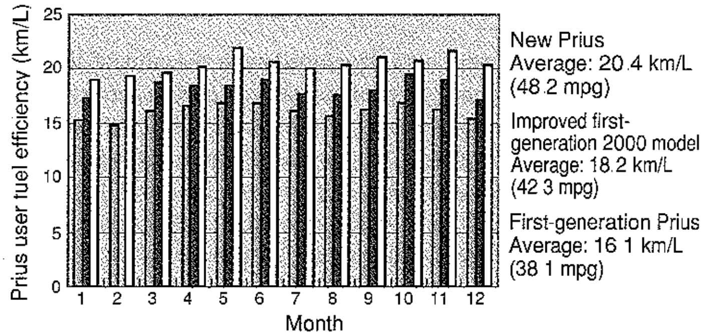


Fig. 6 Air Conditioner Fuel Efficiency

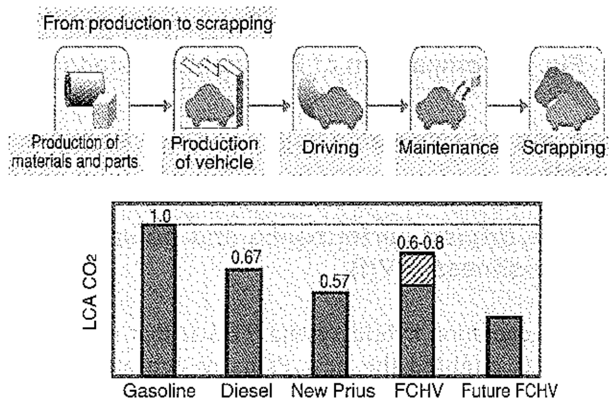


Source: Japan fuel efficiency response website (http://www response.jp/e-nenpi/)

Fig. 7 Prius Fuel Efficiency as Reported by Users

(3) Life Cycle Assessment (LCA) CO_2 evaluation

Reduction of emissions and fuel consumption during driving as described above is not the only important factor in improving the environmental performance of a vehicle. It is also important to evaluate and reduce the potential emissions of a vehicle during its entire life, from the production stages of the vehicle, parts and component materials, to the extraction and refining of fuel, the maintenance of the vehicle, and the final stage where the vehicle is scrapped **Fig. 8** shows an example of LCA analysis with the new Prius The fuel efficiency value used here is the European official fuel efficiency value that is close to the average fuel efficiency value reported by the Japanese users shown in **Fig. 7**



Calculation conditions: European official fuel efficiency/mileage: 150 000 km

Fig. 8 Example of LCA Analysis for New Prius

When compared with conventional vehicles, the ratio of CO_2 emissions during the driving process decreases due to the increase in efficiency. The LCA shows a CO_2 reduction effect of over 40%. Fuel cell hybrid vehicles (FCHV) show zero CO_2 emissions in the use process but generate high levels of CO_2 in the fuel and vehicle production processes. This means that the CO_2 emissions of these vehicles may exceed those of the newest gasoline HVs. As a result, technological breakthroughs to radically reduce CO_2 emissions during the production processes of FC parts and hydrogen fuel, and improvements in running efficiency are required before FC vehicles can be commercially implemented.

4.3 Cleanliness of exhaust emissions

Hybrid vehicles were also developed with the aim of leading the market for advanced environmental vehicles in terms of the cleanliness of exhaust emissions. All strong hybrid vehicles have attained the highest category of cleanliness regulations specified around the world, such as the Super Ultra Low Emission Vehicle (SULEV) category in the United States. This has been accomplished with engines that make use of electric power assist, which is one of the typical hybrid functions, in combination with exhaust treatment systems found on conventional vehicles. In addition, emissions during start-up have been reduced by enabling quick warm-up of the exhaust emission control catalysts, and by using a powerful generator as the engine starter. **Fig. 9** compares the cleanliness of the new Prius with the European diesel regulations (Euro4).

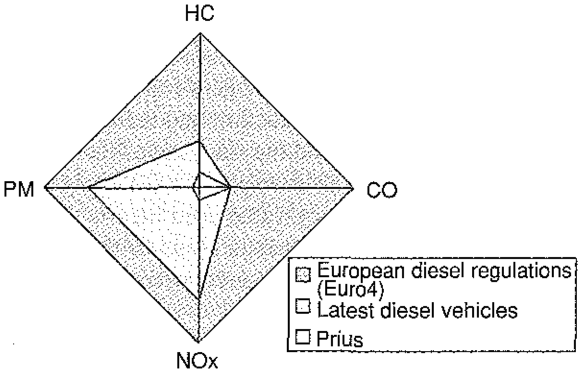


Fig. 9 Comparison of Exhaust Emissions

5. THS II and Improvements in Fun to Drive Performance Aspects

5.1 Vehicle driving performance and noise, vibration and harshness (NVH)

The next-generation hybrid system THS II that evolved from the THS, has enabled the new Prius to achieve a driving performance superior to conventional vehicles equipped with a 2.0 L engine. **Fig. 10** shows the driving force characteristics of the new Prius.

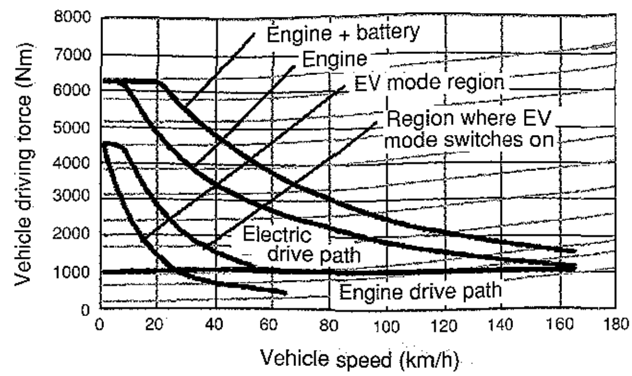


Fig. 10 Driving Force Characteristics of Prius

The details of the working principles of the THS II system are not described in this article. However, in the THS II, a considerable portion of the engine output is converted into electricity, and battery output is added in driving where a large driving force is required. The THS II does not use a mechanical transmission, but allows continuous use of the highest hybrid system outputs (engine output + battery output) in a wide region from medium to high vehicle speeds. The system has achieved a considerable improvement in passing acceleration performance, which is frequently used in the on-road environment. **Fig. 11** shows trends for passing acceleration in comparison with a conventional vehicle.

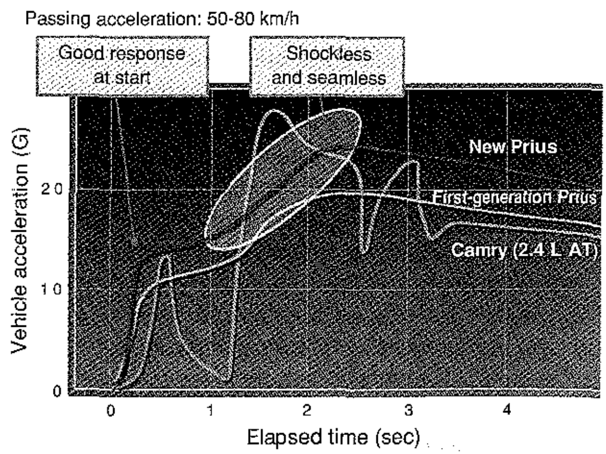


Fig. 11 Passing Acceleration Performance

Shockless and seamless acceleration is achieved by making use of stepless continuous system output where battery output assists a fast response electric motor. In the RX400h, the power of the electric drive system has been radically increased to cope with the 3.3 L V6 engine. This increase in power alongside the adoption of newly developed high-output batteries enables the RX400h to achieve a shockless and seamless acceleration performance superior to V8-engined SUVs in the same class up to the super fast region. Moreover, the quiet cabin during EV mode with the engine stopped and during cruising at optimum engine efficiency operation is an appeal point unique to a strong hybrid vehicle.

5.2 New functions of hybrid system

e-Four

In 2001, "e-Four," the world's first four-wheel drive system where the rear wheels are driven by an electric motor was adopted in the Estima Hybrid. e-Four is also an example of hybrid technology application The dramatic improvement in electric driving power in the THS II described below has radically increased the driving power of the rear motor, improving the 4WD performance of the RX400h.

Hybrid VDIM

The RX400h uses the newly developed Vehicle Dynamic Integrated Management (VDIM) This system detects the behavior of the vehicle through a combination of the high-controllability ECB, the high-output front wheel driving motor with the brake function capable of performing regenerative cooperative control, the e-Four system that uses a high-output motor, and electric power steering (EPS) driven by a newly developed 42 V motor that receives power from the hybrid battery. VDIM controls these functions together with the Anti-Lock Brake System (ABS), Traction Control (TRC), and Vehicle Stability Control (VSC) in an integrated and seamless fashion to dramatically improve driving safety on slippery road surfaces

External power supply function

In strong hybrids that have a high-output generator, such as those that use the THS II, external power supply is a versatile function that increases vehicle functionality and marketability. The motor-driven air conditioner mentioned in Section **4.2** contributes not only to improving fuel efficiency, but also to improving actual air conditioning performance aspects such as cooling down performance In addition, the Estima Hybrid uses a high-power 100 V power supply system This system, which is capable of supplying power outdoors, for a mobile office and even in disasters, is a function unique to hybrid vehicles.

6. Future Issues and Perspectives on Hybrid Technology

As pointed out in this article, hybrid vehicles cannot expect to gain popularity unless their product appeal, including fun to drive performance aspects, safety, and comfort are upgraded to complement revolutionary environmental performance. The vehicles must also carry a price tag appropriate to their appeal **Fig. 12** shows that Toyota is positioning hybrid technology not as a separate category that competes with conventional internal combustion engine (ICE) and fuel-cell vehicles, but as a core technology to achieve dramatic improvement in the efficiency of vehicles themselves.

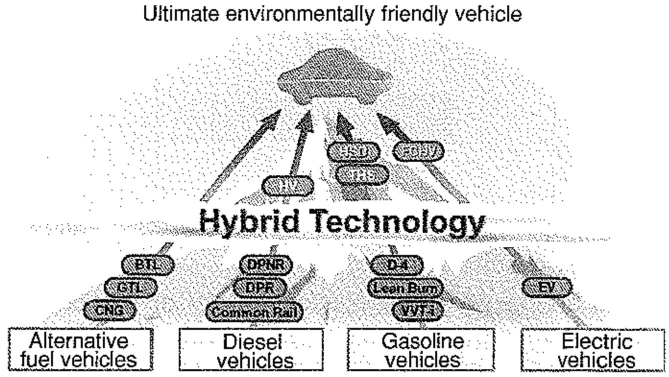


Fig. 12 Approaches to Accomplishing the Ultimate Environmentally Friendly Vehicle

Initially, some people considered hybrid vehicles as a temporary means to facilitate the transition from ICE vehicles to FCHVs However, it is now realized that hybrid technology is indispensable for improving the efficiency of vehicles driven not only by gasoline engines, but also by diesel and alternative fuel engines, as well as in fuel-cell vehicles As described in this article, the role of hybrid technology is not simply to enhance environmental performance. Hybrid technology is also expected to develop in the future as a technology that will increase the appeal of vehicles. Hybrid technology enables this by enhancing the driving performance, quietness and running feel of a vehicle by effectively using high-output, high-capacity batteries as an energy buffer, and by radically improving running stability with high-response electric motors. Toyota took on the challenge of implementing hybrid vehicles on a commercial basis as the first step toward sustainable mobility and in the spirit of the slogan "Today for Tomorrow" Since then, the company has exerted great efforts to advance the technology We are hoping to continue playing a leading role in the approach to the ultimate environmentally friendly vehicle This will entail, for example, furthering the evolution of vehicle and engine technology, combining bio-fuels and synthetic fuels, and applying hybrid technology to the fuel cell. Hybrid technology will be at the core of all these developments

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The History of Hybrid Technology in Toyota

Shoichi Sasaki*

Abstract

This article provides a brief history of the development of hybrid technology in Toyota. In the 1970s, Toyota began development on a gas turbine hybrid vehicle. Subsequent in-house development followed on a motor, inverter and battery for electric and hybrid vehicles. Such effort led to the launch of the Coaster Hybrid, a small bus, in 1997, as well as the Toyota Hybrid System (THS) that powers the Prius, the world's first mass-produced hybrid car. New developments followed in the wake of the Prius with the THS-C mounted in the Estima minivan, and the THS-M in the Crown luxury sedan. In 2003, the second-generation Prius was equipped with the THS II boasting significantly improved power output. Hybrid technology is also utilized in diesel engine and fuel cell vehicles, which are sold as the Dyna HV and Toyota FCHVs on the market.

Keywords: *hybrid system, hybrid vehicle, history, engine, motor, inverter, battery*

1. Introduction

Toyota Motor Corporation is currently developing its hybrid systems as promising power trains for the future This edition of the Toyota Technical Review introduces the latest accomplishments and the outlook for the future, but this article will first review the history of hybrid development at Toyota.

2. History of Hybrid Vehicle Development

The development of hybrid vehicles at Toyota began in the 1970s with a gas turbine hybrid vehicle [(1)] The man chosen to lead the gas turbine development was the late Kenya Nakamura, Toyota's first chief engineer for the Crown and one of our great predecessors At almost the same time, the company also participated in the planning of an Electric Vehicle Development Project under what was then the Ministry of International Trade and Industry

Current hybrid vehicles combine a gasoline engine with an electric motor and battery, but the history of motor and battery development goes all the way back to those early days Thereafter, development was suspended for a time, but motor and battery development continued at the Higashifuji Technical Center.

Meanwhile, research and development on motors was underway in the Machinery Group, where production equipment was developed, and those achievements were reflected in the RAV4 electric vehicle.

Early in the 1990s, measures to improve fuel economy in the future were being studied within Toyota Recognizing that the serious limitations of electric vehicle batteries would make it difficult for a fully electric system to become the power train of the future, the company turned its attention to the feasibility of hybrid systems that combine a motor with a liquid-fuel engine. A variety of hybrid configurations were studied

The Toyota Prius, the world's first mass-produced hybrid car, was developed on the basis of these studies, and in turn, it has ignited the development of a wide variety of hybrid systems. The two main focuses of the studies were whether to transmit motive power electrically or by conventional mechanical means and how to simplify the functioning of the brakes, air conditioning, and other systems that are affected when the engine is turned off to save fuel

Special mention should also be made of the fact that development efforts since the Prius made its debut have reached the level where it is possible to mass produce what were once relatively expensive batteries, motors, and inverters.

Fig. 1 shows the history of hybrid vehicle development over the years. The main hybrid vehicles are described in the sections that follow.

2.1 Gas turbine hybrid [(1)]

The gas turbine hybrid vehicle shown in **Fig. 2** was exhibited at the Tokyo Motor Show in 1977. It was a configuration that took advantage of the compactness that is characteristic of a gas turbine engine.

The extremely compact configuration was achieved by increasing the revolution speed of the generator to match that of the gas turbine engine.

* Hybrid Vehicle System Engineering Div

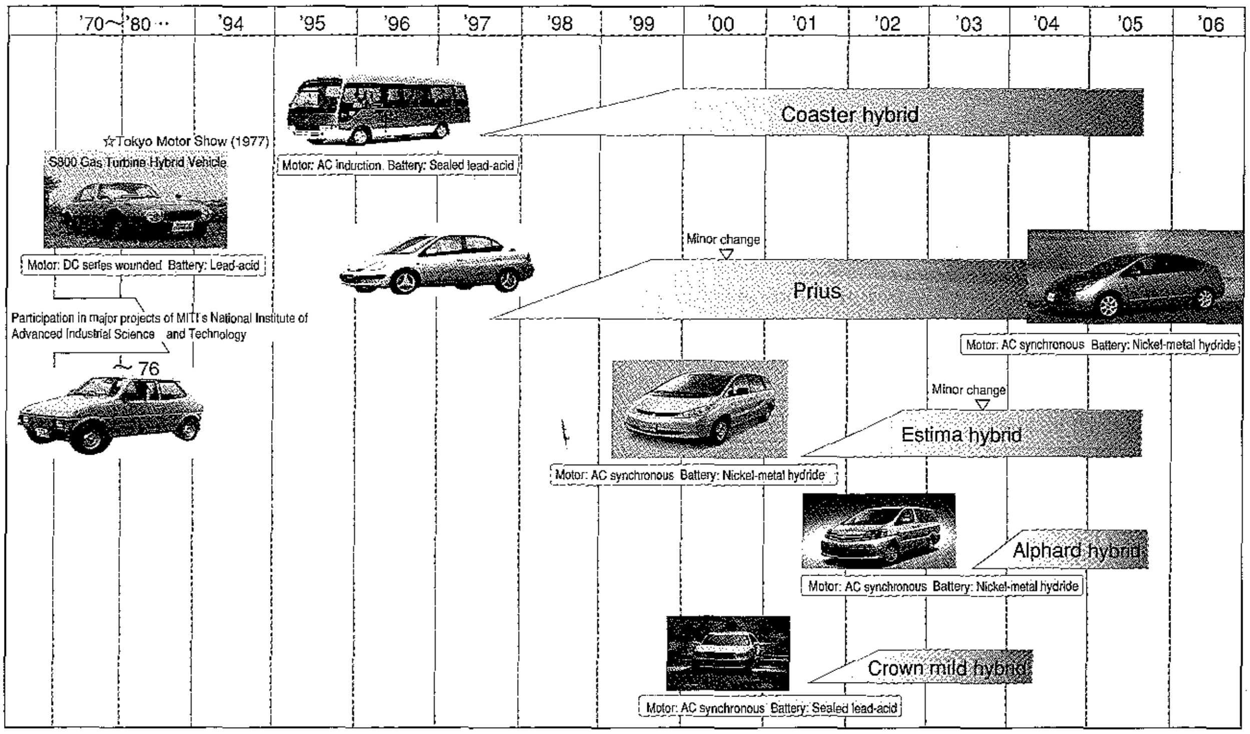

Fig. 1 History of Hybrid Vehicle Development at Toyota

Fig. 2 S800 Gas Turbine Hybrid Vehicle

Figs. 3 and **4** show the equipment layout and the system configuration. This was a series hybrid vehicle. (See Appended **Fig. 1** at the end of this article.) It featured a two-speed manual transmission and a compact motor.

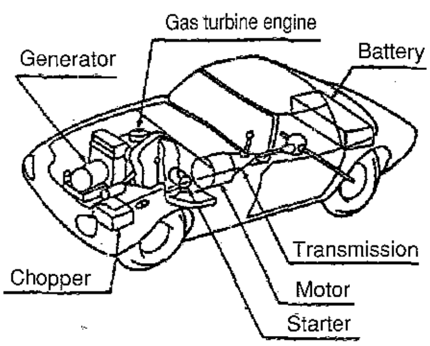

Fig. 3 Equipment Layout

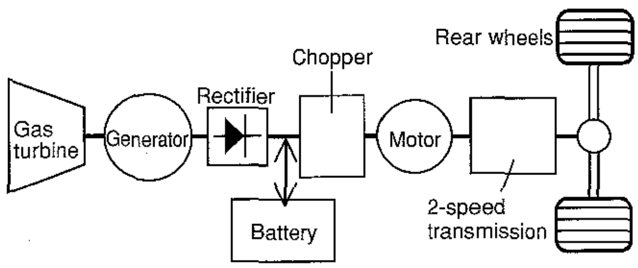

Fig. 4 Gas Turbine Hybrid System Configuration

2.2 Coaster hybrid

In 1997, Toyota developed and put on sale a compact hybrid bus based on the Coaster. It is intended for use by preschools, tourist attractions, hotels, and the like in transporting students and guests. It features a series hybrid layout that combines a 1.5-liter gasoline engine with an AC generator and AC induction motor to reduce exhaust gas emissions of hydrocarbons and NOx. **Figs. 5** and **6** show the vehicle and its system configuration.

The operating principle of the series hybrid requires that the engine power be converted into electricity, and that requires a generator and motor that are equivalent in power to the engine. But while the generator, motor, and control unit can be made bigger to give the hybrid superior power performance, there is a limit to how much the performance can be improved.

Fig. 5 Coaster Hybrid

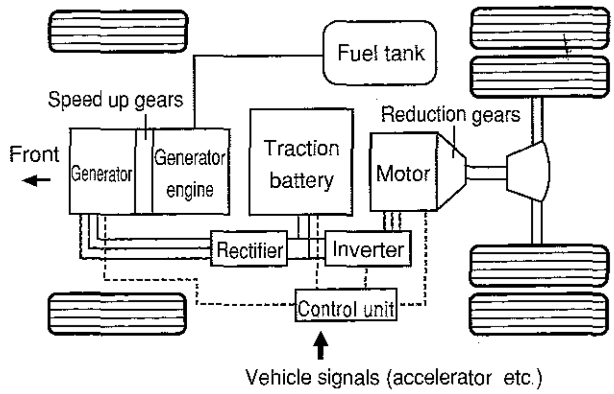

Fig. 6 Coaster Hybrid System Configuration

2.3 Prius [1][3]

Sales of the Prius, the world's first mass-produced hybrid car, began in December 1997. In keeping with the meaning of its name, "leading the way," the Prius, shown in **Fig. 7**, became the pioneer in mass production hybrid vehicle development.

Fig. 7 First-Generation Prius

It is worth reviewing the points that were the focus of system configuration studies for the Prius.

Four functions were identified as the focuses for achieving the main objective of better fuel economy: (1) engine starting and stopping, (2) regeneration, (3) running as an electric vehicle, and (4) the continuously variable transmission (CVT) function. Systems that combined these functions in various configurations were studied and compared to select the optimum configuration for a compact passenger car.

It should be noted that one of the factors in this selection process was that a similar study using an oil hydraulic motor was already studied within the company.

The basis for the hydraulic motor configuration was a 1971 SAE paper [2] by an engineer for TRW Automotive. It described a combination of a 1.6-liter gasoline engine, a 10-kilowatt alternator, a 22.5-kilowatt DC motor, and a thyristor chopper.

Due to physical limitations at the time, the paper described only bench tests, but the integration of technologies developed thereafter ultimately made the Prius hybrid system feasible for a passenger car. Of particular importance were the development of rechargeable batteries, the development of high-performance magnets typified by the neodymium magnet, improvements in power semiconductors, AC motor torque control technologies such as field-oriented control, the use of microcomputers to make on-board control devices more compact, and system simulation technologies.

The Prius underwent a minor change in 2000 before being put on the market in the United States and Europe. The vehicle was modified to meet the US emission regulation for a super ultra-low emission vehicle (SULEV) while also satisfying European performance requirements, thus proving its high potential in terms of both fuel economy and emissions performance.

Fig. 8 shows the configuration of the Prius hybrid system. The engine power is split by a planetary gear train, with one part going to the generator and the other being combined with the motor power and transmitted to the drive shaft. The power is distributed by controlling the speed of the generator. Because the driving force is the total of the motor power combined with a portion of the engine power, the system is designed so that the engine torque can be set to a relatively low value. This allows the engine to be turned off while the vehicle is in motion, so that it operates as an electric vehicle. The system is a series/parallel hybrid layout. (See Appended **Fig. 1**.)

The main components for the system were basically designed and manufactured internally, albeit with some cooperation from suppliers.

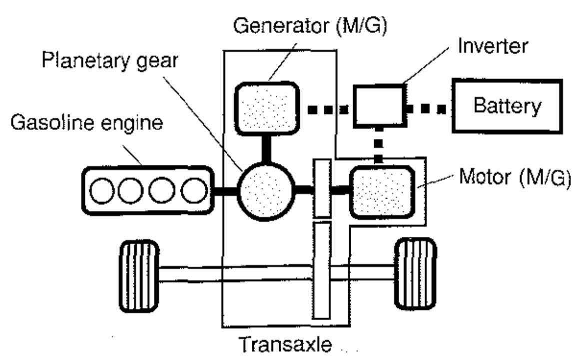

Fig. 8 Prius System Configuration (THS)

2.4 Estima hybrid [4]

The THS-C is a hybrid system that was developed for medium-to-large vehicles like minivans and uses a CVT. The system was installed in the Estima and went on sale in Japan in 2001. The vehicle is shown in **Fig. 9**, and the system configuration in **Fig. 10**. The system is a series/parallel hybrid layout (see Appended **Fig. 1**) comprising (1) a series system that uses the starter motor to generate electricity and the drive motor to propel the vehicle, and (2) a parallel hybrid layout made up of the engine and a power switching mechanism composed of the motor, CVT, and planetary gear train.

The use of the CVT allowed the electrical units to be made relatively small, which in turn made it possible to mount the hybrid system in an already heavy Estima-class vehicle. Another distinctive feature is the electric four-wheel drive system, which uses a dedicated motor to drive the rear wheels, enabling the vehicle to maneuver in a stable manner even on slippery roads. Just like the Prius, the Estima hybrid can turn its engine off while in motion and operate as an electric vehicle to improve its fuel economy to roughly twice that of a conventional car. The hybrid system's generator function also drives a 1,500-watt, 100-volt AC power supply, which can be used in emergencies or for powering a mobile office.

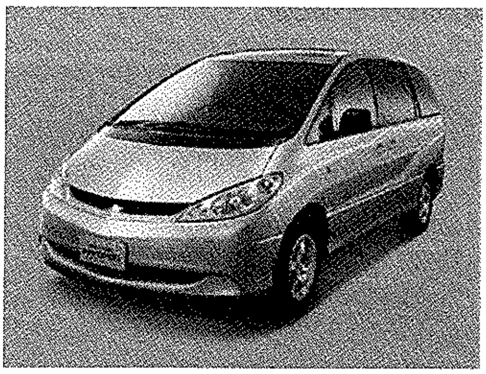

Fig. 9 Estima Hybrid

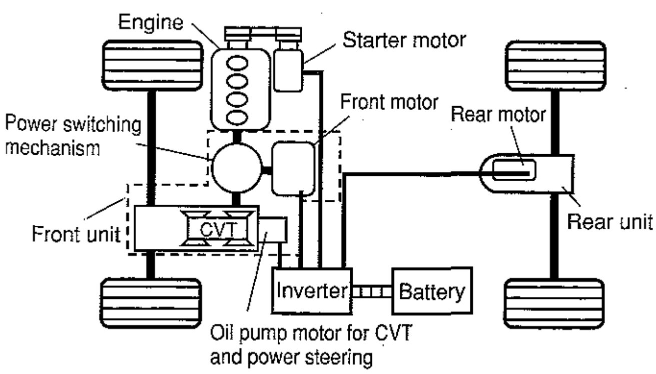

Fig. 10 Estima Hybrid System Configuration (THS-C)

The THS-C system was also used in the Alphard hybrid in 2003.

2.5 Crown mild hybrid [5]

The mild hybrid system (THS-M) uses a 42-volt power system and was developed as a system that could be applied to a wide range of models with only minimal changes to the vehicles themselves. It was put on the market in August 2001, in the Crown, shown in **Fig. 11**.

Fig. 12 shows the mild hybrid system configuration. It is a parallel hybrid layout (See Appended **Fig. 1**.)

In this configuration, a motor-generator that is linked to the engine crankshaft by a belt replaces the alternator that is used in a conventional vehicle. Because the motor-generator is controlled electronically, the environmentally friendly, yet comfortable vehicle can make a smooth transition from a full stop into motor-driven take-off, regenerate the energy of braking, and ensure air conditioning function even when it is stopped, while reducing fuel consumption and emissions.

Fig. 11 Crown Mild Hybrid

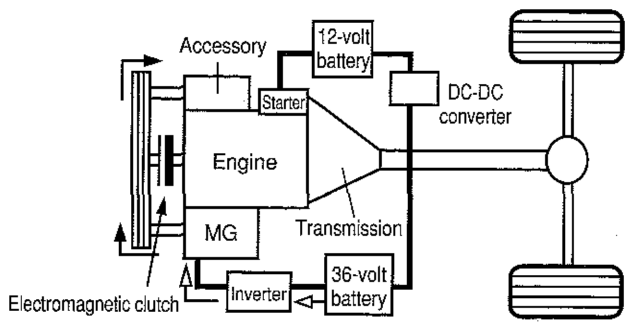

Fig. 12 Crown Mild Hybrid System Configuration (THS-M)

2.6 New Prius [1]

The new Prius that resulted from a full model change in 2003 features even better fuel economy and a remarkable improvement in power performance. The vehicle's weight has been reduced by using aluminum for some body parts, and the power performance has been enhanced by increasing the power of the engine, generator, and motor. The vehicle is shown in **Fig. 13**

The power of the generator, motor, and inverter was increased without making the units larger, allowing the system voltage to be increased from 288 volts to 500 volts

Increasing the voltage of a motor or inverter generally allows the unit to be made smaller, but by contrast, a battery tends to increase in size. This problem was solved by using a booster system that allows the battery to be made more compact even as the motor power is increased by using a higher voltage

The booster system configuration is shown in **Fig. 14**

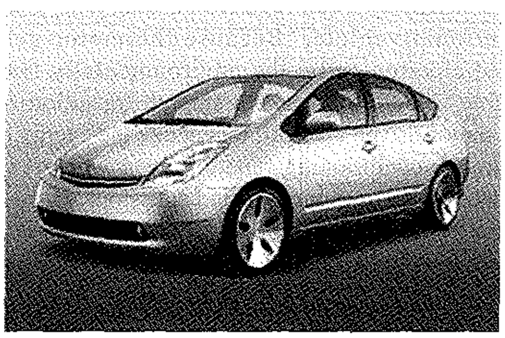

Fig. 13 New Prius

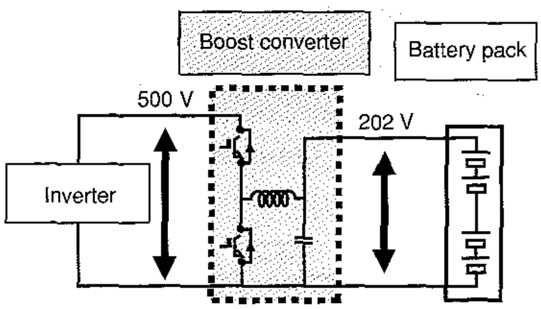

Fig. 14 Booster System Configuration

The boost converter is housed in the same unit with the inverter for the generator and motor. Nonetheless, the unit's size is equivalent to that of the unit used in the original Prius, despite the increase in power.

2.7 Diesel hybrid [1]

Toyota also developed a diesel hybrid system for small trucks and installed it in the Dyna in November 2003, as shown in **Fig. 15**. It is a parallel hybrid layout (see Appended **Fig. 1**) that combines a motor-generator with a 4-liter common-rail diesel engine. The system achieved a 25% CO_2 reduction as compared to a conventional vehicle in the domestic mode. The combination of hybrid technology and engine exhaust technology also dramatically reduces NOx and particulate emissions

Fig. 15 Dyna Hybrid

2.8 Fuel cell hybrid

Limited sales of the Toyota FCHV, a fuel cell hybrid vehicle that uses hydrogen fuel, began in Japan and the U.S. in December of 2002. The current focus in Japan is on lease sales to government-related bodies, local governments, and companies concerned with energy. The vehicle is shown in **Fig. 16**.

This hybrid system combines fuel cell stacks and rechargeable batteries to achieve the conceptual counterpart of a gasoline vehicle

The vehicle's performance is demonstrated by a fuel cell stack output of 90 kilowatts, a maximum speed of 155 km/h, and a cruising range of 300 kilometers

Fig. 16 Kluger Fuel Cell Hybrid Vehicle

This hybrid technology has also been applied to a fuel cell bus.

The fuel cell hybrid bus, or FCHV-BUS2, was operated as a city bus on regular routes in Tokyo from August 2003, until December 2004, as shown in **Fig. 17**. In 2005, it is being used to ferry visitors between attractions at the Aichi Expo.

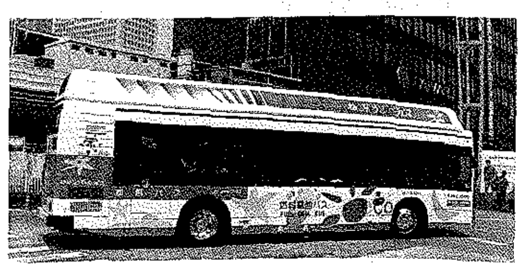

Fig. 17 Fuel Cell Hybrid Bus in Operation (at Tokyo Station, Yaesu Exit)

3. Conclusion

This article has reviewed the history of hybrid technology development at Toyota. That history can be divided into two periods, as described below.

(1) Before the Prius

Development was focused on the series hybrid systems seen in the gas turbine hybrid and Coaster hybrid. These systems just added a generator and motor to the gasoline engine, essentially borrowing electric vehicle technology to make the conversion to hybrid comparatively simple. But the physical form of the components and the improvement of power performance were issues that still had to be addressed.

Research and development work on the elements of a hybrid system, such as the battery, the motor, and the control unit, continued at the Higashifuji Technical Center and in the Machinery Group. The basic technologies for the current generation of hybrids were developed during this period.

(2) From the Prius to the present

Starting with the Prius, Toyota has gone on to develop a variety of hybrid vehicles. The original Prius system, the THS, was developed for passenger cars. The Estima system (THS-C) incorporates a CVT for medium-to-large vehicles like minivans. The Crown system (THS-M) is a hybrid configuration designed to minimize the changes to existing vehicles. Research and development into the optimum hybrid system is still being promoted, and a system has been established to develop and manufacture the main components internally at Toyota.

The development of the fuel cell hybrid vehicle as the power train of the future is also being promoted.

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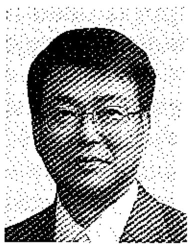

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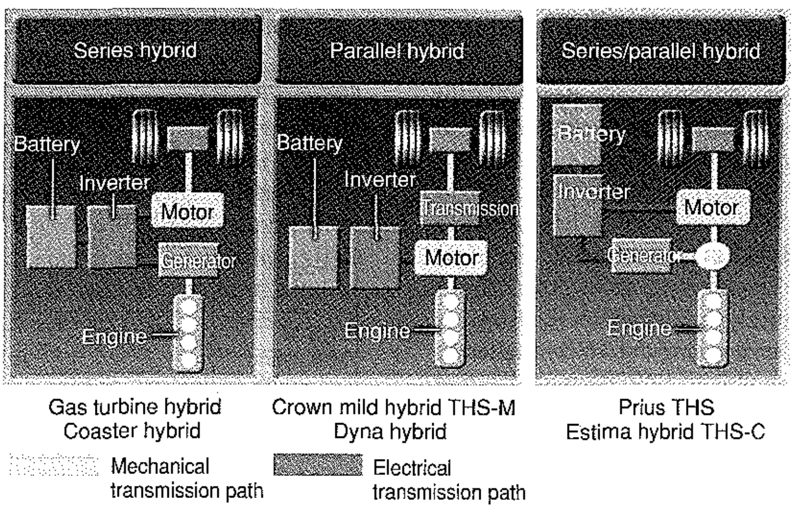

Appended Fig. 1 Classification of Hybrid Systems

As the season begins to turn, we present to you Vol. 54 No 1 of the Toyota Technical Review.

The name Toyota is recognized all over the country and we hope the Toyota Technical Review, Toyota's only technical journal, will become similarly well known With a view to gaining even the slightest increase in our readership, we have decided to switch back to a bi-annual publication of the Review instead of the annual publication in recent years. For this reason and others, we have included as many of the various latest technologies gaining attention at Toyota as would fit in the Review More diagrams and color pages have been added as well, and we avoided obscure technical terms where possible so that general readers may also appreciate the content. The articles published in the Review are written by engineers and researchers at the front line of Toyota Therefore, we believe that not only fans of Toyota, but also anyone with an interest in automotive technology will find subscribing to the Review worthwhile With the Review, you too can become an expert on Toyota and get a window into the latest technological trends at Toyota (Yamazaki)

"'Hybrid' will probably be this year's keyword in the automotive industry"

It was around January when I first saw that line written in a magazine article At that time, we had just started preparations after deciding to make hybrids the topic of this Toyota Technical Review Since then I have often seen the word "hybrid" in automotive-related magazines, making me glad that we focused on hybrids in this Review. The spotlight on the hybrid technologies and trends of carmakers has been growing brighter I hope Toyota's only technical journal, the Toyota Technical Review, will generate further interest in Toyota's technologies among our readers

This being my first turn as editor of the Review, I must admit that it has been an overwhelming experience. Thanks to the contributing authors and generous cooperation of others, we were able to see the smooth publication of this Review I am deeply grateful for everyone's help. Starting this year, the Review will be published on a bi-annual basis and we intend to continue publication of the Toyota Technical Review with an emphasis on timely topics Thank you for reading the Toyota Technical Review. (Hayashi)

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