# Notwendige Fortschritte in der Antriebsstrangentwicklung zur nachhaltigen Mobilität mit Hybridtechnologie

## *Powertrain Approach for Sustainable Mobility with Hybrid Technology*

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It has been 31 years since I visited Aachen for the first time during the Christmas season in 1976. At that time, I was working on hydrogen engine research in the master course in the university, and I got a chance to give a presentation for the London IMechE meeting. Then, here in Aachen, I was given the opportunity to observe Professor Pischinger's laboratory. Since, I have been working for Toyota for 30 years, now being the leader of the Hybrid development. I truly would like to thank for this opportunity to explain to you what kind of powertrain we at Toyota believe is required for sustainable mobilility.

You certainly know the effects of global warming everywhere in the world. Still, pictures visualising them remain shocking even when seeing them again and again. Here in Europe, famous glaciers have been dramatically changing within only 100 years.

This is the photo of the North Pole ice by NASA. The ice field has been shrinking in a 10% pace during 10 years. All the ice will disappear by around 2040, if this pace continuous.

CO2 is the alleged cause of global warming. It has been increasing drastically after the Industrial Revolution. It is the result of a massive consumption of fossil fuels, so it is not a natural occurrence, but a man-made phenomena.

About one quarter of the world's CO2 emissions comes from the transport sector, and a big part of this is from automobiles. This is why we as an automaker must take actions to reduce CO2 immediately.

Toyota's yearly production volume of vehicles has increased steadily. Realising our responsibility as automaker, we have moved into action for CO2 reduction already many years ago.

In 1996, at the first EVS electric vehicle symposium held in Osaka, the honorable chairman of Toyota Mr.Shouichiro Toyoda delivered a keynote message on the necessity to work on environmental technologies to prepare for sustainability in the 21st century. Before that, he initiated the development of a front-runner eco-friendly vehicle with the target to reduce CO2 emission by 50% compared to a conventional gasoline vehicle in Japanese driving conditions.

As a result, the first Prius was launched in 1997 on the Japanese market. Since a high and thus cost efficient production volume could not be expected only with Prius, we have continuously improved the hybrid system and implemented it to other models to increase the hybrid production volume. Parallel to that, we have developed various hybrid systems in order to fully understand which hybrid system has the best cost/benefit ratio.

As a result, within less than 10years after the 1st Prius has been introduced to the market, the total sales volume of Toyota and Lexus hybrid vehicles has reached more than 1million. Hybrid and non-hybrid vehicles are produced on the same production line with usual tact-time.

So, during my speech here, some 26 new hybrid vehicles are going off the end of the production line in our factories. All of these 26 vehicles are gasoline hybrids, not diesel hybrids. Let me explain the background for this.

It is well known that from a perspective of efficiency, the diesel engine has a wider high efficiency area than the gasoline engine. This results in lower CO2 of the diesel car when comparing to an equivalent gasoline car.

This however means that efficiency improvement by Hybrid technology is very effective for gasoline engines. The figure shows the contribution for CO2 reduction of each of the technologies like idling stop, regenerative braking, EV drive and engine improvement. Hybrid technology allows gasoline engine powered vehicles to have lower level of CO2 emission than diesel powered vehicles from city conditions like shown here up to higher highway speeds, as also a well-known interesting study of Professor Hohenberg of the University of Darmstadt confirms. In the future, we believe that further CO2 reduction will be possible with Plug-in hybrids that can be charged externally.

Of course, hybrid technology applied to a diesel vehicle would allow even lower CO2 levels than a gasoline HV. However, the reduction rate is not as big as for gasoline HVs due to the low CO2 emission of the base diesel vehicle.

Moreover, the environment can only benefit from a real CO2 reduction, if the low CO2 car is sold in higher volumes. In other words, developing cars for sustainable mobility means not only environmental performance, but also a reasonable price for the customer to achieve high sales volume. On the other hand, sustainability also means profitability for the car maker, who then can use the profit to develop again new technologies.

This is the problem of the diesel hybrid. The cost of a conventional diesel vehicle is higher than that of a gasoline vehicle. If a hybrid system is added to the diesel vehicle, the cost rises even more, but the CO2 benefit and for the customer the fuel saving benefit is lower than for a gasoline hybrid.

The cost of a 1 motor hybrid system is not significantly lower than that of a 2 motor system because even though the cost of 1 motor is saved, a conventional transmission is needed. The 2 motor concept of Toyota's hybrid system replaces the conventional transmission and thus saves cost.

This cost issue for diesel hybrids may cause that we will see other technologies like idle stop for diesel engines earlier than hybrid diesel powertrains in high sales volumes. We do not consider Idle stop systems as hybrids, following the SAE definition, therefore I will also not go to further details but rather focus on the strong hybrids. Strong hybrids allow strong improvement of fuel economy, however also inherit high costs.

As you can imagine, to ensure profitability we had to put a lot of efforts in cost reduction of the hybrid system. At the introduction of the 97 Prius, the cost was high, let me say very high. However, with the second generation Prius, the cost of the hybrid system was reduced by 70%. Such cost reduction is of course only possible at the very beginning stage of a technology, but still we are reducing the costs continuously, also for our future hybrid systems. Increasing sales volume helps to reduce cost, but additionally to that our heartless accounting division forced us to develop further cost reduced technology on each component.

The cost reduction for each of the Hybrid system units, such as motor, inverter and battery had to go in line with performance improvement. Higher output not only at lower cost, but also at reduced size and weight of the unit. This makes hybrid development a true challenge.

As a result of various motor optimization steps, the output density of the electric motor of the recent Lexus LS600h is 6 fold the one of the first generation Prius.

The power control unit that incorporates the inverter has also been improved drastically. The output density of the Power control unit of the recent LS600h is 3 times the one of the first Prius' inverter. We think that there is a possibility for further optimization by cooling performance improvement.

As for the battery, both space for packaging as well as weight for the overall vehicle mass are critical. Thus we need to optimise both mass based as well as volumetric output density. Both have been significantly improved when comparing the RX400h and LS600h batteries with the first Prius. It is difficult to achieve further big improvements with the current NiMH technology. When considering efficient batteries for the future, we have to think about revolutionary battery technologies, beyond Lithium-Ion technology.

The evolution of the units on technical and cost level that I explained was running parallel to the development of new models, which then step by step incorporated also new technologies. After 10 years of hybrid vehicle mass production, we are very happy today to see that at recent motorshows several other car makers have shown hybrid prototypes with clear CO2 results and introduction targets. We strongly expect with these vehicles being introduced that competition in all areas like performance, cost and thus also price for the customer will finally lead to a big benefit for the environment by reduced CO2 emissions.

Looking towards future hybrid vehicles, I have already indicated the key importance of battery technology. One of the future hybrid technology directions will be Plug-in hybrids.

The possibility to plug in Hybrid vehicles to the electric grid to recharge allows to combine the advantages of electric vehicles and hybrid vehicles. CO2 reduction and high daily driving range by hybrid as well as driving with electric energy in the city with zero emissions can be achieved. Plug in hybrids however require infrastructure and additional actions by the owner.

In order to deeply understand all issues for Plug-In hybrids, we have started tests with Plug-in hybrids based on a current Prius. With an EV cruising distance of about 13km, battery capacity is double of the production Prius. For feasibility of a mass production Plug-in hybrid, battery development is still the key. So it is necessary to promote the development of battery innovation, even beyond Lithium-Ion technology.

The merit of a plug-in HV for CO2 reduction and oil saving depends strongly on each country's mixture of electric power source, here shown with the examples of France, Japan and the US. For a total driving distance of 25km per day, the CO2 reduction is about 13% in Japan compared to the base Hybrid vehicle which emits already about 40-50% less CO2 than a conventional gasoline vehicle. In America with a high share of coal-fired power stations, CO2 reduction will be only about 4% compared to a base hybrid vehicle. In France with a high rate of nuclear power generation, it is possible to reduce CO2 by about 45% compared to the base hybrid vehicle. The environmental benefit of a PlugIn hybrid is most favourable in case of renewable resources like water, wind and solar power. For the owner`s benefit, energy cost for driving can be reduced by replacing fuel with electricity, meaning lower cost, especially beneficial when using nighttime charging in some countries.

Additionally to the described benefit in CO2, Plug-in hybrid technology also offers a potential to further improve air quality by very low pollutant emissions. Today's Prius has a CO2 emission of only 104g/km for a full size family car with extremely low NOx emission less than 0.01g/km in the new European Driving Cycle, much lower than cars with conventional gasoline and especially diesel powertrains. Even further reduction of both CO2 and pollutants like NOx will be possible in the future by plug-in technology.

Plug-in technology allows to further stretch the 4 features that characterise hybrid vehicles: Energy efficiency, clean emission, fun-to-drive and quietness.

With the experience of more than 1 million hybrid vehicles sold to customers, Toyota is convinced that hybrid is one of the important technical solutions for environmental and energy issues, essential to prevent global warming by providing low CO2 and low pollutant-emission vehicles, while at the same time giving the user an enjoyable driving experience in a high level. We consider Plug-in technology as promising for the future, however battery issues with regard to energy density and cost need to be solved.

As you have heard, my career path lead me through the world of motor sports. So it was a special challenge for me to bring together my previous ambitions for racing with my new assignment for hybrid technology. With the hybrid racing vehicles we have been able to create motor sports vehicles that are eco-friendly and enjoyable for motor sport fans. These pictures are from races in Japan. Toyota's hybrid could win the 24hour race of Tokachi in 2007.

The most urgent thing that we have to do is to stop global warming, and revert to the original condition.

I understand many of the floor today are engine engineers. Also I am an engine engineer originally. Hybrid however is a technology closely related to electronics. In order to further develop advanced technologies like hybrid and to progress towards the goal to stop global warming, it is necessary to integrate conventional research like on engines and electronics development much closer than in the past.

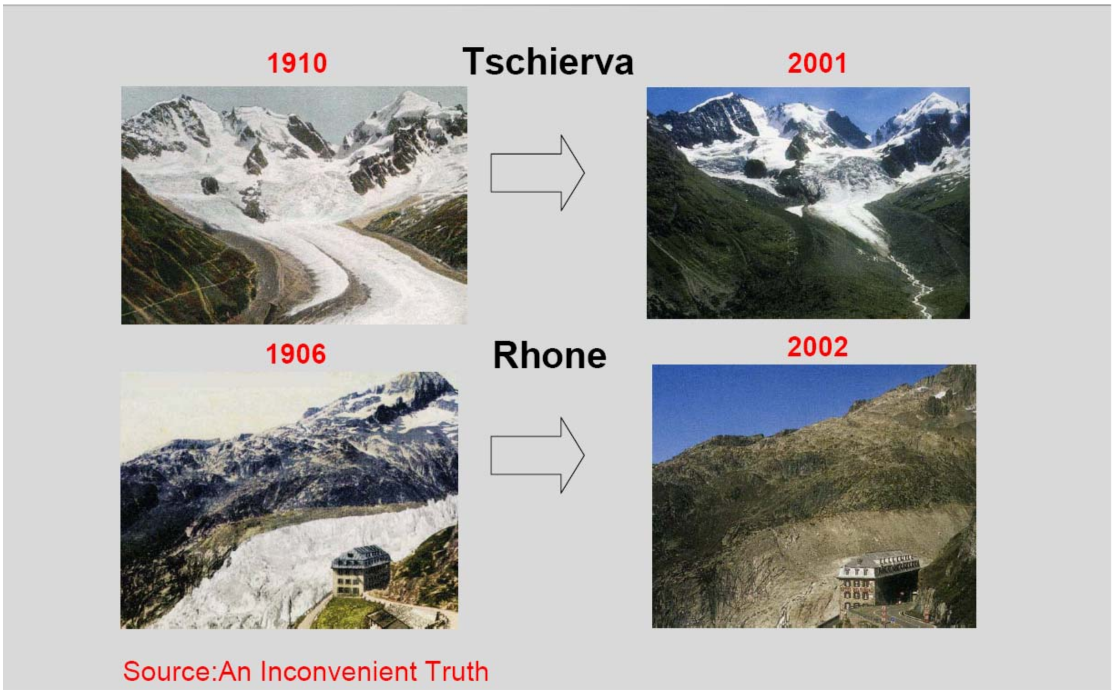



*Fig. 1: Warning from Nature*

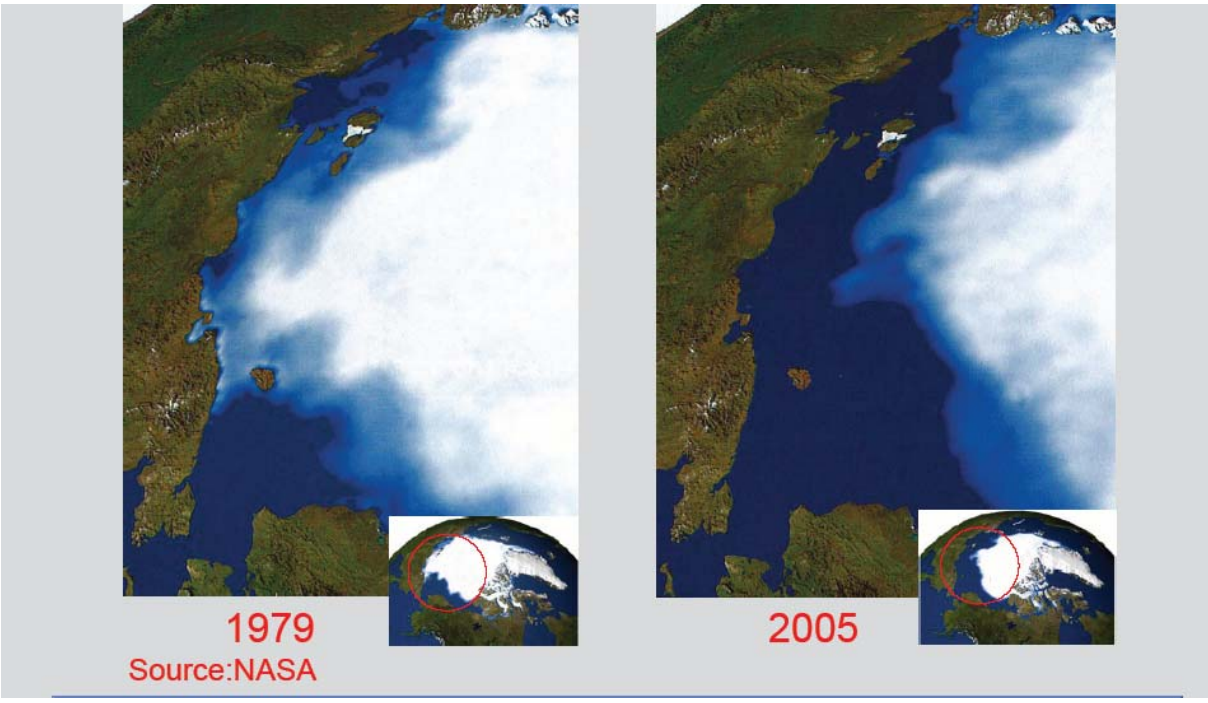



*Fig. 2. All Artic Ice will Thaw Around 2040*

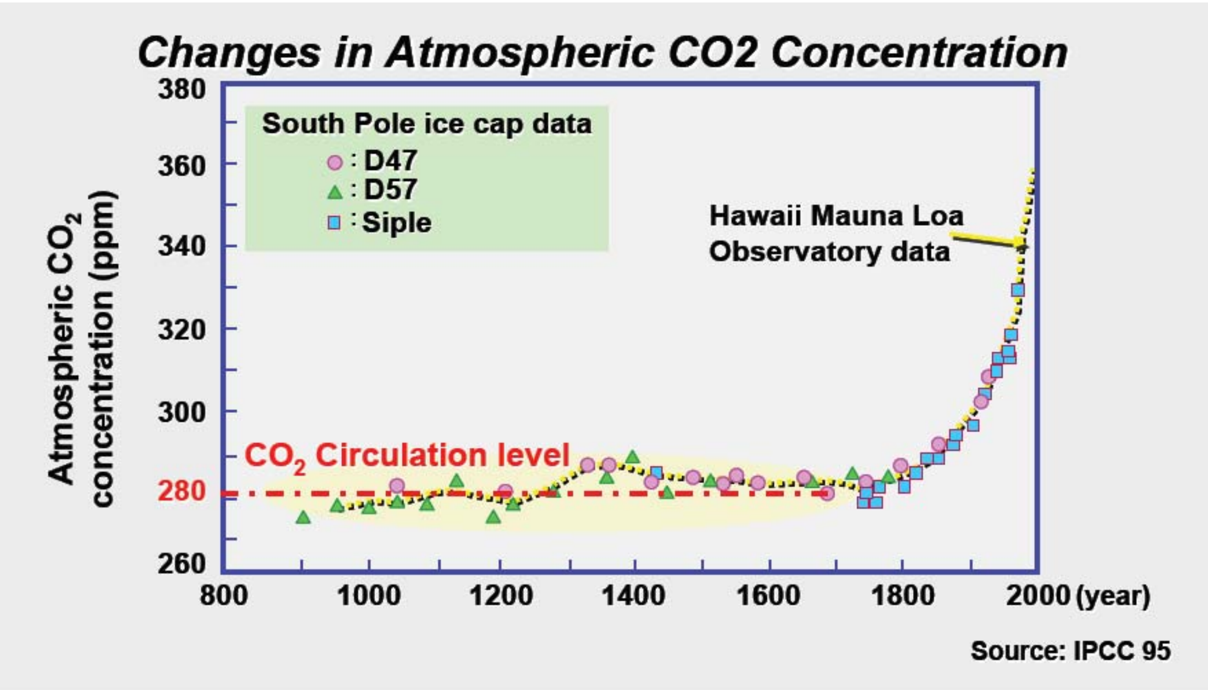



*Fig. 3: Rapid Escalation since the Industrial Revolution*

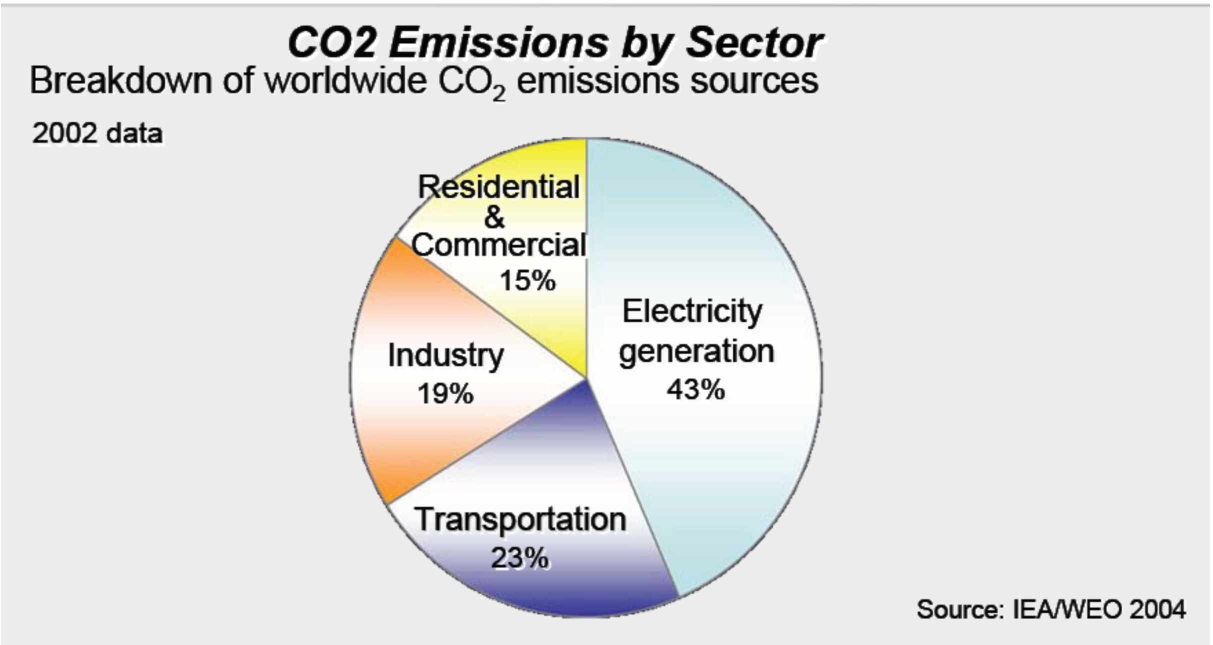



*Fig. 4: Tranportation Accounts for 23% of Anthropogenic $CO_2$ Emission*
*All Sectors to Take Measures to Postpone Oil Deletion*

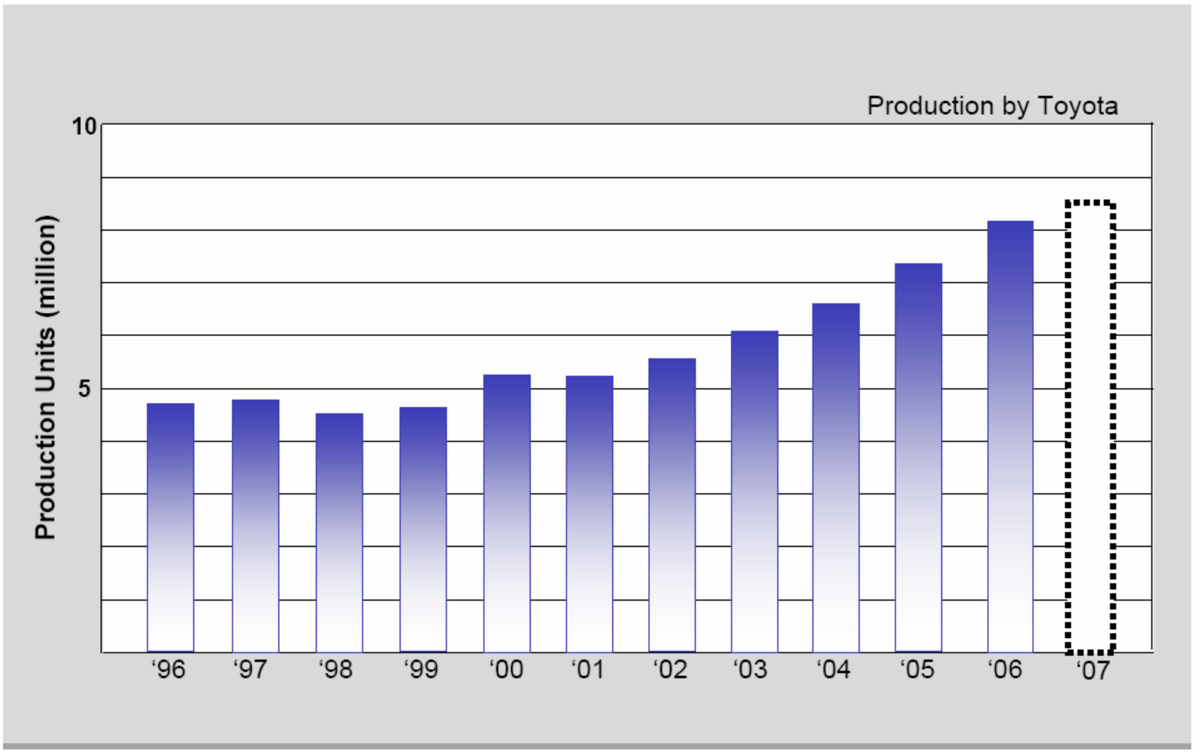



*Fig. 5: Toyota Production Vehicles*

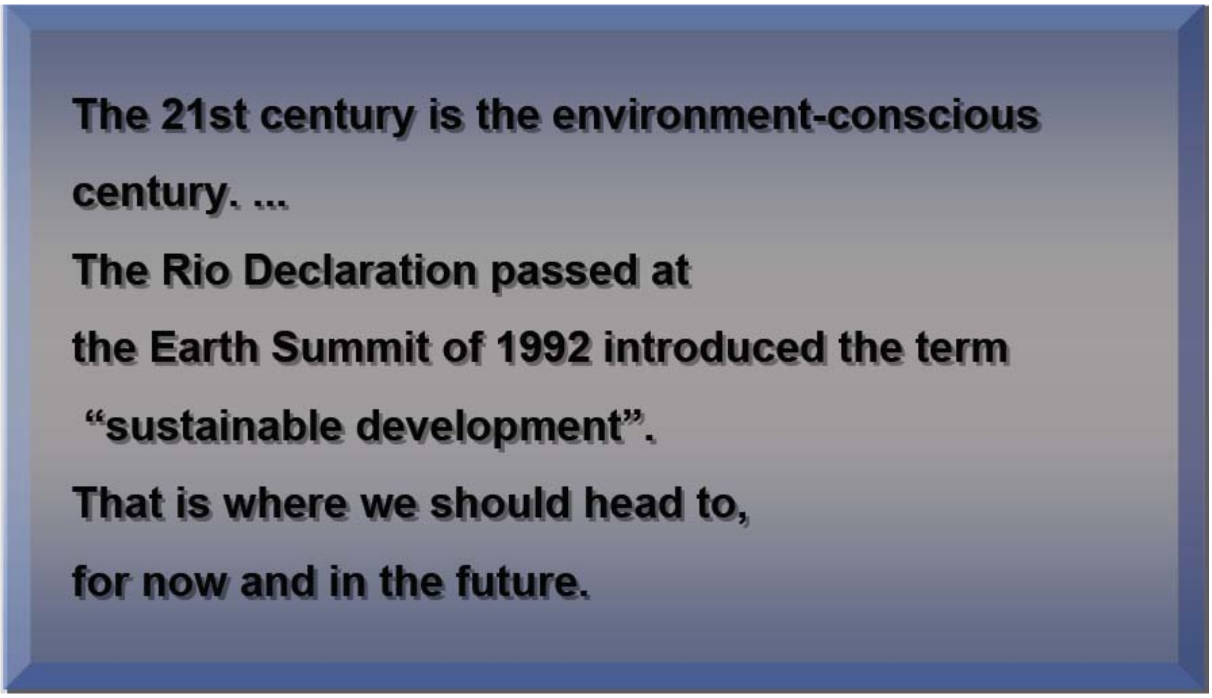



*Fig. 6: Cars for the 21st Century*

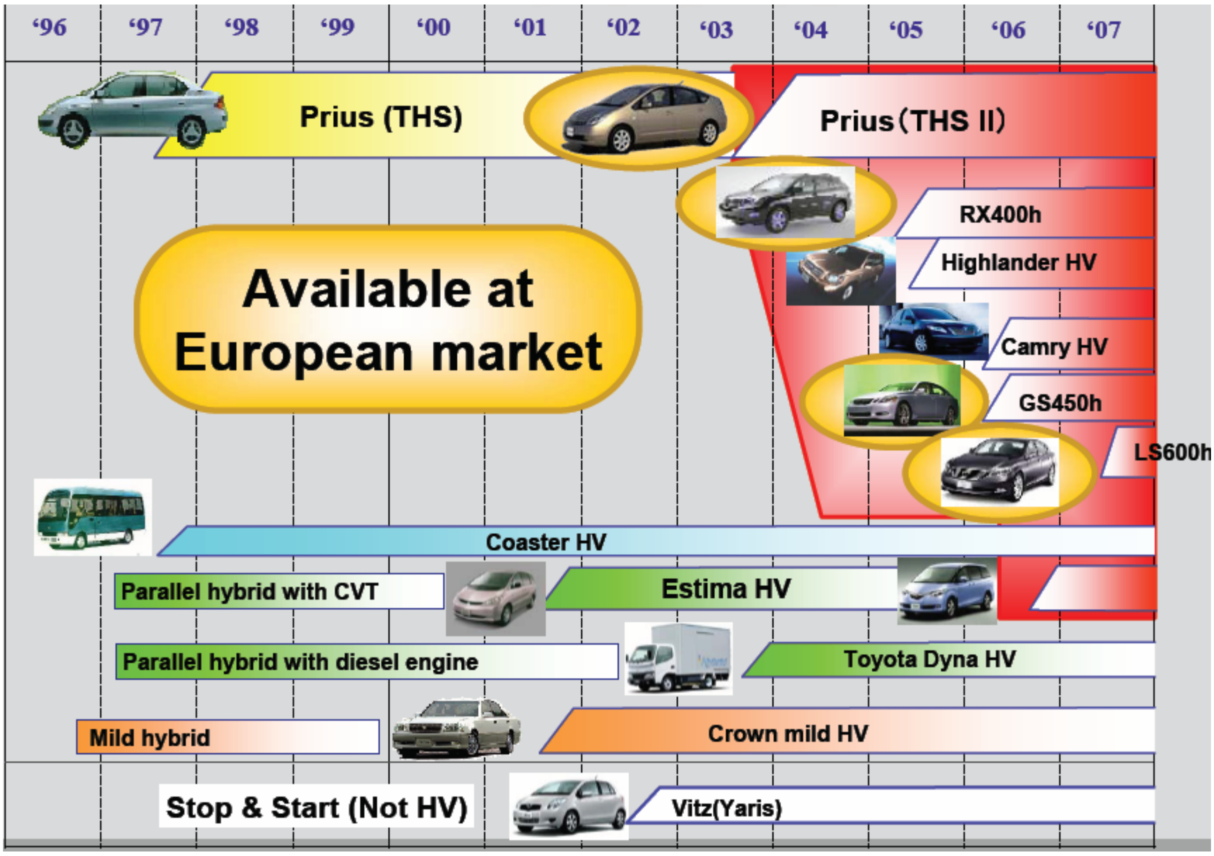



*Fig. 7: History of Toyota's HV Development*

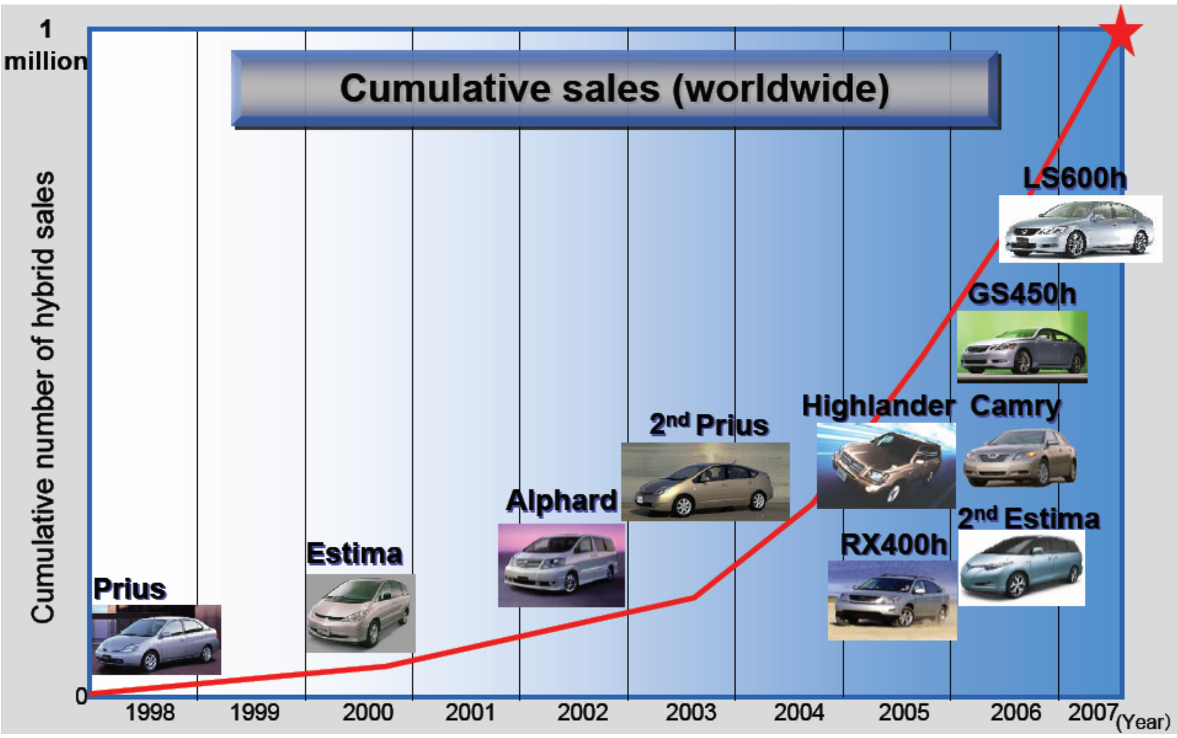



*Fig. 8: HV Market*

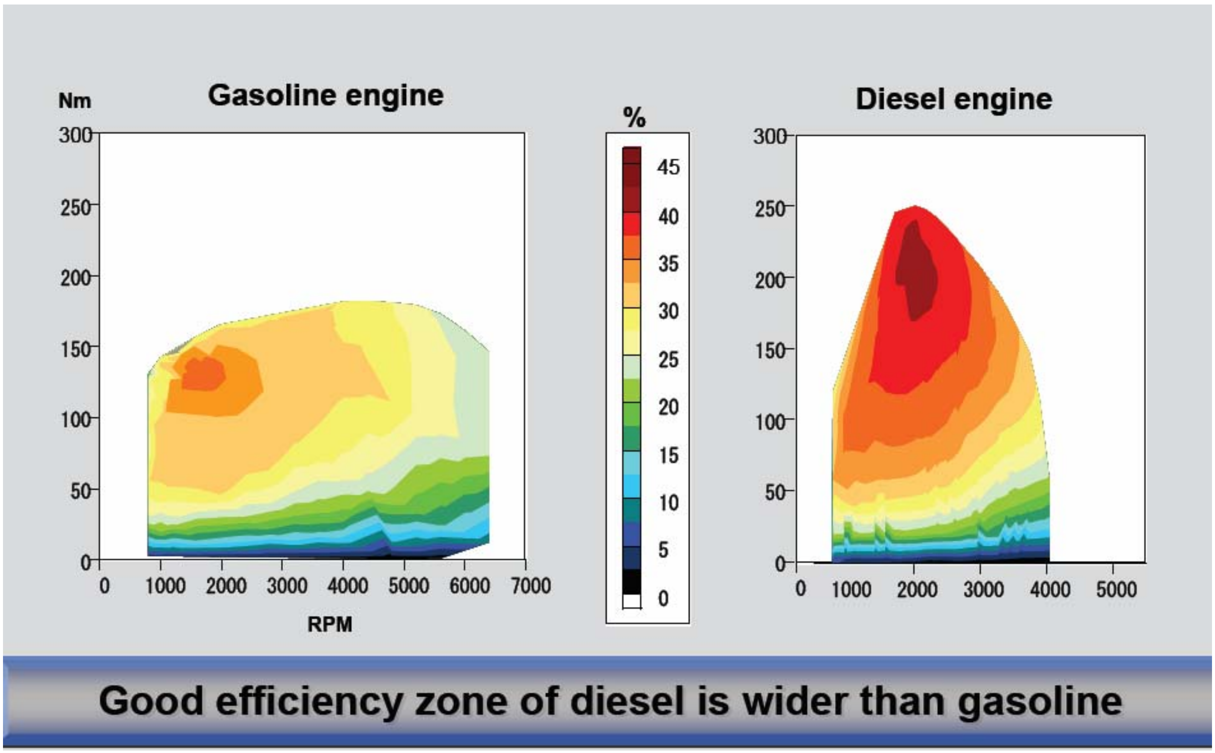



*Fig. 9: Difference between Gasoline and Diesel in Efficiency*

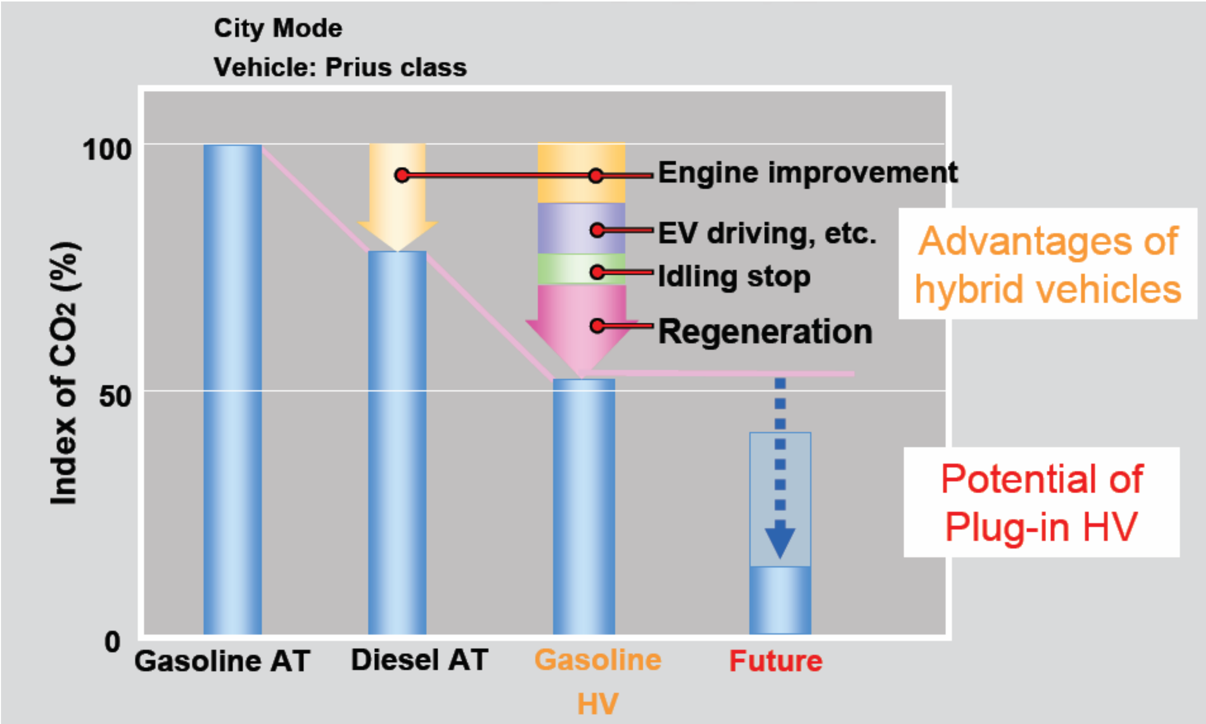



*Fig. 10: Why Hybrid Vehicles? $CO_2$ Advantage*

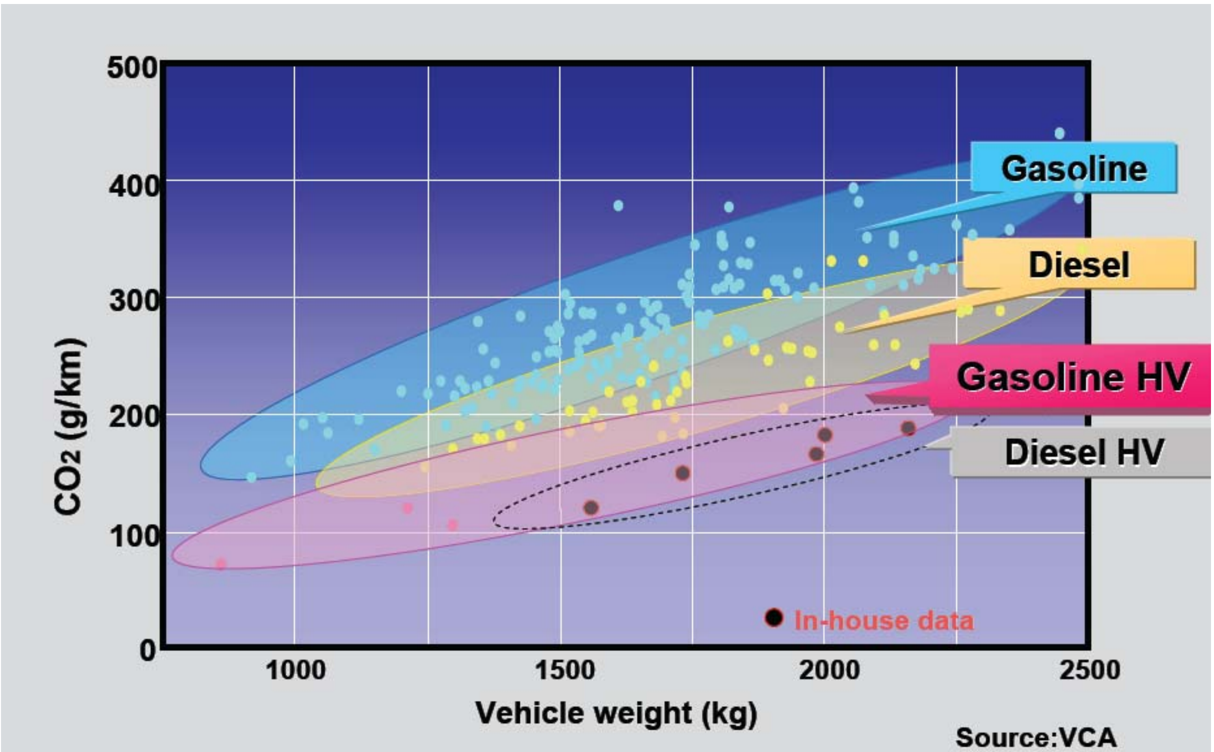



*Fig. 11: Actual $CO_2$ Emissions in European Market*

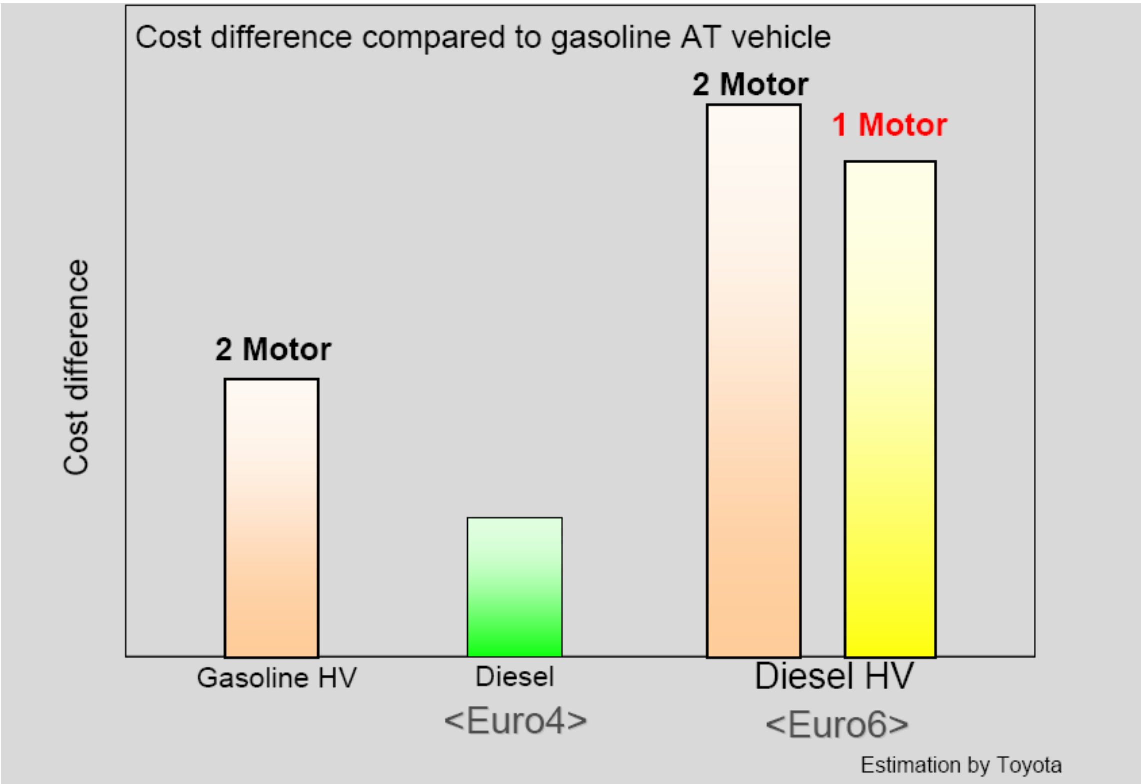



*Fig. 12: Cost Increase by Hybridization*

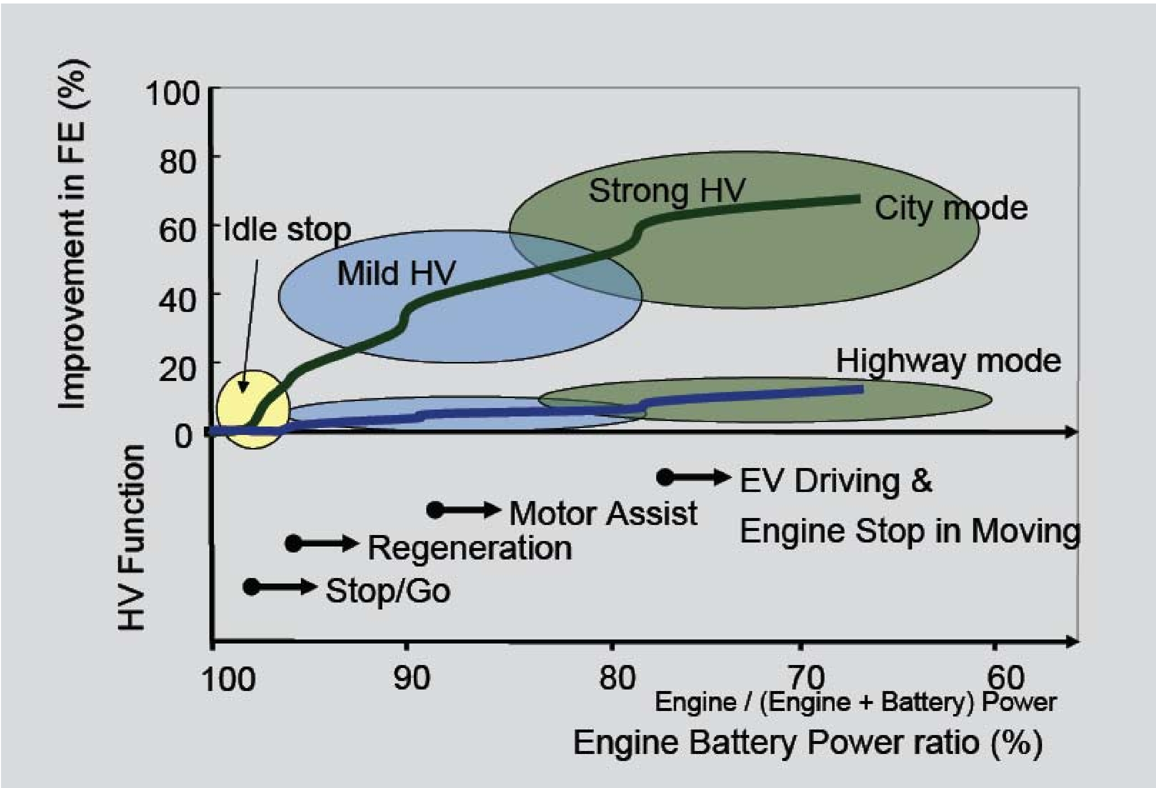



*Fig. 13: Classification of Hybrid Vehicle*

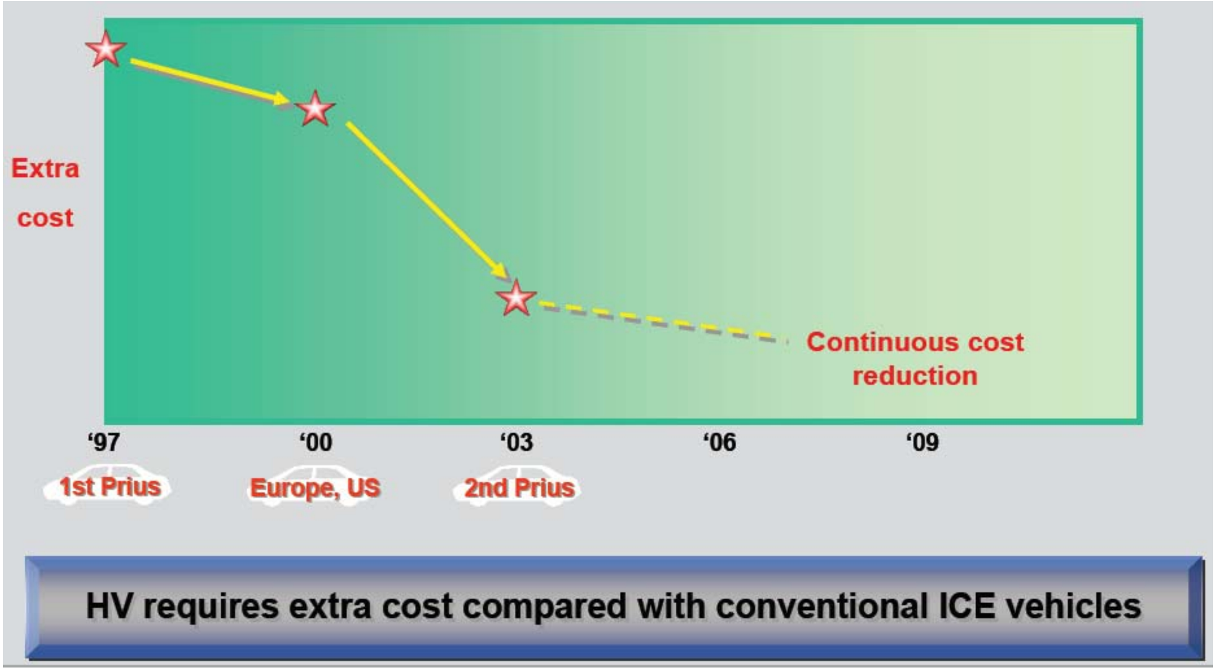



*Fig. 14: Cost of Technology*

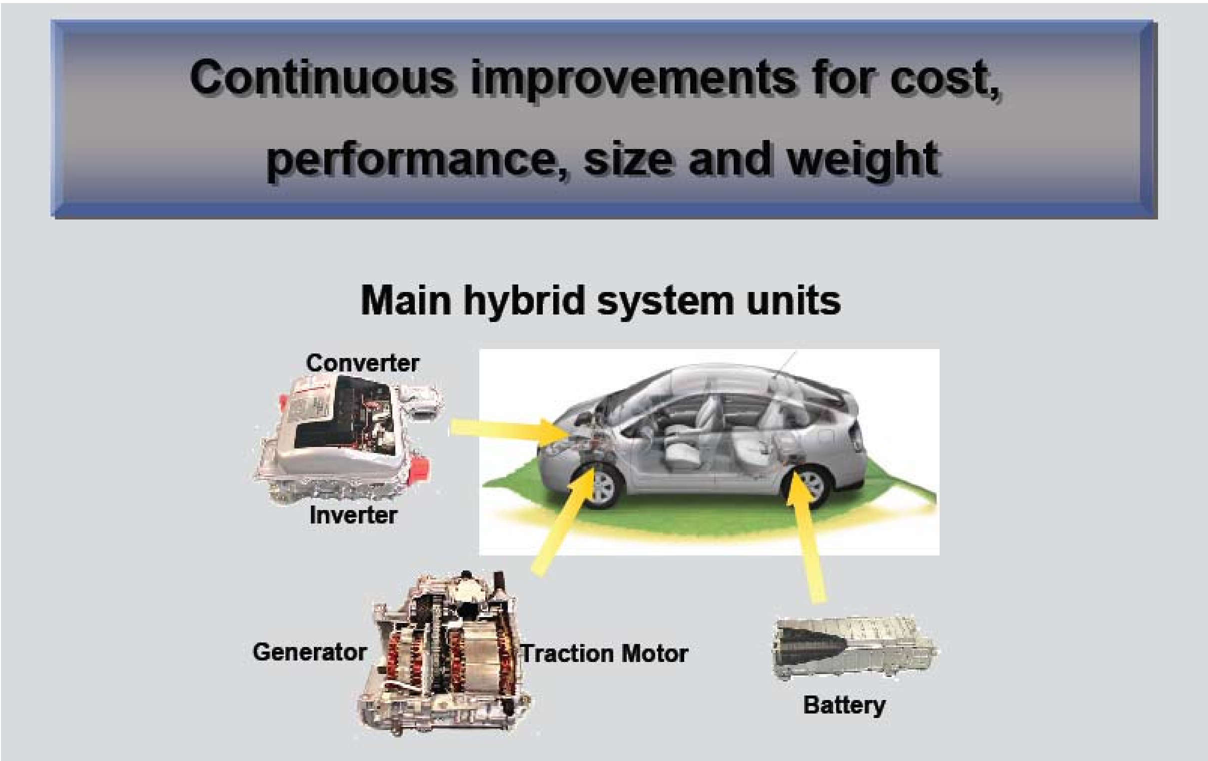



*Fig. 15: Evolution of HV Units*

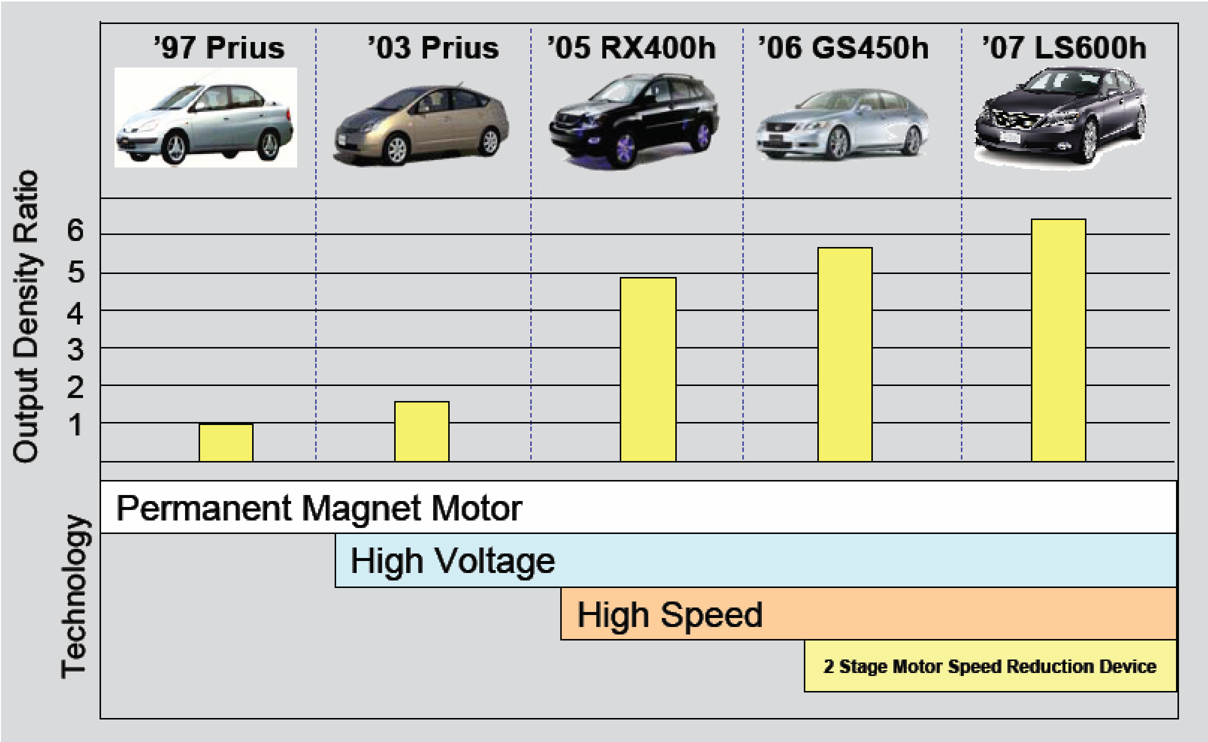



*Fig. 16: Evolution of HV Units-Motor*

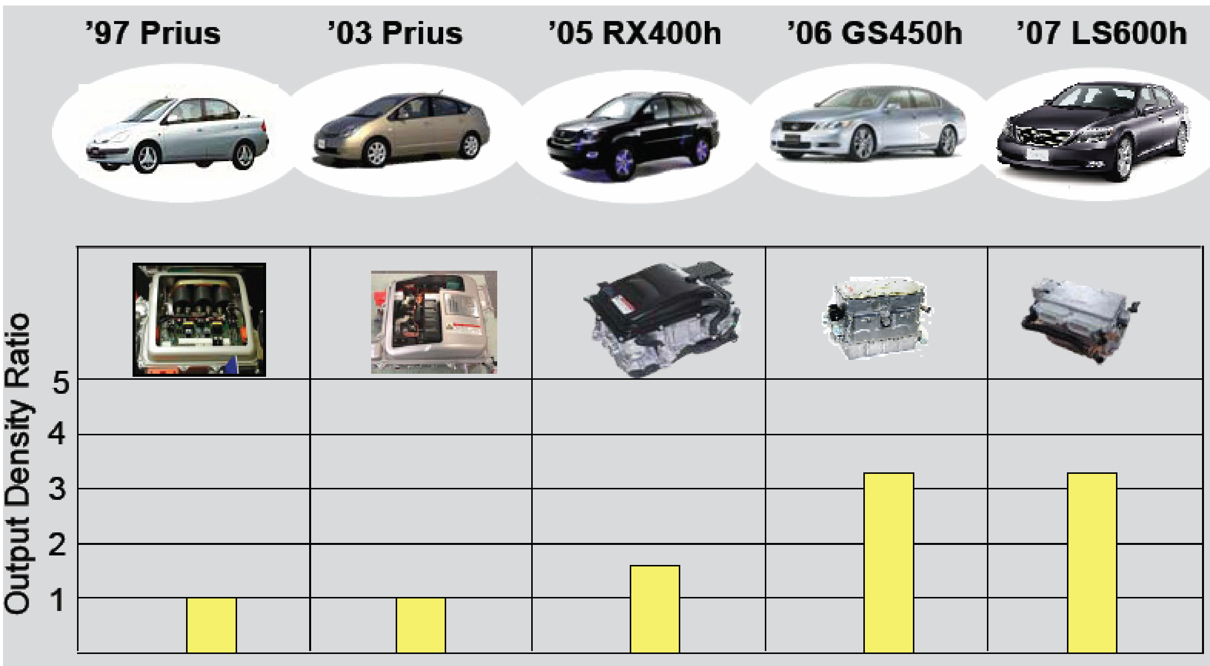



Fig. 17: *Evolution of HV Units-Inverter*

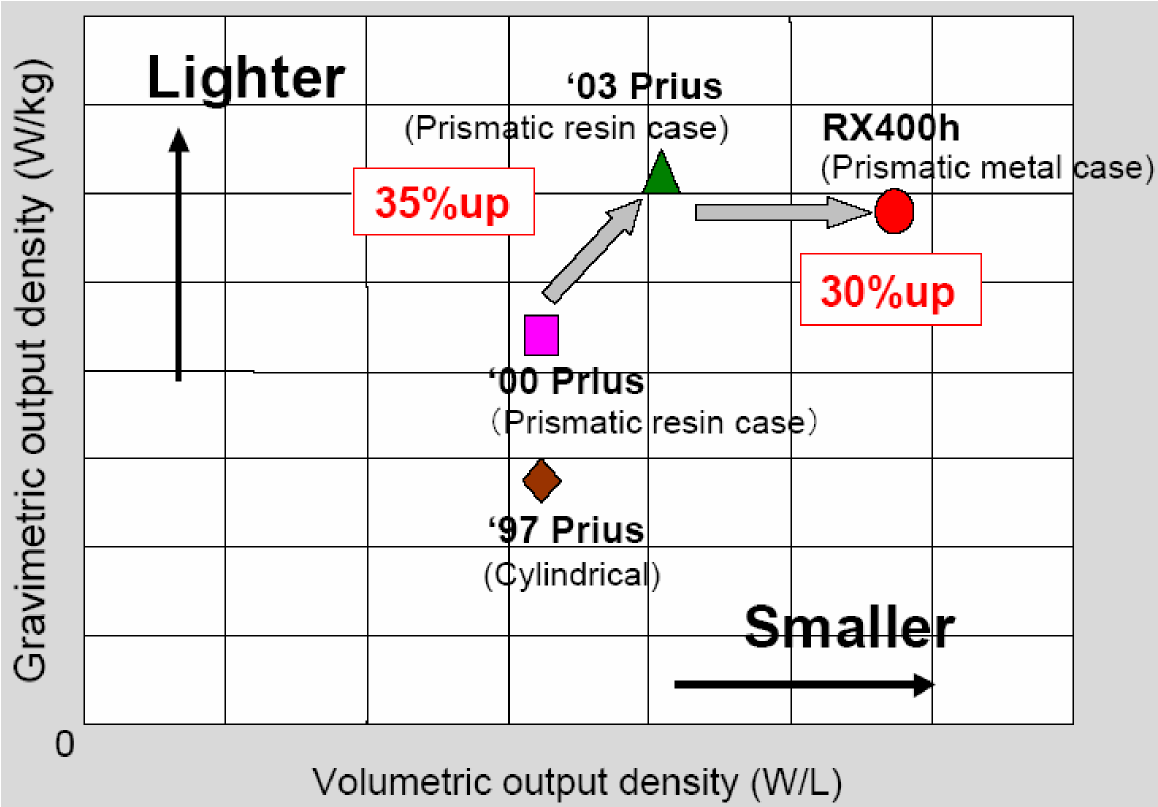



Fig. 18: *Evolution of HV Units-Battery*

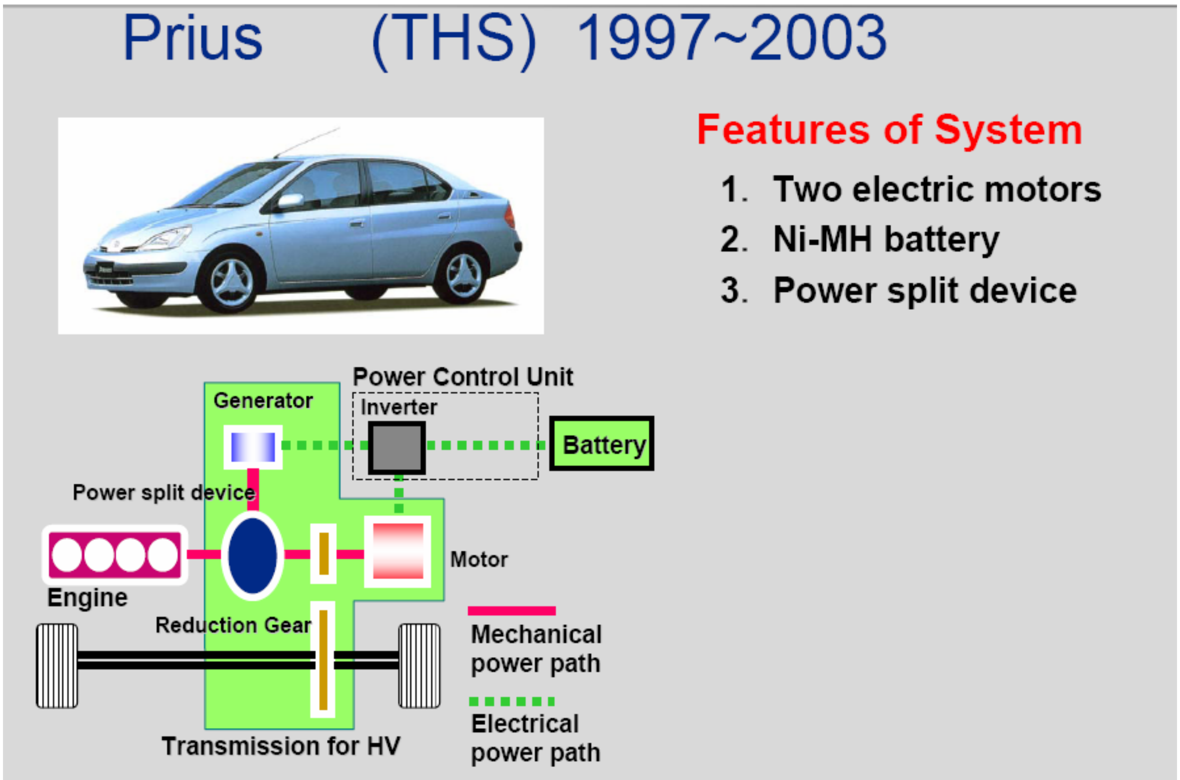



*Fig. 19: Evolution of Toyota Hybrid System 1*

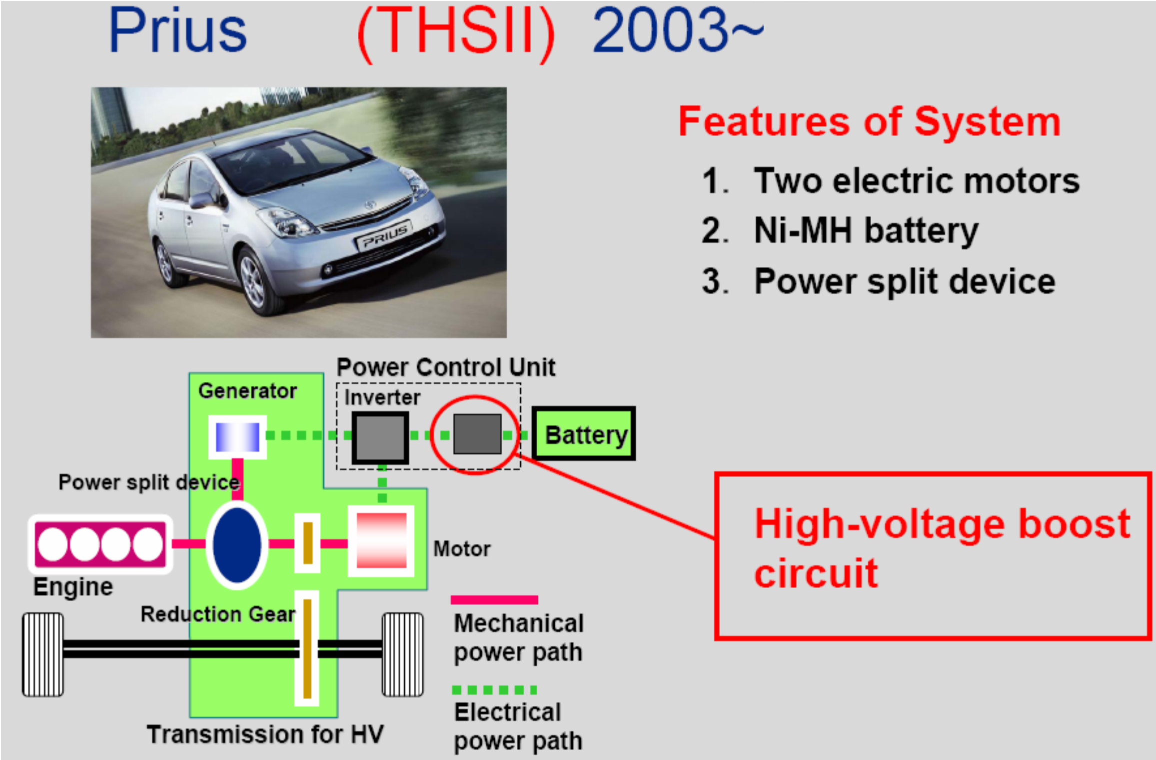



*Fig. 20: Evolution of Toyota Hybrid System 2*

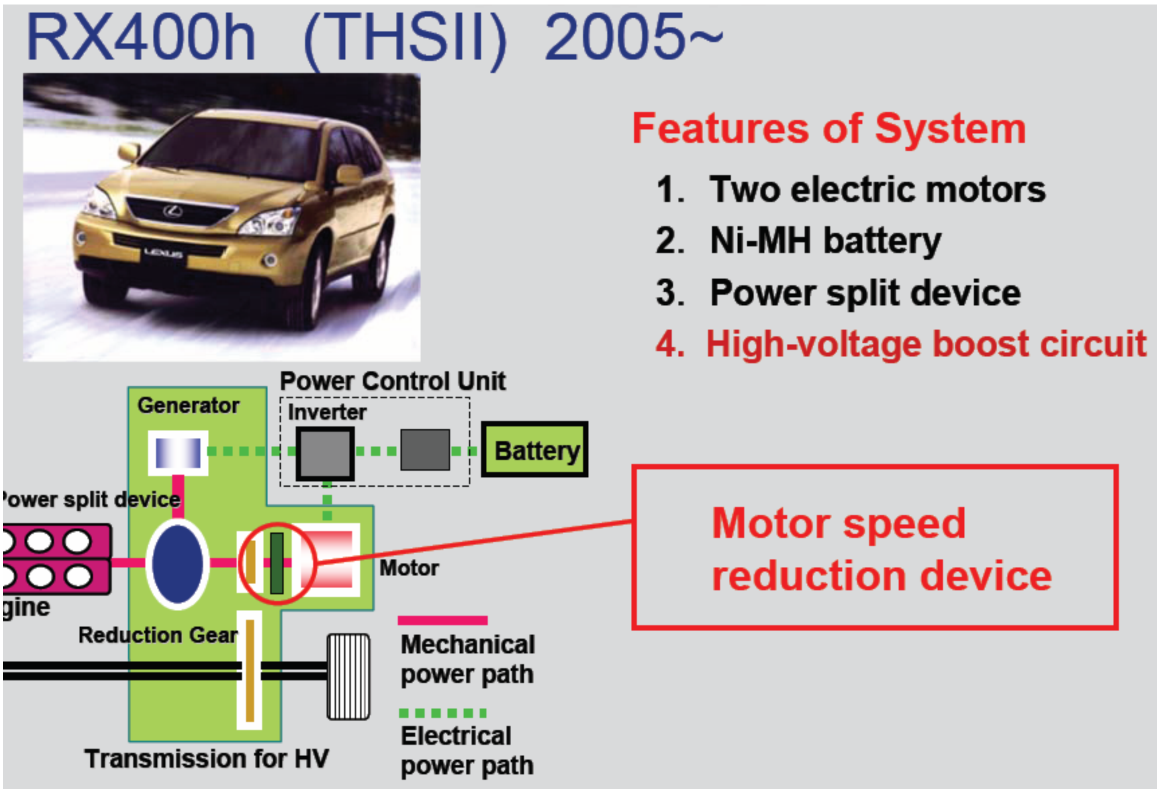



*Fig. 21: Evolution of Toyota Hybrid System 3*

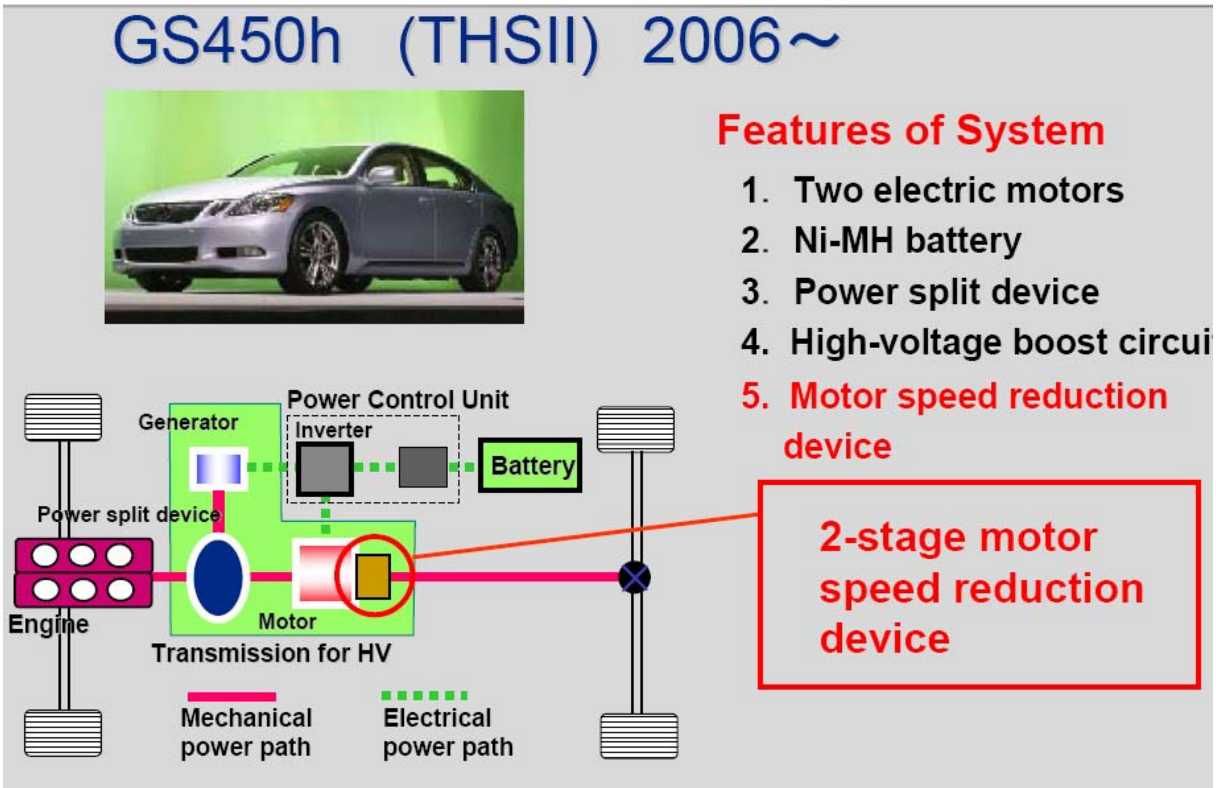



*Fig. 22: Evolution of Toyota Hybrid System 4*

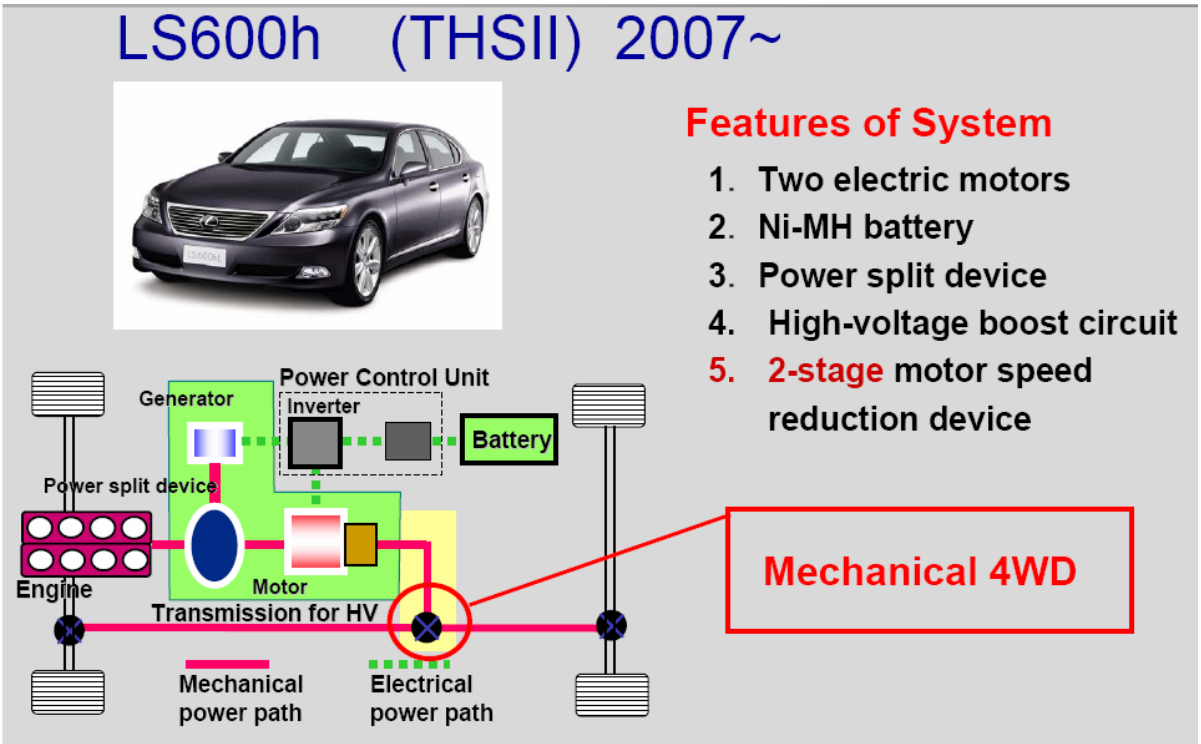



*Fig. 23: Evolution of Toyota Hybrid System 5*


*Fig. 24: Plug-In Hybrid Vehicle (PHV)*

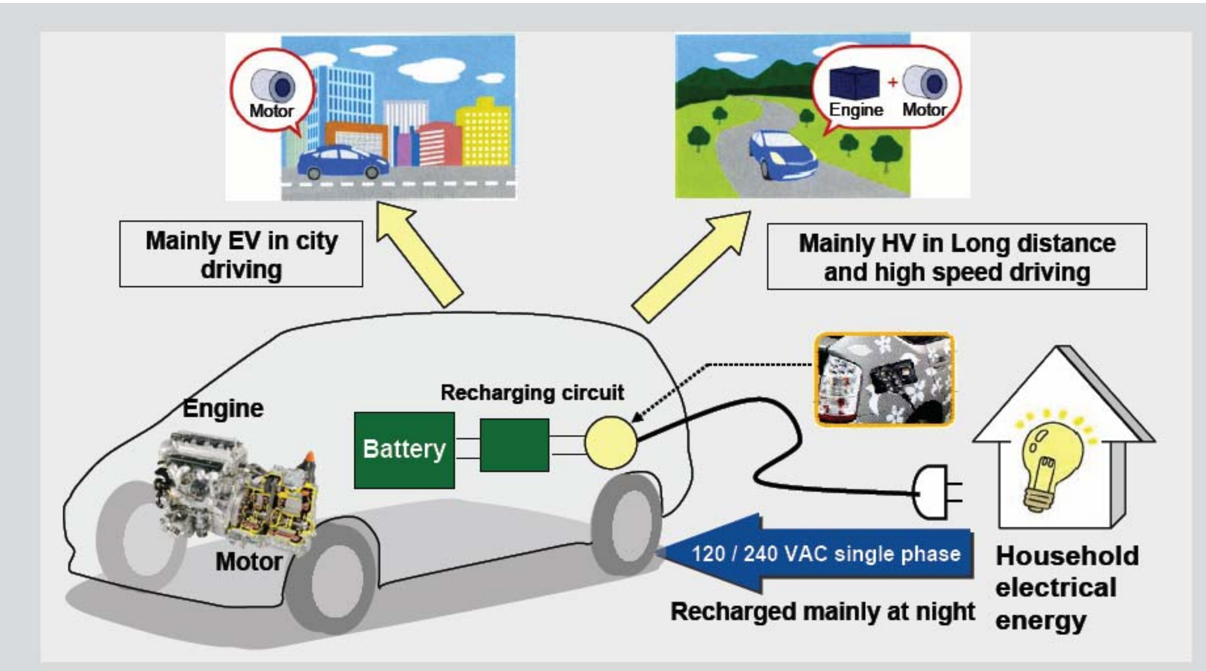



*Fig. 25: Plug-In Hybrids are Expected as a New Style of Electricity Utilization*

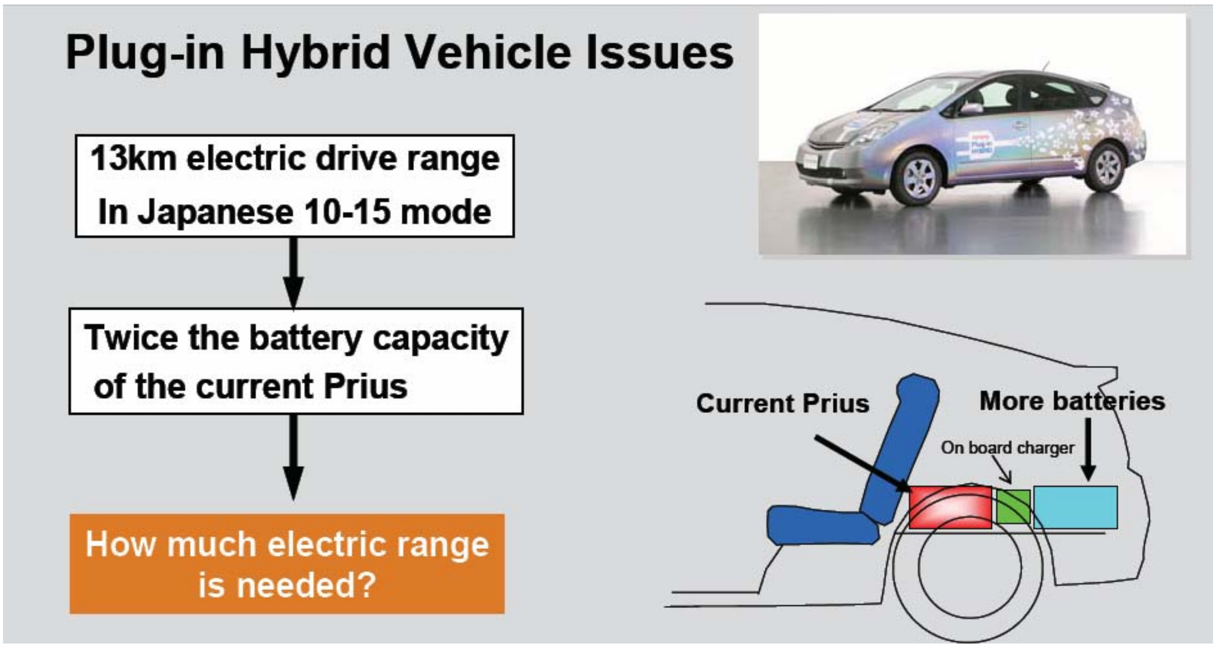



*Fig. 26: Battery Innovation = Key for Plug-in Hybrid Concept*

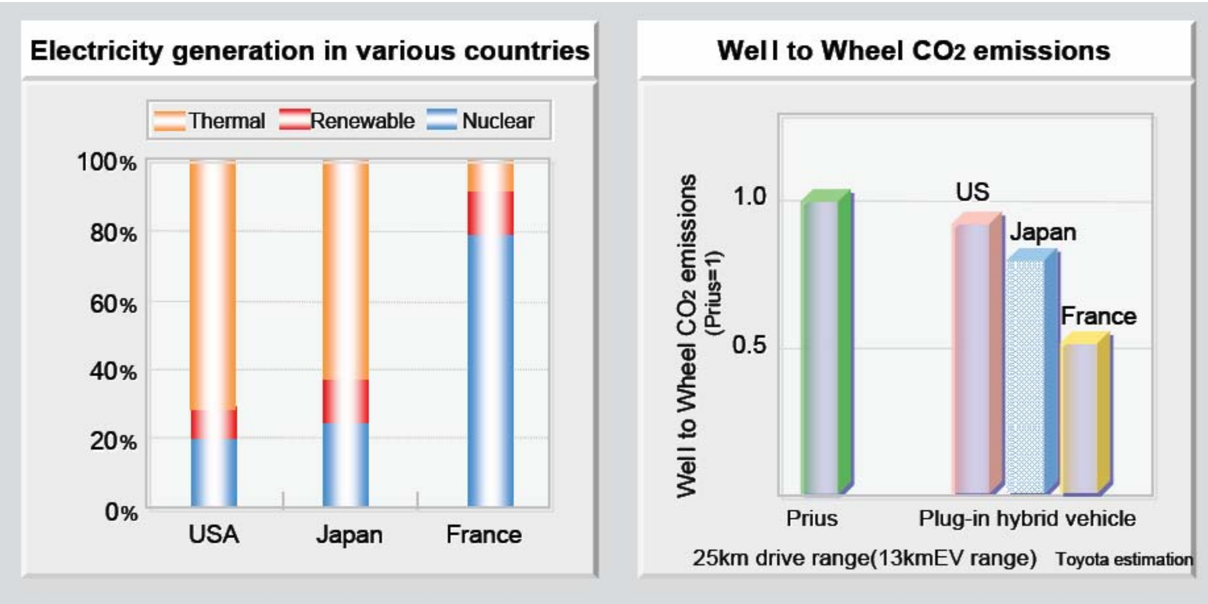



*Fig. 27: Environmental Benefit: $CO_2$ Reduction in Well-to-Wheel*

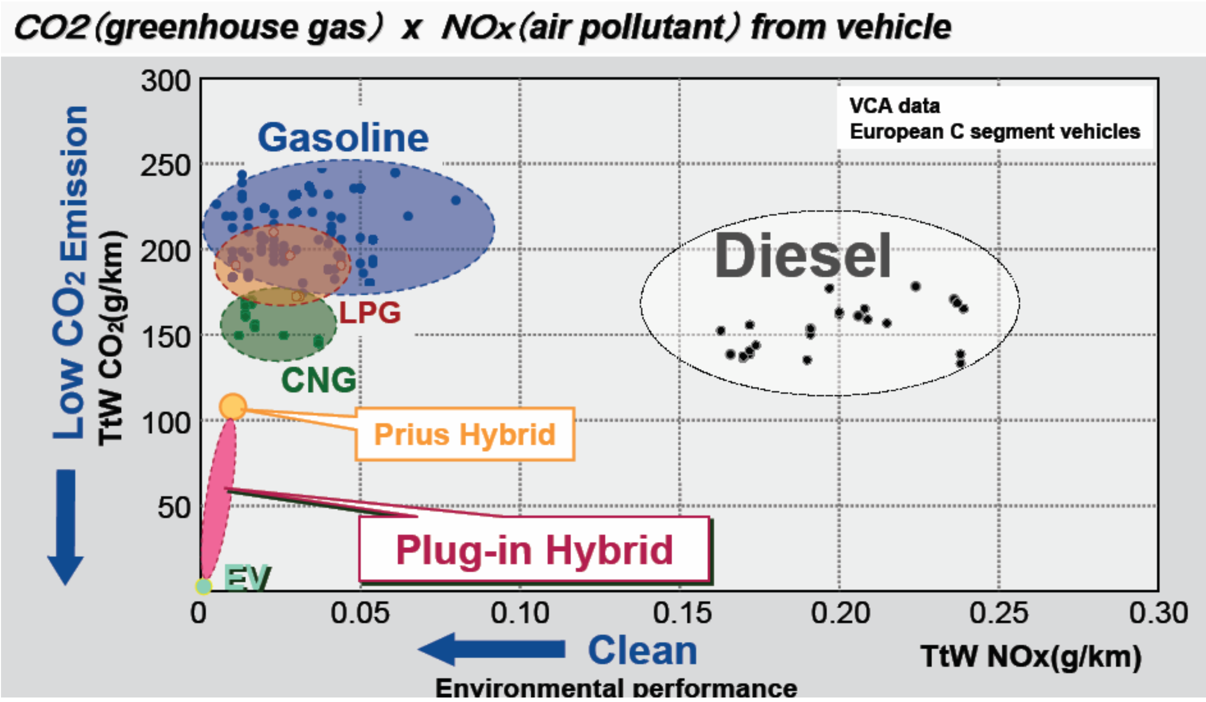



*Fig. 28: Plug-In Technology will Further Improve Hybrids Both in $CO_2$ & NOx*

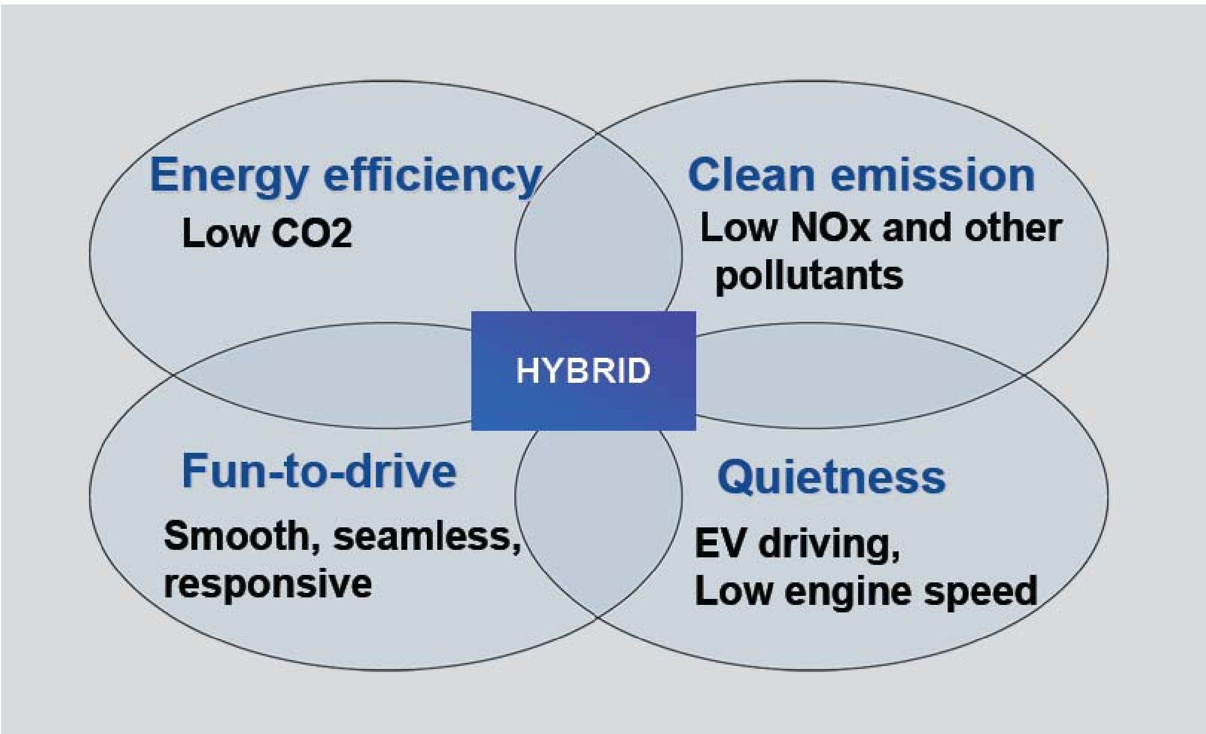
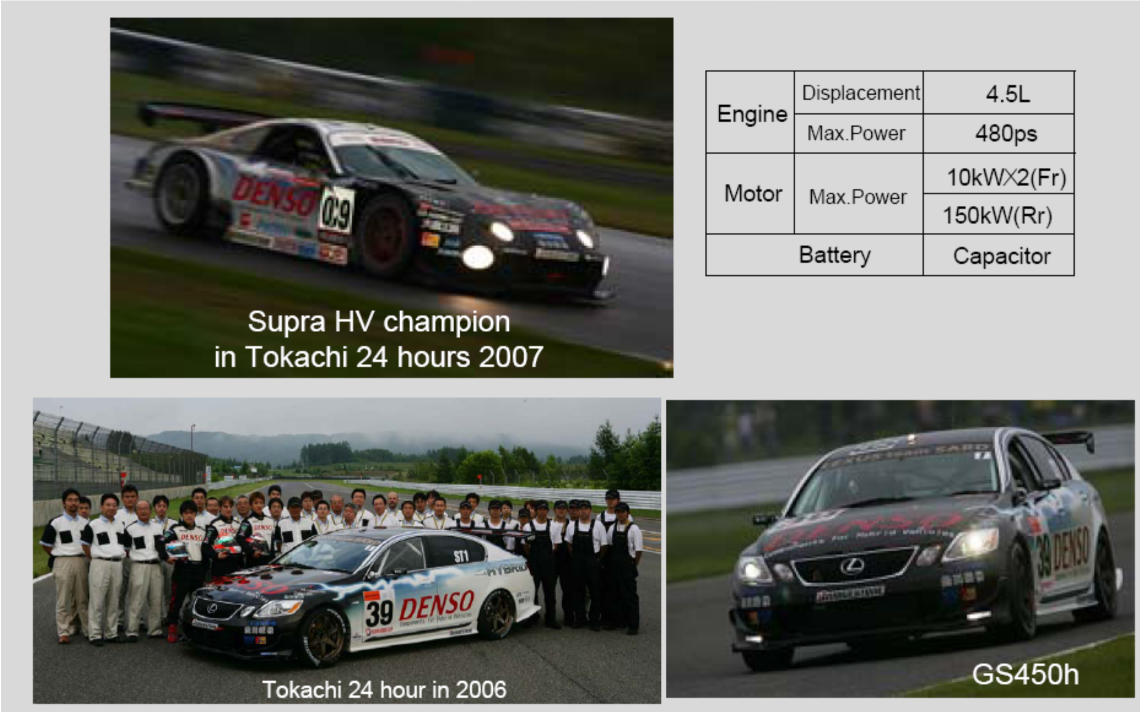



*Fig. 29: 4 Features*




| | | |
|---|---|---|
| Engine | Displacement | 4.5L |
| | Max.Power | 480ps |
| Motor | Max.Power | 10kW×2(Fr) |
| | | 150kW(Rr) |
| Battery | | Capacitor |

*Fig. 30: Fun to Motor Sport 1*

*Fig. 31: Fun to Motor Sport 2*


*Fig. 32*