Development of Toyota Plug-in Hybrid Vehicle

Shizuo Abe

Hybrid Vehicle Engineering Management Division, Toyota Motor Corporation, shizuo@abe.tec.toyota.co.jp

Abstract

This paper introduces the performance of PHV comparing other ICE, EV, FCHV. Toyota's future outlook of automobiles is also shown based on the use of PHV. It is pointed out that HV and PHV are the most realistic solutions at this time. HV technology is not only a technological bridge but the core technology for future EV, PHV and FCV.

Keywords

Toyota PHV, demonstration, cost, driving range, Prius

1. INTRODUCTION

It has become very important to obtain energy resources for automobiles. Among them, various energy resources are explored for ICE, EV, FCHV. The resources are such as oil, natural gas, coal, biomass, nuclear energy, hydro, solar, geothermal energies. They have individually will face lots of hurdles in the future. Oil is said to be dried up. However, drilling and refining technology and cost, new oil resources from deep-sea oil fields, oil shells are the challenging issue. Among the resources, oil is still the most important and useful for automobiles.

Automobiles cover different categories, from personal commuters to large trucks and buses. Among them, EV is used for short range, FCV is for mid-distance and buses, while HV and PHV can be used widely as shown in Figure 1.

	RAV4 EV	e-com
EV range	215 km	100 km
Charging time	6-6.5 hours	3-6 hours
Introduction year	1996 (Japan)	1999

Fig. 2 Vision of response to environmental and energy issues

Figure 2 shows the specification of Toyota RAV4 and e-com. EV has the following difficulties to be popularized.

(1) Limited driving distance, causing driver's anxiety
(2) Need of charging infrastructure
(3) Battery cost and life
(4) Charging time

By plotting the driving distance of EV (fully charged)

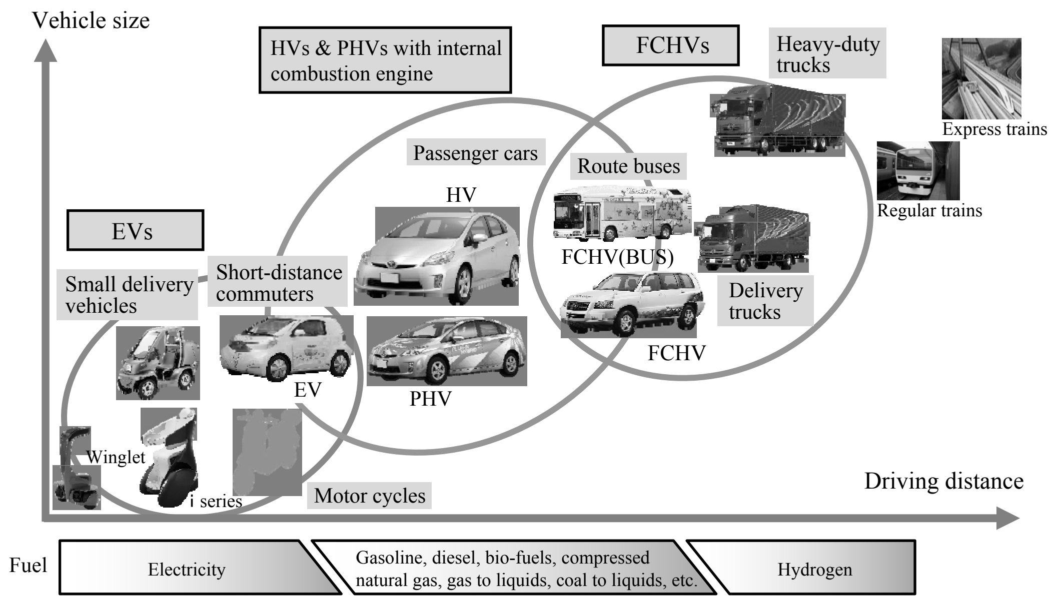


Fig. 1 A long and rich history of EV

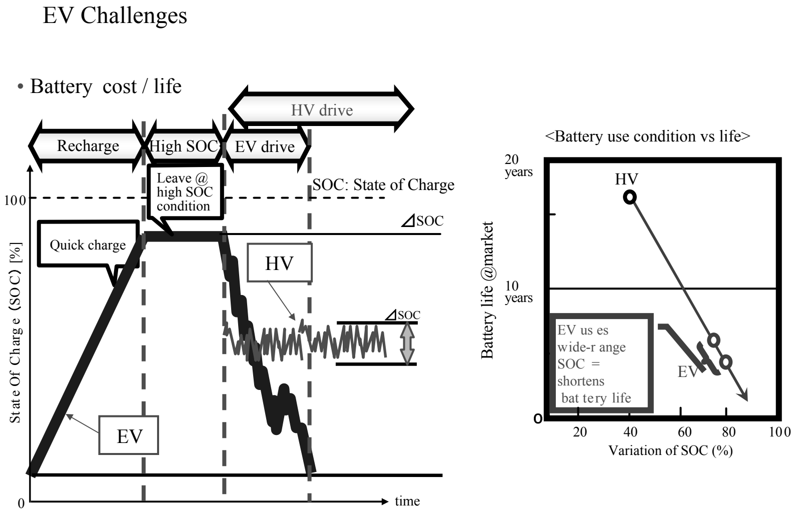


Fig. 3 Battery cost and life

and the vehicle's costs, the performance of EV is clearly insufficient compared to gasoline vehicles mainly because of the price and the limited driving distance.

Considering the battery cost and life, EV's SOC changes from zero to 100 % by charging and then comes to be zero % again by discharging as shown in Figure 3. Such a wide range of the SOC (state of charge) variation makes the EV's battery life very short. HV not only takes advantage of good mileage, but the battery life is long because of the small variation of SOC, resulting in a small running cost.

2. APPLIED BATTERY TECHNOLOGY

Figure 4 shows the annual sales of Prius and HV of Toyota. Total production of HV by Toyota was more than 2 million in 2010. Such high technologies for HV are applicable for other EV, PHV, FCHV. The following is a discussion about the features of PHV.

As mentioned in the introduction, EV has limited performances. The purpose of PHV development is to contribute to compensate the EV performance and provide an early widespread of electric-powered mobility. PHV is used as an EV for short distance, and it is used as HV by using ICE together. PHV has the fol-

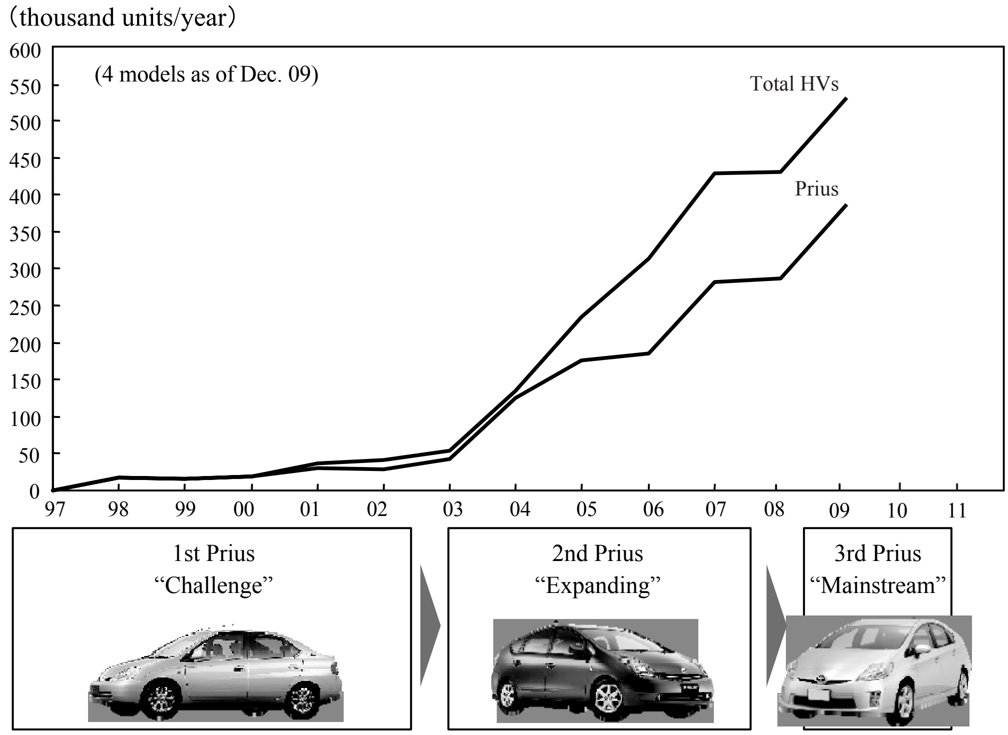


Fig. 4 Annual sales of Prius and hybrid vehicles

lowing advantages as automobiles.
(1) Without concern about the driving range
(2) Without special charging infrastructure
(3) With affordable price

Toyota performed PHV demonstrations in Japan, EU, and U.S.A. during 2007-2009. The purpose of these demonstrations is to confirm charging habits and customer acceptance. The objectives are also to verify PHV benefits, such as fuel efficiently, CO_2 and emissions.

The specification of the prototype Toyota PHV is shown in Table 1. The Ni-MH battery of 13 Ah is used. The EV cruising range is about 11 km based on LA#4 test cycle).

Table 1 '07 Prototype specifications

Engine displacement, output	1,496 cc, 57 kW/5,000 rpm
Motor output	50 kW/1,200-1,540 rpm
EV maximum speed	About 100 km/h
Battery type and capacity	Nickel metal hydride, 13 Ah
EV cruising range	About 11 km (LA#4 test cycle, TMC estimate)
Recharging source	Household electric outlet
Recharging time	1-1.5 hours at 220 V; 3-4 hours at 110 V

As shown in Figure 5, the verification testing was performed during 2007-2009 in Japan, France, and U.S.A. It was found that the fuel efficiency of PHV improved more than HV Prius and any other gasoline cars. According to the driver's feedback, they expect the EV driving range to be 10 km (22 %), 20 km (30 %), and 40 km (22 %).

The limited leasing of Prius Plug-in Hybrid started in 2009 in Japan, EU and U.S.A. The details of the Prius PHV specification are shown in Table 2. The Li-ion battery of 5.2 kWh is used and the electric consump-

Table 2 Prius PHV system specifications

	Prius PHV	Prius
Size (length/width/height)	4,460/1,745/ 1,490 mm	←
Curb weigh	1,490 kg	1,350 kg
Seating capacity	5 people	←
Motor max. output	60 kW (82 PS)	←
System max. output	100 kW (136 PS)	←
Battery (capacity)	Li-ion battery (5.2 kWh)	NiMH battery
Engine displacement/max. output	1,797 cc/73 kW (99 PS)	←
PHV fuel economy	57.0 km/l	–
Hybrid fuel economy	30.6 km/l	32.6 km/l
EV range	23.4 km	About 2 km
EV max. speed	100 km/h	55 km/h
Electric consumption ratio	6.57 km/kWh	–
Charging time	About 100 min. (200 V), about 180 min. (100 V)	–

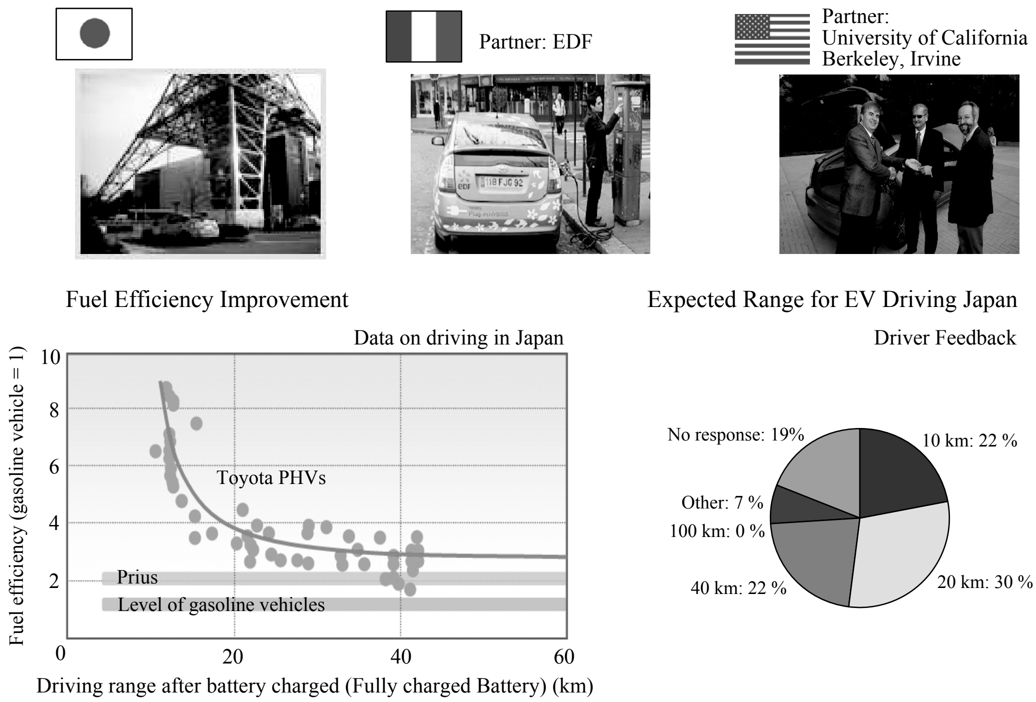


Fig. 5 2007-2009 results of verification testing

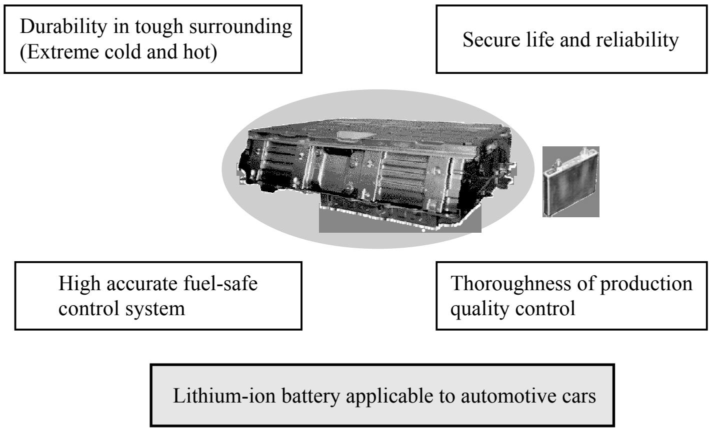


Fig. 6 Lithium-ion battery for PHV

tion rate is 6.57 km/kWh. In 2009, total sales of Prius PHV were 600 units (Japan 230, U.S.A. 150, EU 200, other 20).

The Prius PHV uses a lithium-ion battery for propulsion as shown in Figure 6. Li-ion battery has the following points for automobile applications.

(1) Durability in tough surrounding environments (extreme cold and hot),
(2) Secure life and reliability,
(3) High accurate fuel-safe control system
(4) Thoroughness of production quality control.

The durable evaluation tests of the Li-ion battery were performed in Spain, Denver, U.S.A. and Fairbanks, U.S.A. The environmental conditions were about -30 deg. C to +40 deg. C. The total range of the tests was 7.2 million miles.

Figure 7 shows the details of the battery used for base Prius and the Prius PHV. The voltage of the battery was changed to 345.6 V for PHV. The driving range of EV-mode is extended from about 2 km (Prius) to 23.4 km (PHV).

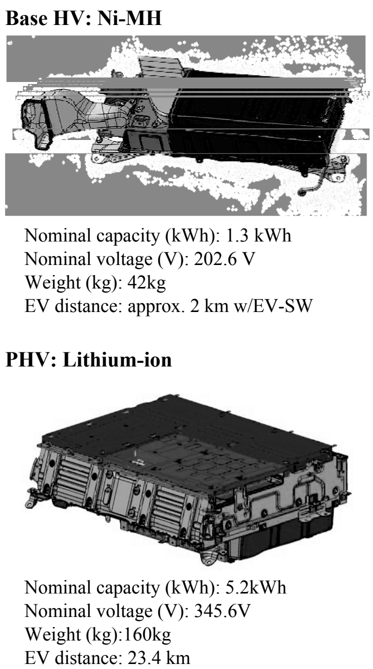


Fig. 7 Battery pack comparison

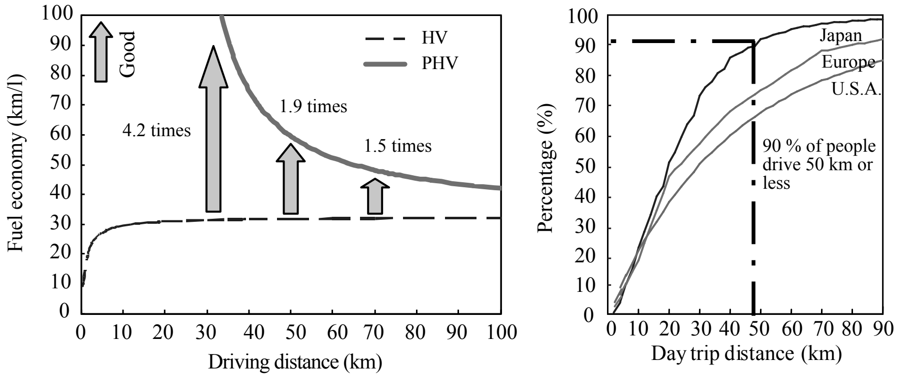
Next, the fuel economy is evaluated. Figure 8 shows the calculated fuel economy vs. the driving distance based on JC08 driving cycle. By using charged electricity from grids, the fuel economy is improved. The value depends on the driving distance. As shown in the figure, 90 % of Japanese driver's average day trip distance is 50 km, while they are about 60 km and 75 km in the EU and U.S.A. respectively. It means that the average fuel economy of Prius PHV is about 1.9 times better than that of simple HV mode driving. As shown in Figure 9, it is concluded that the average CO_2 emission reduction ratio of Prius PHV and Prius to the Prius size ICE based on the traveling distance of 30 km are 90 % and 55 % respectively. By using the EV-mode, PHV can provide an outstanding CO_2 reduction ratio to the ICE car without the anxiety of running out of electricity.

Figure 10 shows the effect of running cost reduction by using Prius PHV compared with Prius size ICE and Prius. The estimate depends on the price of electricity. In Japan, the price in daytime and late-nighttime is 23 JPY/kWh (about 20 cents/kWh) and 9 JPY (about 8 cents/kWh) respectively. When the charging is made in daytime, the cost reduction becomes 58 %, while at late-night, the cost reduction is about 77 %.

Figure 11 shows the PHV roadmap into the market. Mass production will be started in 2012. In Figure 12, the conceptual idea for the life with PHV Prius is shown.

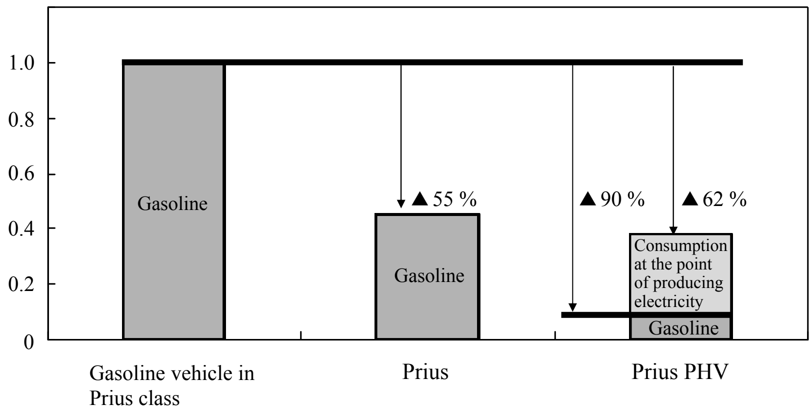
3. CONCLUSION

This concludes by introducing Toyota's outlook on future mobility. At the beginning of this paper, it was shown that it is still difficult for pure EV's to take



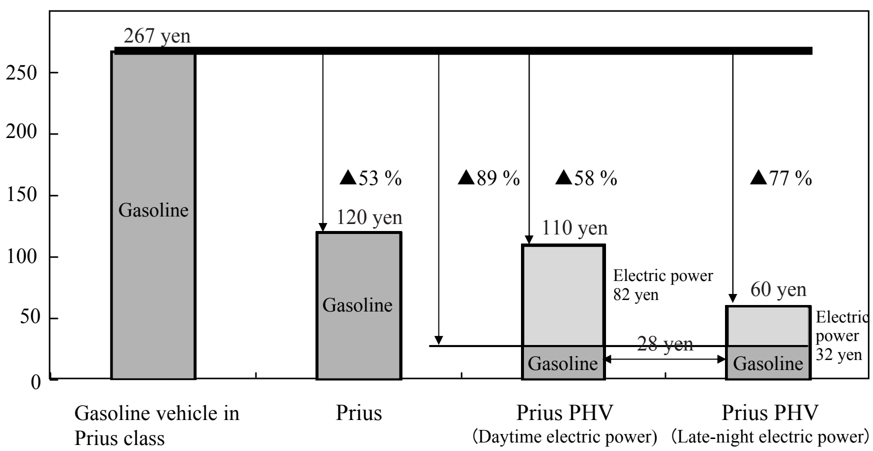
Up to 90 % of people in Japan can increase their fuel economy by 1.9X

Fig. 8 Fuel economy vs. driving distance (JC08)



Precondition
・Driving condition：traveled 30 km with JC08 mode
・Amount of CO_2 emission when generating power: condition of power generation in Japan

Fig. 9 Effect of CO_2 reduction



Precondition
・Driving condition: traveled 30 km with JC08 mode
・Petrol price: 130 yen/
・Electric power cost: daytime 23 yen/kWh, nighttime 9 yen/kWh

Fig. 10 Effect of running cost reduction

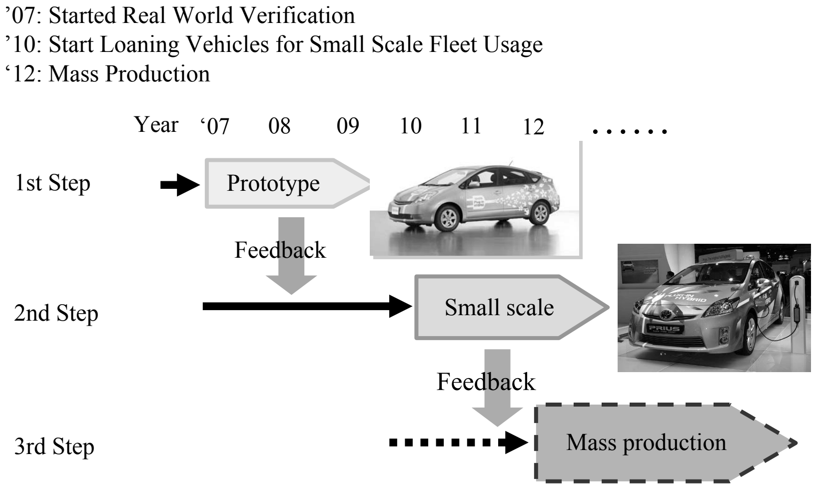


Fig. 11 PHV roadmap into the market

Fig. 12 Concept idea for sustainable mobility

part in transportation by automobiles. Toyota would like to point out that automobiles have to diverse energy sources by region and time. Toyota is committed to sustainable mobility by providing power train with various technologies (HV, PHV, EV, and FCV) in accordance with the energy mix development and customer’s needs. At this time, HV and PHV are the most realistic solutions. HV technology is not only a technological bridge but the core technology for future EV, PHV and FCV.

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