Applied Mechanics and Materials Vols. 809-810 (2015) pp 1139-1144
© (2015) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMM.809-810.1139

Submitted: 2015-02-18
Revised: 2015-04-21
Accepted: 2015-05-04

Toyota Prius – A Successful Pioneering in Hybrid Vehicle World

FILERU Iordan Florin

Politehnica University of Bucharest, Spl. Independenţei, No.313, Bucharest, 060042, România

fiordan@yahoo.com

Keywords: product development, automotive industry, hybrid electric vehicle, Toyota Prius.

Abstract. With more than 4,000,000 units sold worldwide, Toyota Prius represents a successful story in the hybrid electric vehicles industry. The paper presents the economic and social context that led to the development of this new type of car and the evolution of Toyota Prius, which arrive now at the fourth generation. This spectacular achievement was the result of an impressive R&D effort that led to hundreds of new inventions and innovations. Some of them (engine cycle, battery, hybrid system etc.) are presented in this paper, with emphasis on truly revolutionary solutions for the automotive industry, which clearly distinguishes Toyota Prius from other hybrid vehicles. Besides the innovative character, these solutions offer better environmental and economic performance, but without compromising the well-known Toyota reliability. Toyota Hybrid System receives his confirmation by the prestigious organization TUV Germany, which ranks Toyota Prius first in reliability top in the recent years. We can thus say that besides the economic and ecological advantages Prius has made an important contribution to growth and strengthening Toyota brand, being a truly successful product.

Introduction

The concerns for a sustainable development, materialized in more restrictive standards regarding the pollutant emissions, forced manufacturers to develop vehicles with internal combustion engines of increasingly performance. The introduction of catalyst, electronic engine control, variable valve timing and other systems to improve engine efficiency, have contributed to lower emissions and consumption.

In recent years, there has been a particular concern for reducing CO2 emissions due to the greenhouse effect. Cars are responsible for around 12% of total EU emissions of carbon dioxide and European Union legislation sets mandatory emission reduction targets for new cars. The fleet average to be achieved by all new cars is *130 grams of CO2* per kilometer (g/km) by 2015 – with the target phased in from 2012 - and *95g/km by 2021*, phased in from 2020. The 2015 and 2021 targets represent reductions of 18% and 40% respectively compared with the 2007 fleet average of 158.7g/km [1]

Since carbon dioxide emissions are a normal product of burning hydrocarbons, their reduction involves actually the reducing of fuel consumption. In fact, this legislation is the cornerstone of the EU's strategy to improve the fuel economy of cars sold on the European market. In terms of fuel consumption, the 2015 target is approximately equivalent to 5.6 liters per 100 km (l/100 km) of petrol or 4.9 l/100 km of diesel and the 2021 target equates to approximately 4.1 l/100 km of petrol or 3.6 l/100 km of diesel [1].

For a top global manufacturer like Toyota, producing cars with carbon dioxide emissions far below the limit is essential for further development. This help to lowering fleet average emissions and enabling sales rising, even for some vehicles beyond the limits. Concern for the future means vision, and Toyota Motor Corporation has been working constantly to develop new vehicles that satisfy both actual and future requirements.

Consequently, taking into account that the rules for emissions tend to be more stringent, in September 1993 the R&D Executive Vice President of Toyota Company created G21, a committee to research cars for the 21st century. The aim was to create a car that is resource and environmentally friendly while retaining the benefits of modern cars [2].

Toyota Prius. At the end of 1994, the G21 team made a hybrid prototype for Tokyo Motor Show 1995. The concept car is named "Prius," the Latin word for "prior" or "before" [2], thus assuming the role to smooth the way for other manufacturers and show that it works.

The hybrid car is no longer a fad but a necessity and tends to become a widespread technical solution over the next decade.

Fig. 1. Prius prototype 1996

Fig. 2. Toyota Prius NHW 10 (1997 -2000)

In 1996 starts tests with the prototype and on December 10, 1997 is launched the first model of Toyota Prius (NHW10), exclusively on the Japanese market. This is the first mass production hybrid car and was launched two years before other manufacturers.

Hybrid Electric Vehicle, a Solution for Environmental Problems

Hybrid electric vehicle represents a mixture between a conventional vehicle with thermal engine and an electric vehicle. The purpose is to combine the advantages of both types of vehicle and reducing the drawbacks.

The presence of the internal combustion engine on the vehicle ensures a higher autonomy compared with an electric vehicle and allows a small amount of batteries, with a low environmental impact and a lower cost for the vehicle. On the other hand, the presence of the electric motor allows the engine to a steady state operation close to the economic pole, avoiding as much as possible transient regimes. The energy deficit is taken from the battery and the excess is sent to the battery.

The figure below shows the energy flows related to different operating conditions of the hybrid electric vehicle. We can easy observe that at low speeds the traction is usually full electric, for better acceleration the electric motor is assisted by the engine and for medium loads, the engine works at a steady state, assisted by the electric motor. The final part reveals an excellent feature of the hybrid systems, the regenerative braking.

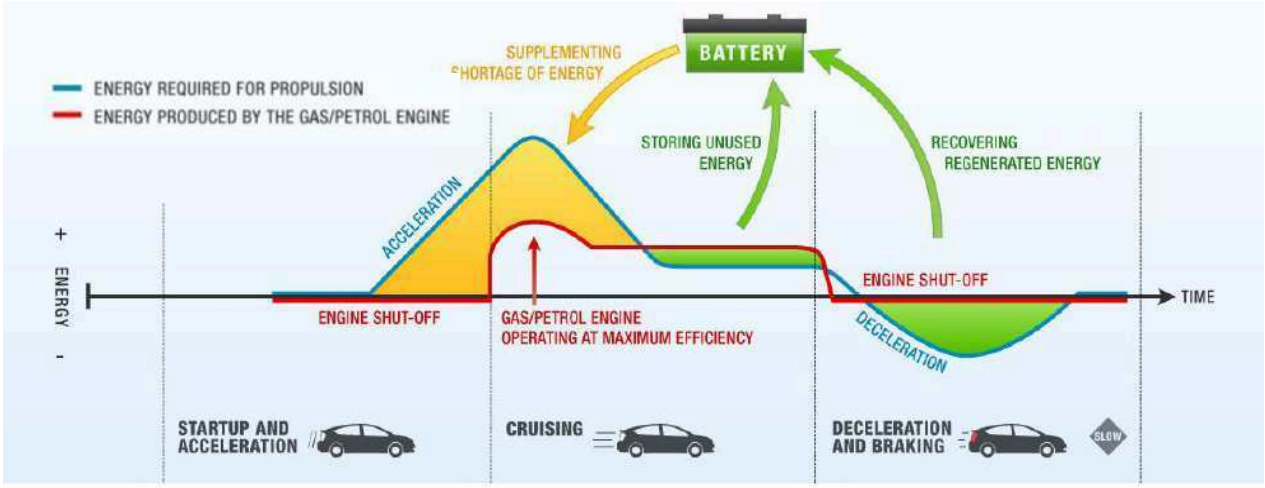

Fig. 3. Energy flows for different operating modes of hybrid electric vehicles

Hybrid Vehicle Architecture. The classical hybrid vehicle are found in two types of architecture: *parallel* and *serial*.

Series Hybrid System (Chevrolet Volt / Opel Ampera). The wheels drive is made exclusively by the electric motor. The electricity provided by the heat engine via a generator, will be distributed to the motor and/or battery. It can be viewed as an electric vehicle with range extender. For moving on short distances, if the battery power is sufficient, it is very similar to a pure electric vehicle (the heat engine does not start).

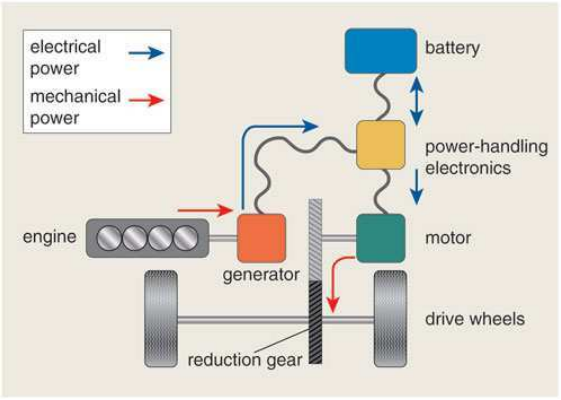

Fig. 4. Series hybrid system

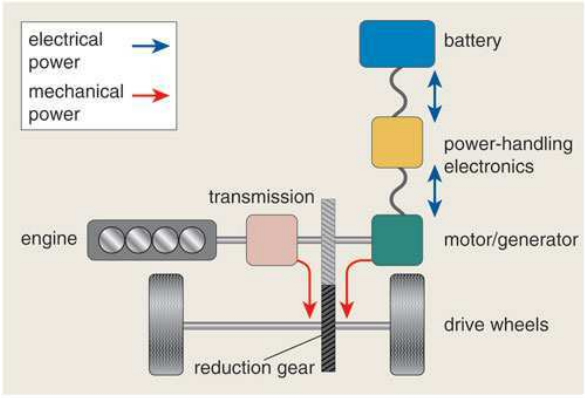

Fig. 5. Parallel hybrid system

Parallel Hybrid System (Honda Civic/Insight). As the name says, the wheels are drove in parallel by the electric motor and the combustion engine through the transmission. The electric motor comes to supplement the available power or to load extra the engine to maintain a functioning economic regime. The power supplement is taken from battery and the surplus is sent to them**.**

Special Features at Toyota Hybrid System

Toyota proposed an innovative hybrid system that sought to combine the advantages of both parallel and series hybrid systems. This mixed architecture was named *Toyota Hybrid System* and later *Hybrid Synergy Drive*. The last appellation wants to emphasize cooperation between engine, motors, batteries and the planetary gear.

The mechanical system consists in two electrical machine MG1 and MG2, an internal combustion engine, a planetary transmission and the final gear. The cornerstone is the planetary transmission, named *Power Split Device* (PSD), which is designed to split power supplied from the motor in two directions.

In one direction, the mechanical energy is converted by a generator (MG1) in electrical energy which is supplied through the power electronics to the electrical motor (MG2) and possibly to batteries. In this way the system is very similar with a serial hybrid.

In the other direction, the remaining amount of power is supplied direct to the wheels through the final gear, add to this the power supplied by the electric motor MG2, thus obtaining a function similar to that of a parallel hybrid system.

The ratio in which energy is divided by PSD between the two ways varies permanently, bringing this mixed architecture closer either to a parallel system, either a series one.

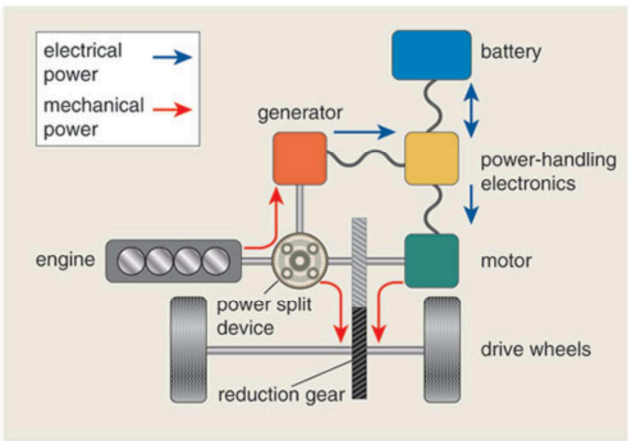

Fig. 6. Toyota Hybrid System

The Engine. Besides the special hybrid architecture and special benefits resides from this, Toyota also optimized the engine. It is a small 1.5 l engine (consider the US market) with low consumption and emissions. Unlike regular gasoline engine that works after Otto cycle, this engine works after *Atkinson cycle*. This assumes that the hot gases are kept longer in the cylinder (prolonged expansion) leading to an improvement in engine efficiency. Unfortunately it comes with a lower specific power of the engine [3], which made this cycle unusual on conventional cars. In the case of hybrid vehicle, this drawback is compensated by the electric motor, keeping the efficiency advantage.

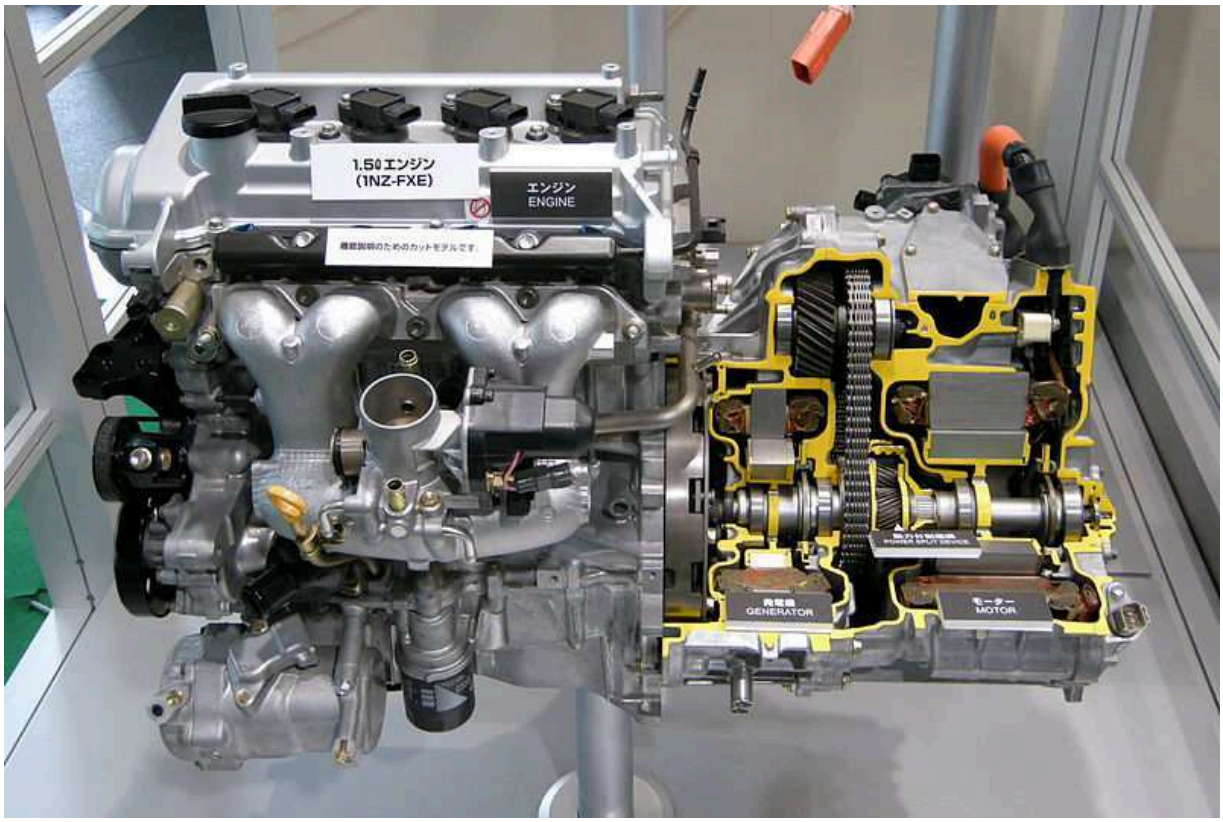

Fig. 7. General view of the Toyota Hyrid System
(Engine, Electric Motor/Generators, Planettary Gear, Transmission Chain)

Another feature of the hybrid cars engines is the fact that they can be stopped and restarted automatically during vehicle function without driver action. Considering this aspect, the coolant is kept in an adiabatic sealed vessel, to keep the engine at a high temperature and a good efficiency.

The Electric Machines. The system has two electric machines, MG1 and MG2 which function as a motor to provide torque for traction and as generator to ensure regenerative braking. Due to continuous improvement, both mass and size of these electric machines were reduced from one generation to another and their power increased.

Battery Pack. Despite progress in the development and superior storage capacity of Lithium-ion batteries, Toyota decided to remain at the Ni-MH batteries that provide a higher number of charge cycles. Besides being a very important feature for a hybrid vehicle, the prolonged battery life helps to achieve a vehicle that does not cause additional costs to users, facilitating the acceptance of this new type of vehicle.

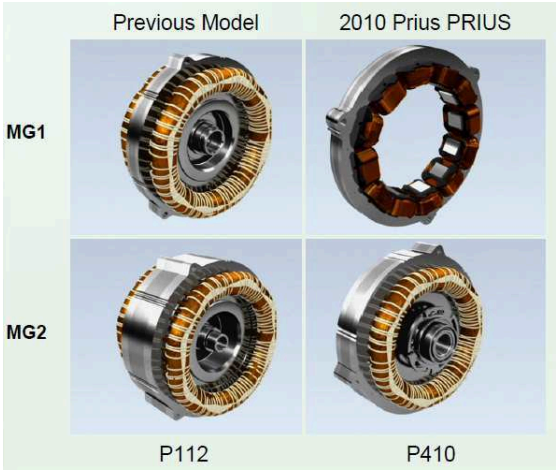

Fig. 8. Two generations of the electric machines MG1 and MG2

The Evolution of Toyota Prius

After two years on the Japanese market, Toyota launch on the US market a revised version of the Toyota Prius (NHW11), which has enjoyed great success. The car became more powerful partly to satisfy the higher speeds and longer distances that North Americans drive [4]. Like most of Toyota car's engine in 2000, Prius engine was equipped with a variable valve timing system. Air conditioning and electric power steering were standard equipment [4].

The second generation of Prius (XW20) launched in 2004 represent a real evolution of the model. It comes with a totally new shape (Fig. 9), special designed for a very low aerodynamic drag coefficient (Cd=0.26). The engine performance get better and the hybrid system feature a more powerful electric motor. The development effort, led to 530 patents for the vehicle [4].

Fig. 9. Toyota Prius 2004 (XW20)

With the launch of the third generation (XW30), 1.5L engine was replaced by one of 1.8L which provides 73 kW. The electric motors and other components of the hybrid powertrain are also smaller and more efficient (Fig. 8). The body has been improved, reaching an incredible drag coefficient Cd=0.25. Toyota states that it filed 1000 patents during the development of the XW30 Prius [5]. The fourth generation is announced for 2015.

Table 1. Toyota Prius Performances

Characteristics	**Unit**	**NWH 10 (1997-2001)**	**NWH 11 (2000-2003)**	**XW20 (2003-2009)**	**XW30 (2009 – 2014)**
Engine		1.5 L 1NZ-FXE	1.5 L 1NZ-FXE VVT-i	1.5 L 1NZ-FXE VVT-i	1.8 L *2ZR-FXE* VVT-i
Power	kW	43	52	57	73
Torque	N.m	102	110	115	142
Electric motor	V	288	273.6	500	650
Power	kW	30	33	50	60
Torque	N.m	305	350	400	207
Hibrid power	kW	-	-	82	100
EPA City	L/100km	-	5.6	4.9	4.6
EPA Highway	L/100km	-	5.7	5.2	4.9
CO2 emmision	g/km	-	135	120	111

It can easily notice a permanent increase of available power while the fuel consumption and CO_2 emissions have dropped. This reflects a permanent improvement of hybrid system efficiency.

The Prius Family. The third generation comes to prove the maturity of the model and proposes an entire range of hybrid vehicles, under Prius name. Thus with the launch of the facelifted 2011 Prius, which became *Prius Liftback*, Toyota expanded the Prius family to include the *Prius v*, an extended hatchback wagon, and the *Prius c*, a subcompact hatchback. In 2012 Toyota release the *Prius Plug-in Hybrid* or *Prius PHV* which is based on the conventional third generation with a 4.4-kWh lithium-ion battery that allows an all-electric range of 23 km.

Fig. 10. Toyota Prius v

Fig. 11. Toyota Prius c

Fig. 12. Prius Plug-in Hybrid

Success of Toyota Prius

The Prius family reached global cumulative sales of 4.8 million units by September 2014, representing 67.7% of the 7 million hybrids sold worldwide by Toyota Motor Company since 1997 [4], and represent a powerful brand which stimulate the selling of other hybrid cars made by Toyota (fig.13). Thereby, Toyota takes a big share of the hybrid US market (*69.59 %* in January 2015) [6].

The Prius was the most efficient car powered by liquid fuel available in the U.S. in 2009, based on the official rating [7].

The Toyota Prius is the first vehicle with alternative drive technology to win first place in the TÜV Report: the hybrid pioneer from Japan is top of the rankings for three-year-old vehicles with the lowest rate of major defects, namely 2.2 % [8]. 95% of all Toyota Prius models sold in the last 10 years are still on the road [9].

Fig. 13. Toyota hybrid vehicles

Conclusions

The development of Prius was a complex process which involved the adoption of new solutions but also rediscovery already known solutions (such as Atkinson cycle), their recombination to obtain a new solution (series and parallel in Hybrid Synergy Drive) and selecting the best solution, even if are not the newest (Ni-MH instead to Li-ion battery).

The Prius was an important step toward the future, proving that a hybrid vehicle is reliable and could be a car for everyday use. We can say that Prius has successfully accomplished his mission to "open the road" for other hybrid vehicles, promoting Toyota in top of the hybrid vehicle producers.

Acknowledgement

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/134398.

References

[1] Reducing CO2 emissions from passenger cars, available at http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm, accessed: 21.02.2015.

[2] Toyota Prius Chronological History, available at http://www.toyoland.com/prius/chronology.html, accessed: 21.02.2015.

[3] J.B. Heywood, Internal Combustion Engine Fundamentals, McGraw-Hill Mechanical Engineering, 1988.

[4] http://en.wikipedia.org/wiki/Toyota_Prius, accessed: 21.02.2015.

[5] http://en.wikipedia.org/wiki/Toyota_Prius_(XW30), accessed: 21.02.2015.

[6] http://www.hybridcars.com/january-2015-dashboard/, accessed: 24.02.2015

[7] http://www.fueleconomy.gov/feg/best/bestworstNF.shtml, accessed: 21.02.2015.

[8] TÜV Report 2011: Triumph for future technology, Press Release, 20.02.2010, at https://www.vdtuev.de/dok_view?oid=230509, accessed: 23.02.2015.

[9] IHS Automotive: Polk U.S. Vehicles in Operation registration statistics MY 2004-2013 as of October 2013.