Aiming at Sustainable Mobility

By Morimitsu Nobutaka

1. Introduction

The automotive industry faced its first environmental challenge – over exhaust gas control – in the 1970s. No control technology was established at that time. Emission regulations were gradually tightened in line with progress in technological development. Automakers could not produce emission control systems on a commercial basis until after their durability and reliability were fully confirmed. So they were once under fire for their slow response to environmental considerations. But the auto industry has reached a maturity level in environmental technologies. And automakers are expected to cap many years of technological achievements in the form of integrated technologies by around 2010.

The next challenge for automakers is how to cope with the issues of global environmental protection and natural resources. Automakers have the responsibility to improve the energy efficiency of vehicles and prepare for diversification of energy sources. Toyota Motor Corp. has been studying a variety of possibilities as energy sources for automobiles. Basically, the main theme is gasoline and diesel engines, and automakers are primarily responsible for developing technologies to control exhaust emissions and improve fuel economy. There are various ways to pursue an ultimate ecologically friendly car. Toyota has adopted the concept of providing "the right vehicle for the right place at the right time." The concept calls for developing a wide range of technologies in parallel, without focusing on any particular one. *(Chart 1)*

2. Hybrid Technology

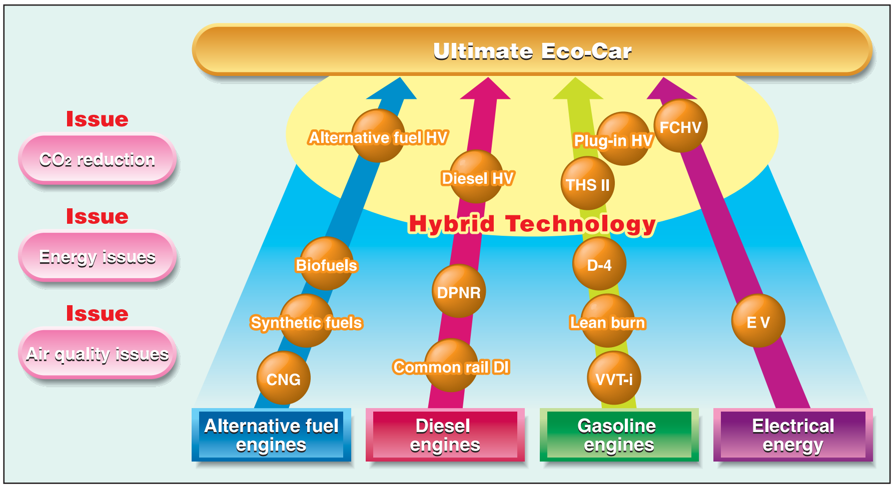
Under such a development philosophy, it is the hybrid power-train technology that can be commonly applicable to all types of motor vehicles. Automobiles will need to use electric motors as their power source in the future. Toyota believed motor / generators, inverters and their control technologies would be essential when primary power sources other than an internal combustion engine (to be called simply an engine hereafter) are used for automobiles. And around 1995, Toyota launched an ad hoc task force to develop hybrid technology by assembling personnel resources scattered across the company. Those efforts led to the debut of the *Prius* hybrid model in 1997.

The task force thought that the gasoline engine will remain the primary automobile power source for the time being. The team promoted development of elemental technologies and systems, anticipating a future "soft landing" in the use of fuel cells and solar power and in an era of electric motor-powered vehicles.

There are two major types of hybrid systems – a "series hybrid" and a "parallel hybrid." In the series hybrid, a generator converts power from an engine into electricity to power an electric motor. In the parallel hybrid, an engine and a transmission drive a vehicle while electric power is added as extra driving power in parallel. The series hybrid produces a loss in the process of converting power from an engine into electricity and then turning it into driving power. It is also disadvantageous in terms of efficiency because of a loss in the process of charging and discharging a battery. On the other hand, in the parallel hybrid, the primary source of power is limited to the engine. In addition, there is the problem that engine revolutions are controlled by vehicle speed. For the *Prius* hybrid vehicle, Toyota applied a combination of a planetary gear mechanism and two motor / generators. It is a clever system in terms of energy flow, using either or both of the parallel and series hybrid systems depending on the situation.

The *Prius* hybrid uses a motor-assisted, high-expansion ratio engine, known as the Atkinson cycle engine, which is somewhat inferior in power output but excels in thermal efficiency. Its two motor / generators as mentioned earlier offer an electrical CVT (continuously variable transmission). It offers the most efficient conditions (engine speed and torque) to provide power required to

Chart 1 Hybrid technology boosts performance for all power-train systems



Source : *Toyota Motor Corp.*

operate an engine. It cuts off the engine in lower-load operating conditions of low thermal efficiency. The *Prius* hybrid uses the motor as a generator to produce electricity by regenerating kinetic energy during deceleration. *Prius'* energy efficiency is twice that of an ordinary gasoline-powered vehicle. On top of the *Prius* series, Toyota is expanding its lineup of hybrid vehicles. The cumulative sales of Toyota's hybrid vehicles will soon reach the one million mark. We are confident that our hybrid technology will become the automobile industry's standard in the future.

3. Plug-in Hybrid

Under the *Prius* hybrid system, electrically powered driving is possible if enough battery capacity is secured. Therefore, *Prius* is used by many researchers in the world as an experimental model for the so-called plug-in hybrid vehicle in the future. The plug-in hybrid charges high-capacity batteries from electric outlets while being parked and can be operated as an electric vehicle as long as the battery permits it. In principle, the engine functions only in the event of a decline in battery capacity or when high power is required. Development of batteries of high energy density, standardization of a charging system and improvement of infrastructure for battery charging are required to materialize the practical use of plug-in hybrid vehicles. The plug-in hybrid system offers economic benefits for motorists in countries where low-priced electric power is offered, such as the United States. It also contributes to energy security. Moreover, it helps reduce carbon dioxide (CO_2) emissions in countries where the share of hydroelectric generation or nuclear power is relatively large. In other words, electricity prices and environmental factors concerning CO_2 emissions are key elements in the use of a plug-in hybrid.

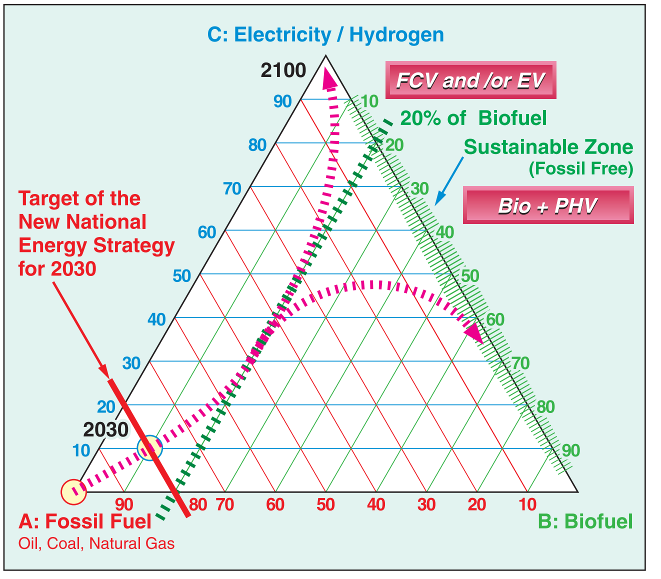
Automobiles emit no CO_2 if they are powered with such energy sources as electricity and hydrogen. However, CO_2 is emitted in the process of generating electricity or producing hydrogen. Some countries depend heavily on coal in generating electricity. These countries need to burn coal efficiently and store emitted CO_2 underground. CO_2 emissions must be considered on a "well-to-wheel" basis, or from energy production to consumption for vehicle driving. Biomass fuel (biofuel) needs similar consideration. That is to say, biomass energy is not necessarily carbon-neutral at any time. CO_2 emissions at the stage of biofuel production should be taken into consideration.

4. Direction toward Sustainability

Next, let me touch on the direction of energy for automobile use in an ultra-long-range perspective. *Chart 2* breaks down automobile energy sources into fossil fuel, biofuel and electricity, in a triangular coordinate. It is a convenient chart that offers a chance to consider the concept of future energy regardless of time elements. Currently, automobile energy depends almost wholly on fossil fuel. Japan's national energy strategy calls for reducing its oil dependence by 20% in 2030. To achieve the target, it is realistic to use biofuel, such as bioethanol and biodiesel fuel produced through hydroprocessing of oils and fats, for half of the 20% figure, with the remaining 10% to be covered by the development and spread of plug-in hybrid vehicles. At the 33rd summit of the Group of Eight (G-8) countries in Heiligendamm, Germany, Japanese Prime Minister Abe Shinzo proposed cutting CO_2 emissions by 50% by 2050 from present levels. But it is still a passing point. From the viewpoint of sustainable mobility, the ultimate target is desirably to become free from fossil fuel.

Thinking of future automobile energy sources, biofuel materials can cover up to 20-30% of oil fuel at most on a global basis for the time being, although there are some countries wishing to spread and expand the use of biofuel, such as

Chart 2 Automobile energy sources



Note : 3D plane defined by A+B+C=1. The chart permits trends to be discussed without any constraint of the temporal axis.
Source : Toyota Motor Corp.

Brazil and Sweden. To depart from fossil fuel, raising the share of electricity for automobile energy is an important idea. Which path future automobile energy sources will take on the triangular coordinate depends on future technological breakthroughs. If such next-generation biofuels as cellulose ethanol, lignin-based hydrocarbon and BTL (bio-to-liquid) fuel are provided at low costs, the future energy course will take the path free of fossil fuel that is close to biofuel. If batteries of high-energy density or low-cost fuel cells are put into practical use, it will take the fossil fuel-free path close to electricity.

Nonetheless, fossil fuel will no doubt remain the mainstay energy source for some time in terms of energy supply capacity and energy economy. It is important to consume precious oil cautiously by utilizing fuel-efficiency technologies like the hybrid system. In the future, the share of oil use as petrochemical materials should rise under the "noble use of oil" concept. Biofuel or electricity for plug-in hybrid vehicles will gradually replace oil as the main energy source for combustion use. JS

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