POINT OF VIEW

Powering Sustainable Mobility: Roadmaps of Electric, Hybrid, and Fuel Cell Vehicles

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I. INTRODUCTION

Since the oil crisis first began back in 1973, the world has started paying more attention to the decreasing supply of oil and the ever-increasing rate of consumption. (As we go to press, the current market price of oil is down significantly and the U.S. automotive industry is in danger of financial failure.) Without a doubt, however, the general trend remains unchanged: the amount of fossil fuel resources is limited but oil demand has increased significantly and will continue to do so in the future. The transportation sector is the largest energy sector and thus the most important market for petroleum products. Furthermore, it has demonstrated the highest growth rate of oil consumption over recent decades. This growth has largely come from new demand for personal use vehicles powered by the conventional internal combustion engine (ICE).

In this paper, we would like to look at the technologies that offer the best alternatives to the current gas-guzzling internal combustion engines of today's automobiles and attempt to suggest a way forward for new innovation and development. We will do this by presenting some guidelines or roadmaps that include technical and commercial considerations to successfully achieve our goals of better and cleaner transport.

II. THE GROWTH FACTOR

In 1992, our planet had well over half a billion cars and trucks. By 2050, it has been estimated that their number will exceed 2.5 billion. If these vehicles were all to be powered by gasoline and diesel fuels, our world would come to a standstill. Therefore, one of the most pressing demands of our time is for alternative fuels, especially for urban transportation systems. We have to develop this technology; there is no

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alternative. Oil and gas take millions of years to form but might be nearly exhausted in the next 40–60 years. Air pollution is also another important concern. If this fossil-fuel trend continues from conventional cars, the sky will become permanently gray. We will have to go through this darkened world to find the dawn. It is the time to think where we are now and where we are going, and we must do so with the long-term picture of diminishing resources in mind, and not the constantly fluctuating price of oil.

Government agencies and organizations therefore have been developing ever more stringent standards for fuel consumption and emissions. Battery-powered electric vehicles (BEVs) look like ideal solutions to tackle this energy crisis as well as a means to reduce pollution and the buildup of carbon dioxide, which contributes to global warming. Electric vehicles have zero oil consumption and zero emissions. However, the high initial cost, short driving range, and long charging times have proved to be their primary limitations. Hybrid electric vehicles (HEVs) were developed to overcome some of these disadvantages of both conventional internal combustion vehicles as well as those fully electric vehicles.

III. HYBRID ELECTRIC VEHICLE TECHNICAL ROADMAP

An HEV combines a conventional propulsion system with an electric propulsion system. It has a significantly longer driving range than that of a battery electric vehicle. It shows improved fuel economy compared with conventional ICE vehicles. The ICE can be stopped if the vehicle is at a stop. The electric drive system in an HEV can optimize the efficiency of the ICE and thus reduce the oil consumption and emissions. The kinetic energy can be regenerated during braking and down-slope driving. A certain range of silent operation with zero emissions is possible when the hybrid is driven in the pure or fully electric mode. The pure electric driving range can be extended if the battery is recharged by connecting a plug to an electricity grid. This kind of HEV is called a plug-in hybrid electric vehicle (PHEV).

Although HEVs can contribute to meeting the challenges in road transport regarding the energy crisis and pollution, there have been mixed results with regards to acceptance by the public. (This appears to be largely an inverse function of the current price of gasoline.) However, three main challenges for vehicle buyers are clearly evident: 1) their high purchase price, 2) the reliability and the warranty related to the lack of electricians in car-repair shops, and 3) the general lack of confidence in the new electric powered vehicle technology. This last concern includes safety issues related to the introduction of high voltage into the vehicle, the electromagnetic interference caused by high-frequency high-current switching, and so on.

IV. FUEL CELL VEHICLES

Besides hybrids, fuel cell vehicles (FCVs), which use fuel cells to generate electricity from hydrogen and air to propel the vehicle, are also potential clean vehicles for perhaps a few decades from now. The electricity is either used to drive the vehicle or stored in an energy storage device, such as a battery pack or supercapacitors. They only emit water vapors and have the potential to achieve high system efficiency.

The major issues related to FCVs are 1) the high production cost and 2) the short life cycle of fuel cells. Future research aims to reduce the cost of platinum catalysts or to replace the platinum catalyst by a new material. It is also necessary to further develop an electrolyte membrane to improve the durability of the fuel cells so they can last for longer than ten years. Moreover, hydrogen onboard storage needs improvement of energy density so that the driving range can be longer than 500 km, the equivalent range of an ICE.

V. HOW CAN WE MOVE FORWARD?

In some markets, hybrid electrics will continue to penetrate more vehicle segments, especially in the developed markets. There is a potential for some form of hybrid to be applied to all vehicle segments, but this is unlikely to occur by the 2015 time frame. Let us consider some possible roadmaps of how we might move forward.

Fig. 1 shows the two potential ways that are possible in a powertrain roadmap of alternative fuel vehicles. The first way is to focus on the development of advanced ICE vehicles by improving the combustion with the aid of automotive electronics and by developing new alternative fuels (Fig. 2). The second way is to focus on advanced electric drive and its optimized integration with ICE. A company may opt to produce a whole spectrum of hybrids from micro to strong hybrids for various types and sizes of vehicles (Fig. 3). Another company may opt to focus on micro or mild hybrids for certain types and sizes of vehicles. There are three important issues related to the development of BEVs, HEVs, and FCVs: the various propulsion topologies, the energy management of such complex architectures, and the development of more efficient energy storage devices.

VI. VEHICLE ARCHITECTURES

Vehicle architectures are then the first issue. There are basically three types of architectures in HEVs: series, parallel, and series-parallel. Among these, series-parallel with planetary gear architectures can operate as series architecture or parallel architecture; hence it has a "maximum" architecture, which can maximize the optimization in fuel consumption, emission, and performance. A hybrid using electric variable transmission (EVT) can behave like series-parallel with planetary gear, which means it can operate like series or parallel hybrid and achieve maximum optimization. In this kind of hybrid, the continuous

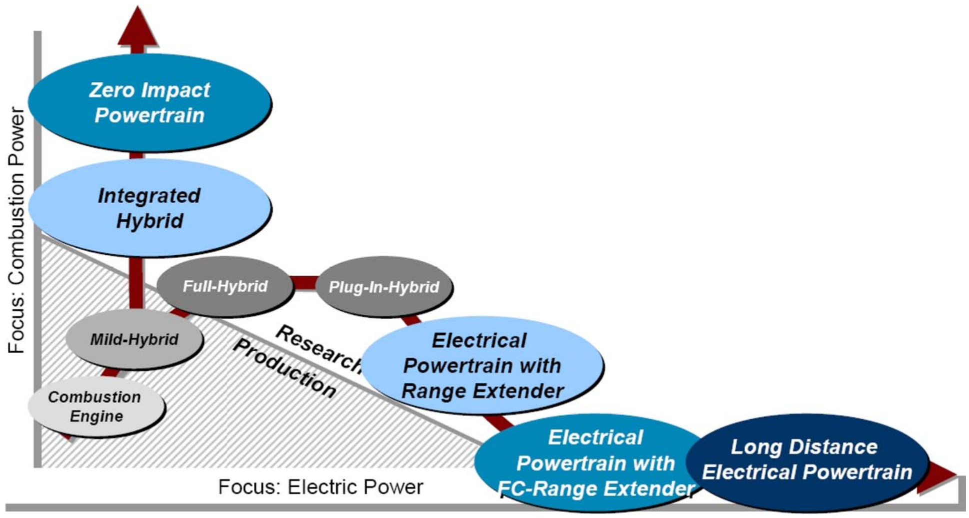

Fig. 1. ***Two-way powertrain roadmap (courtesy of Volkswagen).***

variable transmission is implemented by electrical machines rather than mechanical transmission. Therefore, it is more flexible in the control of torque and speed in order to achieve better performance. The series hybrid configuration is mostly used in heavy vehicles, military vehicles, and buses. On the other hand, parallel and series-parallel are mostly used in small and medium automobiles, such as passenger cars and some buses.

The hybrid engineering philosophy is $1+1>2$. The integration of engine propulsion and motor propulsion fully sizes the advantage and flexibility of electrical, electronic, and control technologies. It not only increases energy efficiency and reduces emission but also improves driving comfort and safety. Just like a mule is the hybrid of a horse and a donkey, the mule possesses the best DNA of the horse and the donkey; hence it is more powerful and has better endurance. In an HEV, the prime key technology is the control algorithm and optimization for energy management and, thus, the development of efficient energy storage subsystems.

VII. COMMERCIALIZATION ROADMAP

Cost reduction, reduction in size and weight, high performance, and support of all stakeholders are the major issues for the successful market penetration of BEVs, HEVs, and FCVs. The support from government agencies, academic institutions, consumers, major components suppliers, and oil, gas, and electricity utilities is critical. The key issues are: What economical or other benefits can the users get? What environmental benefits can the society enjoy? Is it fun to drive without

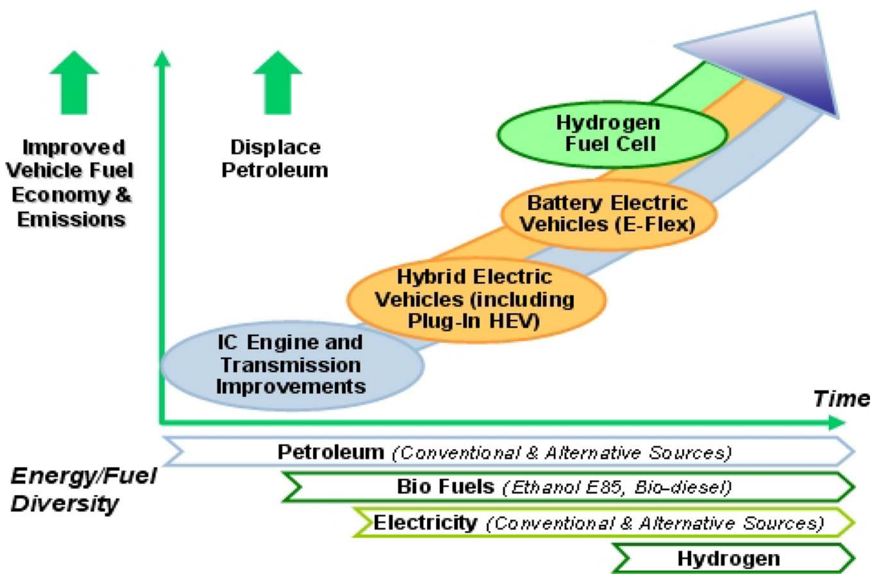

Fig. 2. ***Advanced propulsion technology strategy (courtesy of GM).***

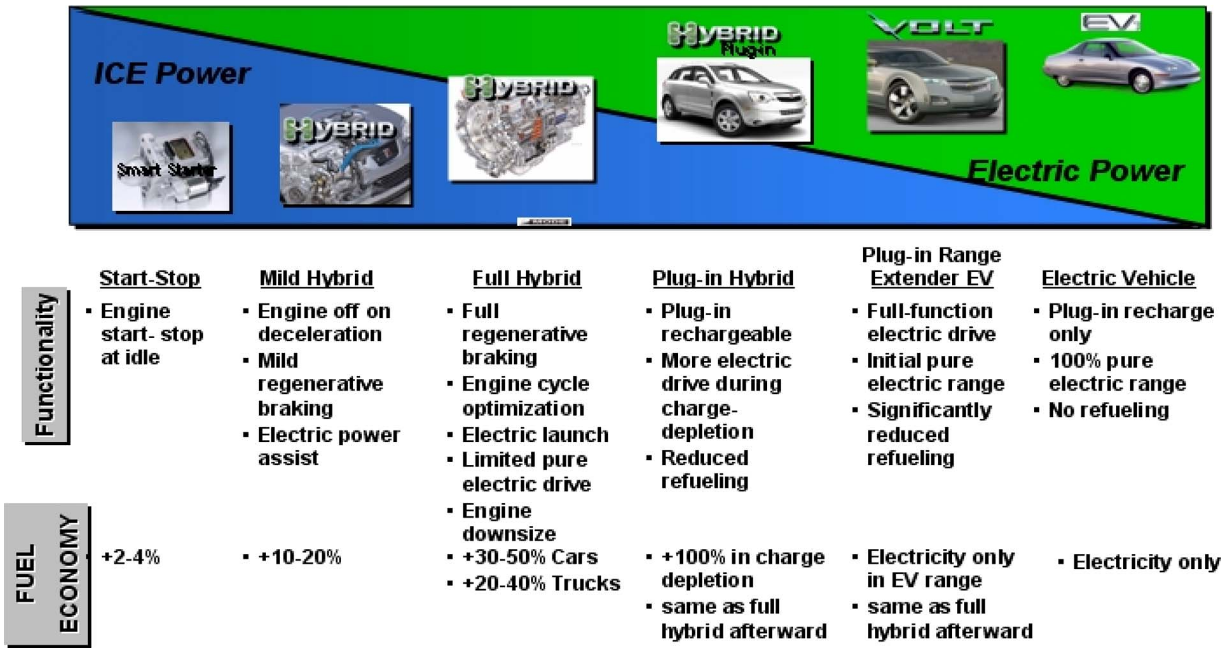

Fig. 3. *Features of hybrid powertrain technologies (courtesy of GM).*

any negative point as compared with conventional vehicles? Suitable legislative measures and incentives are essential in order to effectively reduce carbon dioxide emission and reduce dependence on oil. Levers that impact the penetration of electric and hybrid vehicles include fuel price, regulation and taxes, local legislation, purchase incentive, ownership intangibles such as green image and fun to drive, public education, etc. Table 1 shows a commercialization roadmap of HEVs and FCVs.

VIII. CONCLUSION: LOOKING AT A SUCCESSFUL HYBRID DEVELOPMENT ROADMAP

In a world where environmental protection and energy conservation are growing concerns, the development of electric, hybrid, and fuel cell vehicles has taken on an accelerated pace. The dream of having commercially viable electric and hybrid vehicles is becoming a reality. It is important that the automobile companies have both proper technical and commercialization roadmaps hand-in-hand. The company

Table 1 Commercialization Roadmap of HEVs and FCVs

Year	
2007	More automakers launch own hybrid systems
2007	Tighter diesel standards adopted in US
2007	Diesel hybrids introduced
2007	Advanced gasoline engines introduced
2008	Toyota launches 3rd generation Prius, creating new benchmark
2008	Full hybrids become standard in US
2008	Lithium-based hybrids launched
2008	Tighter diesel standards adopted in Europe
2009	Plug-ins commercialized using high-power batteries
2010	OEMs will have introduced over 50 hybrid models in US
2010	Toyota offers hybrids as option on all models
2010	Hybrids take 10.6% share of new sales globally
2011	Plug-ins commercialized with electric driving range of 5 to 10 miles
2012	Toyota introduces 4th generation Prius
2012	Tougher emissions controls due to climate-change concerns
2013	Plug-ins driving range increases to 20 to 30 miles
2013	Advanced materials introduced
2013	Automakers offer hybridization as option on most models
2014	Nickel battery displaced
2015	Hybrids take 50% share of new sales globally
2020–25	Plug-ins driving range increases to >50 miles
2020–25	Fuel-cell vehicles commercialized
2030	Hybrids take 85% share of new sales globally

Source: AllianceBernstein

CEOs should take the lead in drawing the technical and commercialization roadmaps. This task should not just be dedicated to the R&D departments or sales departments, since this is a major project that will have major effects on the company and society. In addition to having clear objectives, the senior management should also have holistic and creative thinking to oversee the progress of the project.

The following represents a successful experience of a major automobile company in the development and commercialization of hybrid vehicles.

- Have correct strategic plans, including near term, medium term, and long term.
- Have sufficient funding to support the development plan.
- Have innovative core technology, particularly innovative technology related to the integration of automotive technology with electric drive technology and energy storage technology.
- Have proper technical and commercialization road maps.
- Understand state-of-the-art technology and the tradeoff among technology, cost, and market. Understand the different situation in the performance benefit versus cost characteristics in electric vehicles, micro hybrid vehicles, mild hybrid vehicles, strong hybrid vehicles, plug-in hybrid vehicles, and fuel cell vehicles, respectively.
- Thoroughly understand the market demand and the required infrastructure and services. ■

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