Zero-Emission Vehicles Penetration into the ASEAN Market: Challenges and Perspective

Bui Văn Ga, Bui Thi Minh Tu, Pham Xuan Mai, Bui Van Hung, and Le Hoang Phu Pham

Abstract Electric vehicles (EVs) can be considered as zero-emission means of transport. They include battery electric vehicles (BEVs) and hydrogen fuel cell electric vehicles (HFEVs). EVs exhibit several advantages such as high efficiency, suitable torque characteristics, no noise, and no pollution emission in operation. However, the common disadvantages of EVs are related to the low onboard energy density storage, short cruising range, high initial cost, and great investment for charging/fueling infrastructures. Thanks to the development of new technologies and materials, the energy density of the battery has been improved, and the charging time is shortened. The hydrogen storage technology under the form of hydride has also achieved significant progress in recent years. The cost of BEVs and HFEVs drops continuously, and it is predicted that EVs will become cheaper than traditional vehicles in the next decades. The penetration of zero-emission vehicles into the ASEAN market can be forecasted in three phases. In the long-term, with the progress of the hydrogen-based economy, HFEVs may be dominant.

Keywords Electric vehicles · Zero-emission vehicles · Lithium-ion battery · Hydrogen · Fuel cell

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1 Introduction

The transport sector generates about a quarter of the global greenhouse gas (GHG) emissions, of which more than 70% of these emissions are related to road transport. To reduce GHG emission according to the COP 21 Paris Agreement, many countries have developed a sustainable transportation strategy, in which ultra-low carbon vehicles are of special attention [1]. Recently, the governments of the UK, France, Germany, the Netherlands, and some other countries have announced a roadmap to stop the production of vehicles powered by internal combustion engines (ICEV) from 2025 to 2040 [2]. In ASEAN Region, the Singapore government sets a plan for clean energy application on all road transport sectors by 2040 [3]. In the near future, electric vehicles (EVs) will substitute traditional ICEVs.

There are technically two types of EVs: battery electric vehicles (BEV) and hydrogen fuel cell electric vehicles (HFEV). Each type has its advantages and technical challenges. Which EVs will dominate the market in the future depends on technological advancements that help them overcome the challenges.

BEVs exhibit high energy conversion efficiency, no emissions when operating, good acceleration, low operating costs. However, they face huge challenges such as low energy storage capacity, long charging time, short cruising range, high vehicle cost, and low battery life. Compared with BEV, HFEV is also a zero-emission vehicle, but shorter fueling time (like traditional gasoline cars) and a longer cruising range. The GHG emissions in the total life cycle of HFEV are lower than that of BEV. However, the cost of HFEV is still high, and the hydrogen supply infrastructure demands huge investment. Those are the barriers that limit the current use of this type of vehicles.

The two types of EVs have a common technical problem related to onboard energy storage. Improving energy storage capacity and reducing battery charging time are major research directions for BEVs. For HFEV, the current researches focus on hydrogen storage technologies and development of new material for fuel cell production in order to reduce the overall cost of the vehicle. Metal hydrides for hydrogen storage have attracted the attention of numerous researchers around the world. While effective onboard energy storage technologies have not been found for EVs, hybrid vehicles can be seen as a viable solution. There are several powertrain schemas for hybrid vehicles, such as internal combustion engine-battery electricity, internal combustion engine-hydrogen fuel cell, BEV-HFEV…

This paper presents a resume of the current challenges facing BEV and HFEV and the technical solutions that support their development in the future. The perspective of EVs penetration in ASEAN countries is also analyzed.

2 Battery Electric Vehicle (BEV)

- ***Energy storage of batteries***: The energy storage capacity of lead-acid and nickel-cadmium batteries has not improved much since they were put into practical use, while lithium-ion batteries have improved significantly. The current development of the lithium-based battery is to use a solid electrolyte instead of an electrolyte solution. This technology helps to improve the ion conductivity of lithium, thereby significantly improving the battery's energy density. The lithium-air battery has a very high theoretical energy density (3458 Wh/kg [4]), comparable to the energy density of gasoline. It is a promising battery [5], allowing for an extended cruising range of BEV up to 800 km. Currently, the lithium-air battery can provide an energy density of 1214 and 896 Wh/L [4]. Figure 1 illustrates the storage capacity of all types of batteries. The energy density of lithium-ion is expected to double in the next decade [6].

Figure 2 shows the energy storage capacity and cost of lithium-based batteries today and in the next 10 years. Currently, the storage capacity of the battery is about 300–350 Wh/kg depending on the cathode material. It is expected that in the next 10 years, the storage capacity of the battery will be about 500–700 Wh/kg with new generation batteries. The cost of a lithium-based battery has decreased continuously from 380 USD/kWh in 2015 to about 70 USD/kWh in 2030.

- ***Current charging time***: Currently, there are three levels of the charging system [5] (Fig. 3). Level 1 charger with AC voltage 120 V or 220 V, charger capacity is usually 1.4 kW with charging current of 15–20 A. This is a typical charger used for BEVs charging at home. Most chargers today are Level 2 chargers, with AC voltage of 240V, capacity from 6 to 18 kW, charging current from 16 to 40 A. This level requires a separate electrical network for the BEVs. Level 3, also known as fast charging, typically goes up to 800 V with a capacity of up to 400 kW. This level requires a special electrical network and strict safety measures. Currently, it takes normally 5–8 h to fully charge the car's 60 kWh battery. A quick charge can help recharge an electric vehicle's lithium-ion battery in about 10 min.

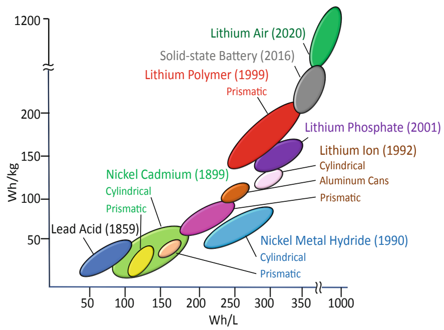

Fig. 1 Energy density of batteries

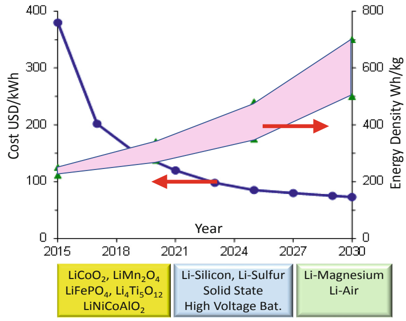

Fig. 2 Current lithium-based battery storage capacity and cost, and forecast to the year 2030 [7, 8]

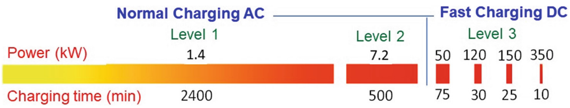

Fig. 3 Charging time for electric cars with a battery capacity of 60 kWh during normal and fast charging [10]

The charging speed is denoted by xC and the charging time is 60/x in minutes. Many attempts are trying to increase the charging speed from 1C to 6C corresponding to reducing the charging time from 60 to 10 min [9]. Thanks to the efforts of EV manufacturers, a 10-min charge-up time threshold is very feasible in the next decade.

- ***Wireless charging technology***: Inductive charging uses electromagnetic induction between a transformer specially designed to transmit energy (Fig. 4). This technology has the outstanding advantage of being safe. However, the charging efficiency is highly dependent on the vehicle location and usually lower than the traditional charging system [5]. Cars need to be specially designed to be able to inductively charge and the electronic systems in the vehicle can withstand the effects of electromagnetic radiation.
- ***Swapping batteries solution***: Fast charging requires a huge investment in the network of charging stations. This cannot be realistic in the short term, especially in developing countries. In that condition, swapping battery technology can be a suitable solution for fast charging. Instead of having to wait for charging, the out-of-charge battery is replaced by a fully charged one at swap battery stations (Fig. 5). The battery replacement can be done in a very short time, but the EVs

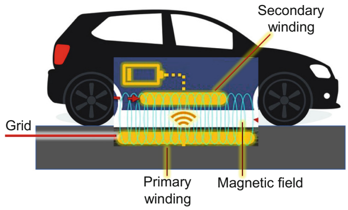

Fig. 4 Wireless inductive charging

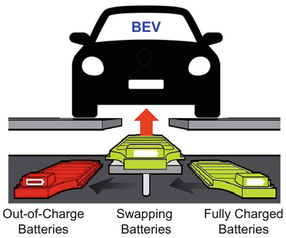

Fig. 5 Exchanging batteries

must be specially designed for interchangeable batteries. It is necessary to have cooperation between EV manufacturers to standardize batteries so that they can be installed for different types of EVs to reduce the scale of investment in swap battery stations.

- ***BEV cost***: EV manufacturers are trying to reduce the production costs of BEV to increase their competitiveness compared to traditional vehicles. Figure 6a shows the cost of a mid-sized BEV [11]. In 2016, battery packs accounted for 48% of the BEV's cost. The share of battery costs has decreased gradually thanks to the advancements in research and development mentioned above. Currently, the cost of battery still accounts for 36% of the total cost of the car and is forecasted that by 2030, the battery cost will only account for 18% of the total cost of BEVs. Figure 6b compares the cost sharing of the main components of BEV and ICEV [12]. The powertrain contributes to the majority cost of the BEV. As battery prices become cheaper and cheaper, electric cars will become lower than those powered by internal combustion engines of the same size in the near future.

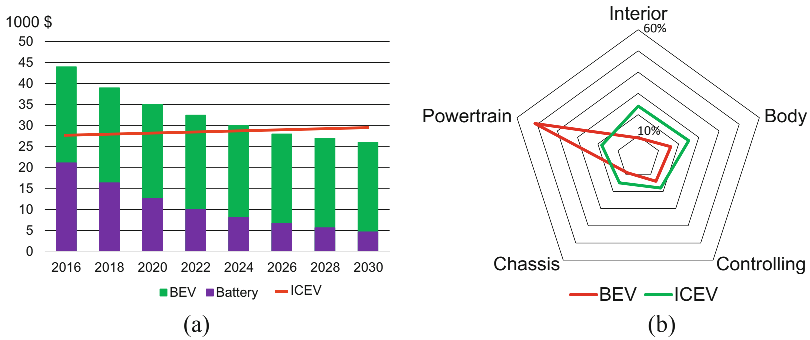

Fig. 6 Price comparison of a mid-size BEV and ICEV (**a**) [11], and cost sharing of the main vehicle's components (**b**) [12]

3 Hydrogen Fuel Cell Electric Vehicles (HFEV)

- ***Hydrogen storage technologies***: Storing hydrogen onboard vehicles is one of the major challenges of the HFEVs. Hydrogen has high gravimetric energy density but very low volumetric energy density. Currently, hydrogen compression technology up to a pressure of about 700 bar is mainly used to store hydrogen onboard HFEVs. This technology exhibits short refueling time, and high hydrogen discharge flow. The main disadvantages of this technology are a high investment in fuel supply infrastructures and safety concerns related to high-pressure hydrogen tanks.

Hydrogen storage in liquid state can significantly improved energy density. But this technology consumes a lot of energy to liquefaction/evaporation. It is estimated that these processes require about 30% of the hydrogen energy contained in the storage system [13]. Besides, the phenomenon of hydrogen boil-off is also a challenging problem of hydrogen storage in the liquid state.

The material-based hydrogen storage technology offers an effective solution for hydrogen application on vehicles [14]. Hydrogen can be stored in numerous metal hydrides which operate at low temperature (LT) (20–100 °C) or at high temperature (HT) (200–400 °C) [15]. The LT hydrides have a relatively low hydrogen storage density, about 1–4% by mass. The HT metal hydrides have a greater hydrogen storage density, about 7.6% by mass, but the desorption temperature is higher than 300 °C. Lightly complex metal hydrides can operate at relatively low desorption temperatures (<150 °C) with an efficient hydrogen storage capacity of about 5.6% mass fraction. In general, the properties of metal hydrides vary in a wide range. Depending on the required storage conditions, the right materials can be chosen.

Figure 7 compares the energy density of various hydrogen storage technologies and lithium-ion batteries with the data extracted from [14]. It can be seen that hydrogen storage solutions, either physical-based or material-based technology, offer a much greater energy density than batteries. This is a great advantage of HFEV over BEV. Figure 8 shows the suitability of different types of vehicles according to usage conditions. The BEVs are suitable for light cars with a short cruising range. In this condition, the cost per kilometer of the BEV is low. But for passenger cars, bus and long-range trucks, HFEV offers many advantages. When BEVs and HFEVs have

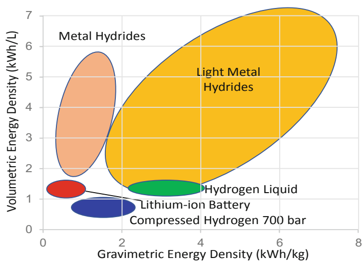

Fig. 7 Comparison of energy storage density

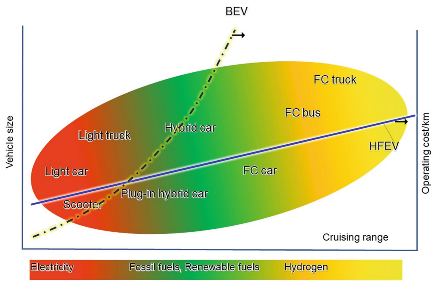

Fig. 8 Usage characteristics of EVs

not been widely developed, hybrid cars, thermo-electric hybrids are the intermediate solution, suitable for the medium cruising range.

- ***Fuel cell cost***: The main factor contributing to the overall cost of HFEVs is the amount of platinum needed to make the fuel cells. Many researchers have focused on using cheaper advanced materials to replace platinum. Thanks to those results the fuel cell's price has reduced by about 65% without affecting its performance over the past decade. In the other hand, the hydrogen electrolyzer's price is also dropped continuously, resulting in a reduction in hydrogen fuel's price. It is expected that the cost of HFEVs will be lower than those of BEVs or ICEVs in the next few decades [16–18].

4 Perspective of EVs Penetration in ASEAN Countries

The above study shows the realistic conditions to support the development of EVs. For BEVs, the energy storage density of new generation batteries will increase, and fast charging technology will thrive. For HFEV, the material-based hydrogen storage technologies are very well developed, the cost of fuel cell and hydrogen production is decreasing. The market sharing of light vehicles with different powertrain by 2030 and 2050 is illustrated in Fig. 9 with the data extracted from IEA (http://www.iea.

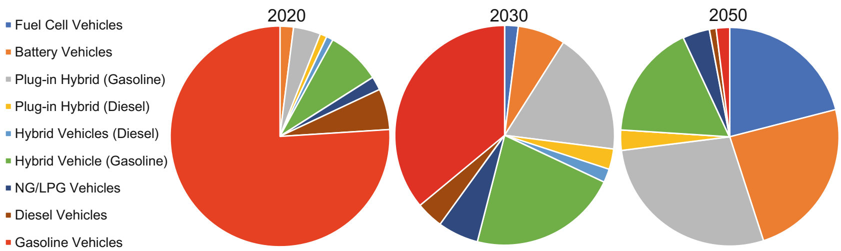

Fig. 9 Automobile market share forecast by 2050

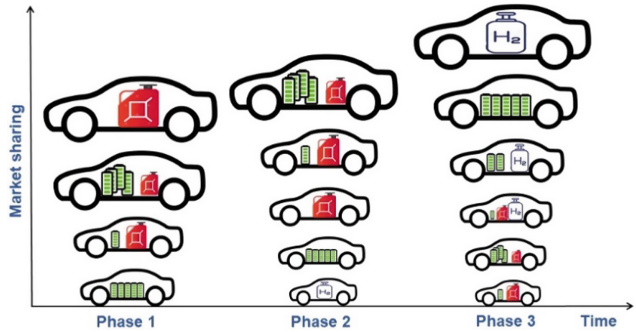

Fig. 10 Outlook of zero-emission vehicles penetration in the ASEAN market

org/). According to the IEA, the plug-in hybrid and the hybrid vehicles will strongly penetrate the market by 2030. The BEVs, HFEVs and plug-in hybrid, hybrid vehicles will substitute entirely the ICEVs by 2050. It is clear that by the second half of this century, the ICE will no longer be the main driving force for vehicles.

Based on the above analysis, the expected roadmap of zero-emission vehicles penetration into the ASEAN market maybe divided into 3 phases as shown in Fig. 10. In phase 1, the BEV, plug-in hybrid and hybrid vehicles share the market with ICEVs. In phase 2, HFEVs will be introduced into the market, the ICEVs will be substituted gradually by plug-in hybrid, hybrid vehicles, and BEVs. In phase 3, the HFEV and BEVs share the majority of the automobile fleet, the others are different types of hybrid vehicles. The ICEVs will entirely disappear in road transport.

The penetration of EVs into the market depends not only on the attractiveness of the vehicles but also on the service infrastructures and the policy of the government. The petroleum distribution system, which has existed for nearly a century, does not disappear easily when the new energy supply system is not competitive. Thereby, the transition from ICEVs to EVs requires a certain time. In the transition phase, plug-in hybrid vehicles can be suitable means of transportation. In a plug-in hybrid vehicle, the electric energy portion will increase gradually, and the fuel energy contribution will decrease in line with the development of EVs. This phase of the plug-in hybrid vehicles is long or short depending on the policy of the country country through the emission regulation, the tax regimes, the ownership subsidization… Countries with a strong shift to zero-emission cars will invest heavily in the development of electric vehicle infrastructure and have policies to encourage consumers to use electric vehicles, which will shorten the hybrid phase. Countries that are not ready for this transition will last longer for a hybrid phase. Generally, zero-emission vehicles have already well penetrated in many regions of the world. ASEAN countries should take a lot of efforts from businesses and governments to catch up the future trend of the automobile market.

5 Conclusions

The above study allows us to draw the following conclusions:

- BEV has high energy conversion efficiency, good acceleration performance, no pollution emissions when in use, and low running cost. The main barrier is the low storage capacity of the battery, the prolonged charging time, the underdeveloped charging infrastructure. HFEV has a lower level of GHG emissions in their lifecycle, higher energy storage density, shorter refueling time, and longer cruising range. The main disadvantages are the high initial cost of the vehicle and the large investment in the infrastructure for hydrogen fuel supply.
- Lithium-ion batteries are the most suitable energy storage source for electric cars. The storage capacity of the batteries is expected to double over the next decade. Fast charging technology can reduce the several hours charging time currently to about 10 min. Material-based hydrogen storage technology offers high energy density, moderate operating pressure, and temperature which is suitable for hydrogen fuel cell automotive applications.
- The cost of the battery, and that of the hydrogen-fuel cell decrease continuously thanks to the development of manufacture technology as well as the application of new materials. In the next few decades, the cost of EVs will be lower than that of ICEVs.
- The penetration of zero-emission vehicles into the ASEAN automobile market depends on the policies of each country and the public awareness. It can be predicted into 3 phases. In the short-term, the BEV, plug-in hybrid and hybrid vehicles share the market with ICEVs. In the medium-term, HFEVs will be introduced into the market, the ICEVs will be substituted gradually by plug-in hybrid, hybrid vehicles and BEVs. In the long-term, the HFEV and BEVs share the majority of the automobile fleet, the others are different types of hybrid vehicles. The ICEVs will entirely disappear in road transport.

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