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Critical issues of energy efficient and new energy vehicles development in China

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ABSTRACT

Energy efficient and new energy vehicles are key measures in addressing China's energy and environment problems. In terms of the prospect of different technologies, the industrial and academic circles have not reached a consensus yet. In this study, the current situation and future development of main technology pathways in China are discussed. Specifically, internal combustion engines will be simpler in the future as a result of electric motor coupling. Battery electric vehicles are faced with a certain challenges currently and should be adopted in smaller vehicles at first. Hybrid technologies should be considered a significant development stage and should be applied before 2018. Plug-in hybrid electric vehicles and extended range electric vehicles are different in essence and should be applied based on their original intentions. Fuel cell vehicles are confronted with multiple challenges currently and will probably popularize after 2025.

1. Introduction

China's automotive industry has experienced rapid development over the past few decades. In 2016, the production and sales volume of automobiles in China exceeded 28 million units, continuing to be the world's first in eight consecutive years (State Council, 2016). Meanwhile, the rapid development poses enormous challenges for the energy consumption and environment in China. In terms of energy consumption, energy safety has become one of the top priorities for China's national security. The degree of foreign dependence on oil of China has reached 65% in 2016, much higher than the international safety line of 50% (National Bureau of Statistics, 2016). According to statistics, oil consumption of automotive industry accounts for nearly 40% in China's total consumption (Zhang et al., 2011). With the rapid growth of vehicle ownership, oil consumption of China's automotive industry will continue increasing. On the other hand, environment pollution issues are increasingly severe in China recently. The frequent hazy weather in big cities has gained widespread attention on air pollution (Huang et al., 2014). Among the urban air pollutions, vehicle exhaust emission is a significant source. Researches show that vehicles are one of the primary sources of particulate matters in large cities such as Beijing and Shanghai (Wang et al., 2014). Under such backgrounds, energy saving and emission reduction have become the key developing trends of China's automotive industry.

Among the energy saving and emission reduction measures, promoting “energy efficient and new energy vehicles” is a key measure. In order to promote energy efficient and new energy vehicles, Chinese government has introduced plenty of policies, including fuel consumption regulations, credit management policies and carbon quota policies. For the fuel consumption regulations, the government has restricted corporation's average fuel consumption (CAFC) of passenger vehicles (State Council, 2015). The average fuel consumption of passenger vehicle manufacturers should be reduced to 4 L/100 km by 2025. For new energy vehicle (NEV) credits, vehicle manufacturers are demanded to gain 10% and 12% of NEV credits in 2019 and 2020 (Ministry of industry and information, 2017). For carbon emissions, *Administrative Measures on Carbon Quota of New Energy Vehicles* has been issued to stipulate the carbon emission reduction quota of vehicle manufacturers (National Development and Reform Commission, 2016). Meanwhile, Chinese government is also considering the systematic integration of multiple credit systems. For instance, the *Measures on the Joint Management of CAFC and NEV Credits* has been released in order to achieve parallel management of CAFC and NEV credits in the future (Ministry of industry and information, 2017).

The development of energy efficient and new energy vehicles in China is supported by three main factors, namely the severe situation of energy and environment, the rapid development of technologies and supportive polices by the government. At present, the powertrain

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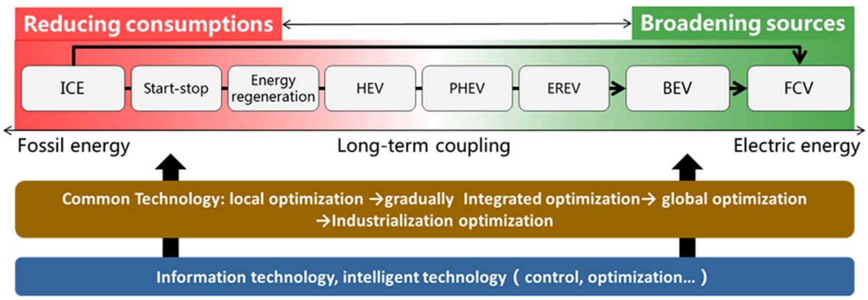

Fig. 1. Relationship between broadening sources and reducing consumptions.

transforming process from fossil energy to electric energy is continuously being deepened. However, the challenges and application scenarios of conventional vehicles, hybrid electric vehicles (HEV), battery electric vehicles (BEV) and fuel cell vehicles (FCV) are quite different. Currently, the industrial and academic circle have not reached a consensus in China yet. According to the literature review, most existing studies focused on a certain kind of technology (Kang et al., 2009; Plotkin et al., 2002). There are also many articles which compared technology pathways from the perspective of life-cycle emission or cost (Hawkins et al., 2013; Hao et al., 2017). However, few articles researched on the choice of technology pathways of enterprises systematically. Therefore, a systematic and clear judgment of different technologies is extremely necessary. In this study, based on plenty of surveys and deliberations, a systematic solution was illustrated.

It should be stressed that broadening sources and reducing consumptions are both indispensable in addressing China's energy and environment issues, as presented in Fig. 1. For the automotive industry, reducing consumptions means improving the current technologies, represented by improving the efficiency of internal combustion engines (ICE) and various hybrid technologies. These technologies are also called energy efficient technologies. Meanwhile, broadening sources means seeking new power sources, represented by BEVs and FCVs, which is also called NEV technology. The proportions of these two types of solutions are fluctuating. However, they do not contradict. On one hand, energy efficient vehicles will gain time for the gradual maturity of NEVs. On the other hand, the development of NEVs will extend the life of ICEs. Therefore, “broadening sources” and “reducing consumptions” should both be attached equal importance. This viewpoint should be regarded as the basic starting point for the development of energy efficient and new energy vehicles.

2. Technology pathway analysis

2.1. Engine powertrains

Although engine powertrain belongs to a traditional power type, it will also experience tremendous changes during this power transformation process. In the past, the engine and transmission combine to output power. Therefore, engines must be able to operate in a wide range to meet the intricate operating conditions. Accordingly, the optimum operating area of the engine must be as wide as possible, which is difficult to achieve (Kiencke and Nielsen, 2000). The demand of intricate operating conditions is met by mechanical structures such as variable valve timing (VVT), variable valve lift (VVL), variable compression ratio (VCR), multiple-speed transmission and continuously variable transmission (CVT) (Guzzella and Onder, 2009). If technology develops in line with this pathway, the engine powertrain will become more and more complex, which will make the control system increasingly complicated and expensive.

In the future, the output power will be provided by both the engine and electric motor, as shown in Fig. 2. Although the intricate operating conditions for the vehicles do not change, the engines can operate in a narrow optimum area (Moore, 2001-10-23). This is achieved by

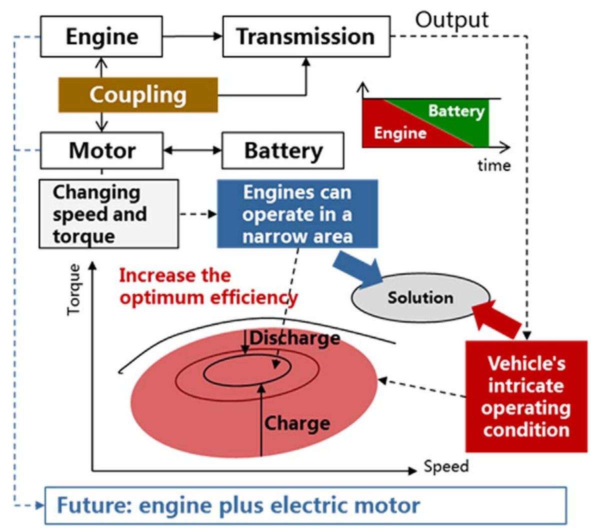

Fig. 2. Future's coupling structure of engine and electric motor.

changing the speed and torque of the electric motor. The essence of the structure is to achieve variable output from electromechanical coupling to meet the requirements of variable driving modes. Because of this structure, enterprises will merely need to increase the optimum efficiency of the engine within a small operating area, instead of adopting intricate variable units and control strategies. Therefore, this electromechanical coupling will simplify the technologies and lower the cost.

To sum up, engines will be simpler in the future. Effective combination of engine and electric motor will be achieved. Therefore, the efficiency optimization within a small operating area will be attached more importance. Meanwhile, the significance of transmission for energy saving will decrease. Effective coupling between engine and electric motor will be paid more attention than transmission efficiency. For technology decision makers, it should be stressed that under the same output, increasing the performance of electric motor will lead to simpler engine technology. Therefore, the cost increase of electric motors and cost reduction of engine should be weighed and balanced. The critical issue for enterprise decision-making lies in reasonably evaluating the balance point of cost.

2.2. Battery electric vehicles

Traction battery means the battery which drives the electric motor in BEVs. In general, the development of BEV industry is a function of time in regard to traction battery performance. Currently, the specific energy of battery system has reached 110 Wh/kg. And the cost of battery system is 2.2 yuan/Wh in 2016 in China (SAE-China, 2016a). Although there have been improvements in the performance and cost, great uncertainty still exists currently for traction battery technology. On one hand, current predictions on battery performance are mainly based on experience or historical data (Nykvist and Nilsson, 2015). On the other hand, future's development of new system battery is difficult to predict (Nitta et al., 2015; Van Mierlo et al., 2006). In view of these uncertainties, enterprises are confronted with great risks in making large-scale investments in traction battery. However, traction battery is vital for BEVs. Manufacturers cannot merely act as battery purchasers. The advice is that manufacturers can develop battery pack technology at first. Then they can appropriately participate in the production of battery cells. In this way, their control capability of traction battery technologies can be gradually improved.

Besides the problem of traction battery, another problem that hinders the development of BEVs is the charging infrastructure. According to official statistics, the number of public charging piles reached 141 thousand at the end of 2016 (National Energy Administration, 2016). However, compared with the new energy vehicle ownership of nearly 1 million, existing charging infrastructures are still insufficient. The scarcity of charging infrastructure increases the range anxiety of consumers (Nilsson, 2011). Therefore, manufacturers have to install more batteries on BEVs to ensure longer electric driving ranges. Addressing the issue of charging infrastructure is not easier than improving the performance of traction battery. On one hand, building charging infrastructure requires cost and time. Only with clear profit models can it attract private business to get involved. On the other hand, uncertainties still exist in future's charging technologies (Fisher et al., 2014). Once charging technologies change in the future, early investments may be wasted.

As discussed above, there exist two main obstacles in BEV industry, which are battery technologies and charging infrastructures. However, promoting BEVs are indispensable for China's enterprises because of national policy and potential competition of new entrants. In promoting BEVs, firstly, manufacturers should consider small vehicles as the most appropriate market segment to popularize BEVs. Secondly, electric driving range should be set appropriately and should not be extremely long. This method aims to save batteries to increase the cost competitiveness of BEVs. Thirdly, manufactures should rely on the construction of charging infrastructure in promoting BEVs. As the obstacles of infrastructure cannot be completely solved in the short term, enterprises should address the charging issues by business model and technical innovations, including battery changing method and extended range electric vehicle (EREV) technology.

In addition, low speed electric vehicles have not been supported by any policies in China at present, but this market developed very rapidly (Wu et al., 2015). Considering market acceptability and requirements of energy saving and emission reduction, products positioned between traditional BEVs and low speed electric vehicles have great potential in China's NEV market. This kind of vehicle products can be called micro electric vehicles (MEV). In definition, MEVs are electric vehicles that have lower maximum speed and driving range (for instance, 50 km/h and 50 km). They should carry lithium batteries instead of lead acid batteries. Compared with traditional BEVs and low speed electric vehicles, MEVs will probably become a significant solution in addressing “the last mile problem” in China. On one hand, the cost of BEVs recognized by Chinese government is extremely high. Their promotion relies highly on national supportive polices. On the other hand, most low speed electric vehicles are not environmentally-friendly and therefore not in line with the trends of China's automotive industry.

2.3. Hybrid power technologies

Hybrid power technologies are often deemed as a transitional technology between ICE and pure electric technology (Liu and Peng, 2008). However, this transition will be undoubtedly a long-term process. Therefore, the hybrid power technology should not be regarded merely as a transition, but a significant development stage. As the common technologies of broadening sources and reducing consumptions, hybrid technologies benefit from technical progress of both technology solutions. They will become inevitable technology pathways in future. Particularly, due to multiple solutions offered by hybrid power itself, they have an extensive range of application. By considering the demands of fuel consumption, performance and cost, enterprises should choose hybrid power solutions in different degrees to meet their own demands. Particularly, start-stop features low cost and high technological maturity, which will be widely applied in the near future. With moderate cost and fuel saving performance, mild hybrid and moderate hybrid technologies will be applied to midsize and small vehicles step by step. With complex systems and higher incremental costs, strong hybrid technology will probably be more applied to midsize and large vehicles.

HEVs do not need to be equipped with large batteries, which is an advantage compared to BEVs (Johri et al., 2017). However, the pros and cons of these two technology pathways should be weighed. If traction battery cannot experience revolutionary breakthroughs in the short term, HEVs will still have sufficient advantages in cost and convenience. Therefore, hybrid power technologies are promising for enterprises and adequate input should be invested.

2.4. Plug-in hybrid electric vehicle and extended range electric vehicle

Plug-in hybrid electric vehicles (PHEVs) are the hybrid vehicles featuring enlarged batteries and direct charging (Yilmaz and Krein, 2013). This technology aims to meet the increasingly stringent regulation requirements and to provide a more flexible solution than BEVs (Curtin et al., 2009). In essence, PHEV technology means “engine and alterable battery”. By adjusting battery capacity, enterprises can improve the pure electric driving range to meet regulation requirements and benefit from NEV privileges. In terms of structure, PHEVs often have parallel or combined configurations, featuring two sets of power system and complex control methods (Andri, 2011). The batteries equipped in PHEVs may not be very large. Some PHEVs only have pure electric driving ranges of 20–30 km (Kontou et al., 2015). In the context of more stringent fuel consumption and carbon emission regulations, the application potential of PHEVs will become larger and larger. However, the weakness of PHEV systems lies in higher cost than conventional hybrid systems, which needs to be addressed in future.

Extended range electric vehicles (EREVs) are electric vehicles equipped with charging units, aiming to solve the problem of range anxiety (Tate et al., 2008). As EREVs are mounted with charging units, they can carry smaller batteries than BEVs. In terms of structure, EREVs adopt series configuration and carry small engines (Smart et al., 2013). The engines do not drive the vehicle directly. Instead, they only charge the battery. Therefore, the control method of EREVs is rather simple. The greatest advantage of EREVs lies in addressing the restriction of charging infrastructure. But the weaknesses are also obvious. Firstly, EREVs require extra engines compared with BEVs. The cost and technology complexity will increase. Secondly, EREVs are still based on battery electric drive system. If charging infrastructures remain insufficient in future, EREVs will not save energy consumption compared with BEVs (Chen et al., 2014).

As discussed above, although PHEVs and EREVs are classified into the same category according to China's government, they are different in essence. The former offer a highly flexible solution to extend the role of the engine. The latter offer a possible solution to address the charging infrastructure issue and can be regarded as a kind of BEV with stronger adaptation. In conclusion, PHEVs should be considered from the perspective of the development of hybrid power technology. Likewise, it is meaningless to argue on the fuel consumption issue of EREVs.

It is worth mentioning that fundamental differences exist between series HEVs and EREVs. Series HEVs aim to seek the driving experience similar to BEVs and to realize better fuel consumption by a relatively simple configuration. For series HEVs, large engines ought to be equipped to meet the requirements of variable working conditions. In contrast, EREVs only aim to solve the charging issue of BEVs. It is not reasonable to equip large engines in EREVs.

For enterprises, PHEV technologies should be applied more in large

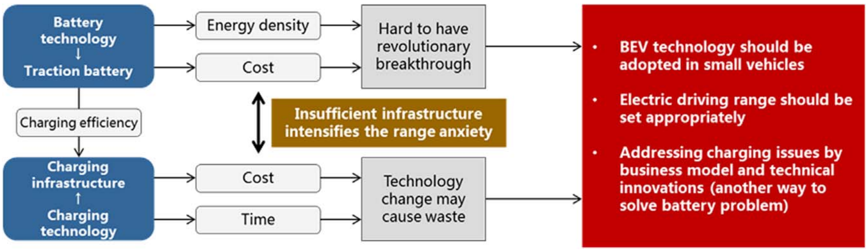

Fig. 3. Challenges and suggestions for BEVs.

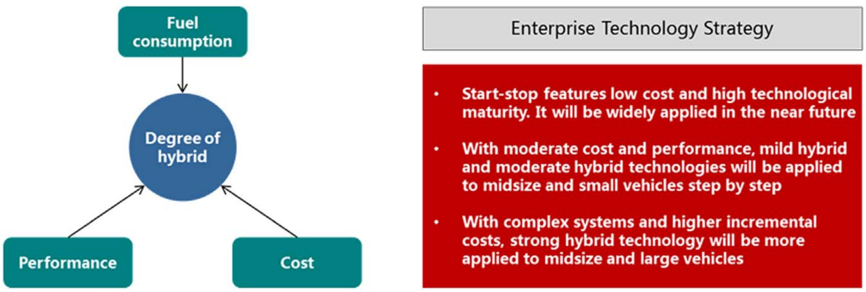

Fig. 4. Enterprise strategy advice on hybrid power technology.

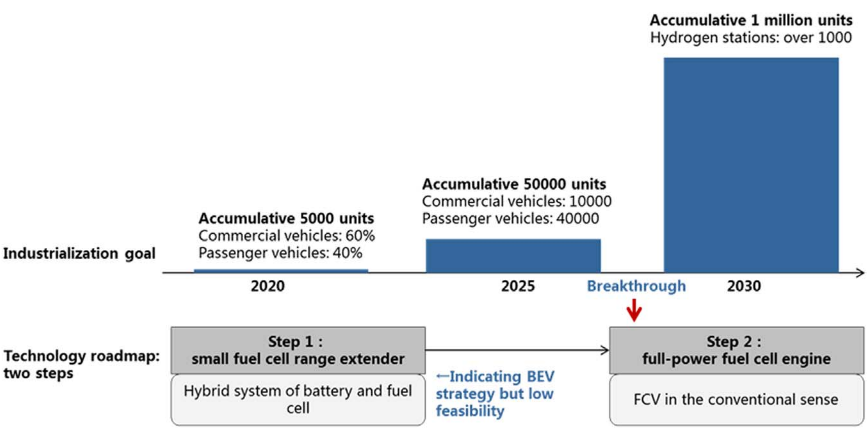

Fig. 5. Industrialization target and technology roadmap of FCV in China.

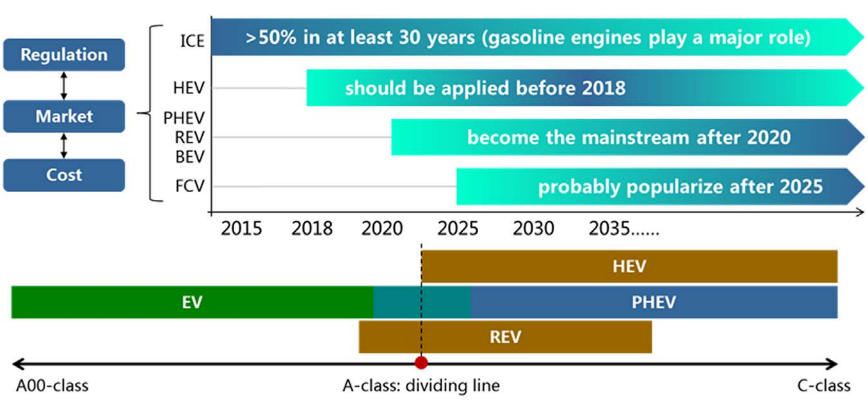

Fig. 6. Judgments of different technology pathways.

vehicles. As large vehicles have strong bearing capability for cost increase, the high cost of PHEV technologies is acceptable. More importantly, by developing PHEVs, enterprises will have a more flexible solution to meet future's regulations and benefit from national policy privileges. On the other hand, EREV technology should be more applied in midsize vehicles.

2.5. Fuel cell vehicles

Fuel cell vehicles (FCVs) represent the ultimate possibility of transferring to hydrogen for automotive power source. Chinese government attached great importance to FCV technologies recently (Haslam et al., 2012). There are views that FCV technologies are rapidly moving towards maturity and may pose challenges for the development of BEVs (Offer et al., 2010). But in fact, FCVs are confronted with multiple critical problems such as high cost, insufficient infrastructure and lack of efficient hydrogen production approach. Firstly, the total cost of a fuel cell system is extremely high, which is mainly caused by the use of platinum-based catalysts (Sharaf and Orhan, 2014). Secondly, the lack of demand and high cost hindered the construction of hydrogen infrastructure. Thirdly, existing methods for producing hydrogen such as electrolysis of water are not efficient and environmentally friendly. Considering current industrial and technology situation, the prospect of large-scale industrialization of FCVs is still uncertain in the short term. This conclusion can be demonstrated by the FCV industry plan in the *Technology Roadmap of Energy Efficient and New Energy Vehicles* released by SAE-China (SAE-China, 2016b). (Fig. 3)

The Technology Roadmap of Energy Efficient and New Energy Vehicles formulated the industrialization target of FCVs. The accumulative number of FCVs for demonstration are projected to reach 5000 units, 50,000 units and 1 million units by 2020, 2025 and 2030 respectively, as presented in Fig. 4. From the target, it is believed that the breakthrough of FCV industrialization may arrive between 2025 and 2030. Besides, a two-step technology plan was put forward. In the first step, small fuel cell range extenders will be mounted in BEVs, which can be considered the hybrid system of battery and fuel cell. In the second step, full-power fuel cell engines will be equipped, which mean FCVs in the conventional sense. The first step lacks practical feasibility in cost, but it reflects China's BEV-first strategy (Figs. 5 and 6).

To sum up, in view of the challenges confronted by FCVs, it is difficult to achieve large-scale industrialization in passenger cars in the short term. But if commercial vehicles (such as buses, logistics vehicles and trucks) are involved in the management area of China's NEV credit regulation, there will be huge opportunities for fuel cell commercial vehicles. Considering from this aspect, FCV technology may make industrial breakthroughs in commercial vehicles. In the long term, it is more suitable to apply FCV technology in commercial vehicles and large passenger vehicles with regard to cost and space layout. FCV technology is not suitable to be applied in midsize and small passenger vehicles.

3. Conclusion

At present, China's vehicle manufacturers are confronted with multiple challenges. The first challenge is the stringent regulations of CAFC, NEV and carbon quota. If enterprises fail to meet the requirements, they will be severely punished. Secondly, the demands in China's NEV market are diversified and changing. The preferences of new-generation consumers are quite different from previous consumers, which tests the quick reaction of enterprises to meet consumers' demands. Thirdly, the requirements for energy saving and emission reduction will increase manufacturers' cost. Therefore, the profitability of enterprises will be threatened. Faced with these three challenges, enterprises need to make wise choices in technology pathways. Based on the analysis above, the predictions on major technology pathways are summarized as follows.

From the perspective of time, vehicles equipped with engines will account for more than 50% of market share in at least 30 years. Gasoline engines are projected to play a major role. But diesel engines will still account for a certain proportion because of the high efficiency. In terms of strong hybrid technology, manufacturers will apply this technology before 2018 to meet the increasingly stringent fuel economy regulations. With technology progress and cost reduction, PHEVs, EREVs and BEVs will gradually become the mainstream after 2020. Considering the high cost, lack of infrastructure and uncertain hydrogen production method, FCVs will probably popularize after 2025.

From the perspective of vehicle class, A-class can be regarded as a significant dividing line. Below A-class, vehicle products should be more concentrated on BEV technology, which contributes to reducing battery capacities so as to lower cost and reduce energy consumption. Above A-class, HEV, EREV and PHEV technologies should be applied. The reason is that these technologies are more economic for larger vehicles.

In the end, it should be stressed that the transformation of vehicle power sources will be a long-term process. During this process, technological breakthroughs, policy changes and energy structure will all pose significant impacts on energy efficient and new energy vehicles. Vehicle manufacturers should make choices based on their own practical situations. Therefore, there is no common technology roadmap for all the enterprises. Enterprises' technology roadmaps need to be constantly examined and improved. Nevertheless, viewing from China's automotive industry, a basic judgment can be made that only from reasonable technology portfolios can manufacturers undertake the task of energy saving and emission reduction.

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