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Research on the Significance of Developing New Energy Vehicles Industry and Its Technical Routes

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Abstract: In this study, the significance of developing a new industry with respect to energy, environment, information, and scientific technology is first analyzed. A strategic plan for China's new energy vehicle development for 2050 is then presented. The technical routes for new energy vehicles, power batteries, and driving motors, and the systematic configurations of the new energy vehicles are discussed. Further, suggestions for establishing national technological innovation alliances to achieve technological breakthroughs in the new energy vehicle industry are provided. It is expected that these suggestions can provide references for the future development of China's new energy vehicle industry.
Keywords: new energy vehicle; major significance; technical route; measures

1 Introduction

As China has entered the period of the 13th Five Year Plan, the development of the automotive industry in China has shifted to a slower yet steadier pace. Despite being one of the world's largest automobile manufacturing powers, China faces issues such as energy scarcity, pollution, transportation congestion, and increasingly intensifying competition in the industry. Furthermore, a new technological and industrial revolution that is driven by information technology (IT), cloud service, and big data is reshaping the industry with new technologies, energy sources, manufacturing processes, and business models. Therefore, the quantitative-to-qualitative change in the Chinese automotive industry is inevitable. The new energy vehicle (NEV), being the future trend of vehicles, with the integration of autonomous driving and connection technologies, is facilitating the transformation and upgrading of the Chinese automotive industry. In this process, the significance and development routes of NEVs must be documented.

2 The significance of developing NEVs

2.1 For environment conservation and energy security

Thus far, the gross domestic product (GDP) of China is under 10 000 USD per capita. With the development model and energy structure being currently adopted, when the GDP per capita of China reaches 18 000 USD, the average energy consumption rate per capita will be equivalent to 8000 kg of petroleum, which equals the average energy consumption rate of the US and Canada, the GDP per capita of which has already exceeded 40 000 USD. In order to achieve this, if China intends to improve its economic strength and become a developed country, it must reform its development model, change its energy consumption structure, and adopt a green and sustainable course of development.

According to the conclusion of the report of the Chinese Academy of Engineering (CAE), the year 2020 will be an important turning point for the optimization of China's energy

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consumption structure; by then, the use of traditional fossil fuels will start to decrease, and the use of clean energy such as hydroelectricity and nuclear power will increase rapidly [3]. Automobile fuel consumption comprises nearly half of China's total fuel consumption, which means that developing NEVs will contribute to a reduction in the fuel consumption and will be one of the main methods of optimizing China's energy consumption structure. Moreover, urban energy quality and the health of citizens will also benefit owing to the low-emission feature of NEVs [4].

2.2 A new technology revolution driven by electrification and intelligentization of vehicles

In recent years, with the growth of the internet, Internet of Things, big data, 4G (the 4th generation mobile communication technology), and global positioning system technologies, the electrification and intelligentization of automobiles has become a global trend. A general consensus has been reached by all the related industries that cars in the future will act as an interactive application platform for mobility, communication, and entertainment, instead of just a tool of transportation. As compared to vehicles that run on traditional fuels, NEVs will be an ideal carrier of intelligentization technologies integration; their combination may result in the creation of more innovative ideas and new models for future development.

2.3 NEV bears the weight of China's auto power construction

Being the typical product of the combination of two themes of the future, low-carbon and intelligentization technologies, NEVs include technologies from the fields of material science, IT, control technology, crafting, and equipment manufacturing. The development of NEVs will effectively accelerate the fundamental research, design, development, testing, and manufacturing in all the related industries.

The core of NEVs is the electrification of driving power, the innovation for which will not only be driven by electric motor, electric control, and whole-vehicle technologies, but also depend on energy management, intelligence and interconnection, and cloud service technologies, the integrated development of which will greatly reshape the entire automotive industrial chain. For China, a country with a relatively weak automotive industrial base, this will be both an opportunity and a challenge. China released *Made in China 2025* in 2015, and listed energy-efficient vehicles and NEVs as one of the 10 development priorities. The development of NEVs will be an important route toward the realization of *Made in China 2025* and an opportunity to realize the automobile power objectives of China [5].

3 Basic technological routes of NEV

By 2050, with the realization of energy savings and consumption reduction being the main driving factors, NEVs will be gradually promoted in various fields and regions in a planned manner until the holding rate of NEVs reaches 50% (Table 1).

In phase one—from the present day till 2020—the main efforts will be focused on the reduction of $PM_{2.5}$ (particulate matter) emissions from vehicles. The use of NEVs will be promoted in the public transportation, logistics, and public service areas. The types of NEVs will be electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs); at the same time, the research and development (R&D) of fuel cell technology will be supported. By 2020, the annual production and sales volume of NEVs will reach 2 million, making up 5%–10% of the market share, and the holding rate will be 2% or higher.

In phase two, from 2020 to 2030, the main focus will be on energy efficiency and $PM_{2.5}$ emissions control, as the emission of CO_2 may increase. The use of EVs and PHEVs will be promoted in society. The industrialization of the fuel cell vehicle (FCV) will be ready to meet market demand. A major effort should be focused on the R&D and application of clean power generation and hydrogen-fuel production technologies. The use of clean energy sources should surpass the use of oil. By 2030, the annual production and sales volume of NEVs will reach 20 million, making up 50% of the market share, and the holding rate will be 15% or higher.

In phase three, from 2030 to 2050, the main focus will be on the reduction of CO_2 emissions, and energy efficiency throughout the industrial chain. FCVs will be promoted in society, and infrastructure that can facilitate the use of FCVs will be developed. Cleaner and more efficient fuel-production technologies will be developed using solar, tidal, and wind energy sources.

Table 1. Strategic goal of NEV development.

Time	Present day–2020	2020–2030	2030–2050
Development priority	Considering emission reduction as driving force and focusing on reduction of $PM_{2.5}$ emissions	Considering energy efficiency as the main driving force, controlling $PM_{2.5}$ emissions, and CO_2 emission may increase	Reducing CO_2 emissions is a priority
Iconic event	—	Use of self-produced gas surpasses use of oil	—
Development strategy	Promotion of bus, taxi, and logistics-related vehicles, as well as promotion and application of small EVs	Mass application of EVs and increased use of hydrogen fuel and fuel cells	Mass promotion of hydrogen fuel and fuel cells and increase in use of biomass fuel
Holding rate of NEVs	Greater than 2%	15%	50%

The types of fuel used will be expanded to include biomass fuel, methanol, and carbon monoxide. By 2050, the holding rate of NEVs will be 50% or higher with a fairly large share of FCVs.

4 Basic technological routes of batteries

Of all the key components of an NEV, high-power-density batteries will be one of the most urgent demands. Thus far, a ternary lithium battery material has been the most promising anode material for business applications, with the main development directions being the use of nickelic materials and high voltage. As high-voltage ternary materials are limited by the immaturity of existing technology, such as the use of electrolytes, they are not suitable for mass production applications. In addition, the combination of nickelic material and a silicon-based anode is the main technological route for a ternary power battery to realize a power density of 300 Wh/kg (Fig. 1). Silicon has the highest theoretical lithium insertion capacity (4200 mAh/g) and relatively moderate lithium disembedding potential (0.45 V vs. Li/Li+), which makes it easier to prevent lithium from separating out or growing dendrites from the pole shoe and thus improves the operational safety of batteries in a relatively wide temperature range with a better rate capacity.

However, with an increase in the use of nickel, oxidizability and structural instability also increase drastically. Thus far, while increasing the material capacity per gram for realizing a power-density improvement, the cycle life, thermomemory, and safety of the battery become compromised. Only when all the advantages and disadvantages reach a stable balance and meet the requirements of practical use can the technology be truly used in mass production.

A lithium battery is a closed system, which means that it has an energy storage limit. In the future, it will be replaced by new types of batteries. The main research directions toward this goal are solid-state batteries, lithium–sulfur batteries, metal–air batteries, and fuel cells.

Solid-state batteries have a high-voltage platform, and under the majority of circumstances, solid electrolytes have a wider electro-chemical window than organic electrolytes, but are also able to hinder lithium dendrite growth. They are the foundation of a new generation of lithium battery technologies with a potentially higher power density. The power density of a solid-state lithium battery is approximately 350 Wh/kg and may reach an estimated maximum of 900 Wh/kg. However, the manufacturing technology and process of solid-state batteries is completely different from that of the current liquid lithium batteries, and thus, its industrialization is difficult. Moreover, as the transmission speed of ions is slower in a solid electrolyte, the resistance between the anode and cathode materials will be high. Therefore, solid-state batteries will have an undesirable rate capability. Moreover, the issues of their cyclicity and temperature performance are still unresolved. Thus, solid-state batteries are not suitable for industrialization.

In a lithium–sulfur battery, with sulfur as the anode material, the theoretical specific energy can reach 2600 Wh/kg, and elemental sulfur is cost effective, abundantly available, and environmentally friendly. The main problem of this technology is a low use ratio of the active material and low cyclicity. With the development of high-performance carbon–sulfur composite material technology and highly stable lithium or lithium-alloy cathode-material technology, the optimization of lithium–sulfur battery technology, and an achievable specific energy is $>$ 500 Wh/kg, the operating requirements for long-distance driving of NEVs will be met [7].

Metal–air batteries have a high theoretical power density of 11 500 Wh/kg, because the active material of the cathode, i.e., O_2, can be obtained from the environment instead of having to be stored in the battery system. Recent research has shown that lithium–O_2 batteries have a cyclicity of more than 100 cycles, and the generation and decomposition of lithium and O_2 during the charging and discharging has also been verified. However, the dynamic process that occur in the lithium–O_2 battery's cathode during charging and discharging is too slow; moreover, it has a large polarization overpotential, and the reported power efficiency of the battery is low. The power efficiency of the lithium–O_2 battery can be improved by developing and using a bifunctional catalyst. As a popular current research topic, the O-electrode catalyst comprises carbon, a base metal (and oxide), and a rare metal (and oxide).

The last main R&D focus is the fuel cell. It has a unique out-phase electro-catalytic reaction, which makes it possible to obtain a high exchange-current density at the surface of the Pt/C catalyst using electro-chemical oxidation of hydrogen or electro-chemical reduction of oxygen. With the features of high

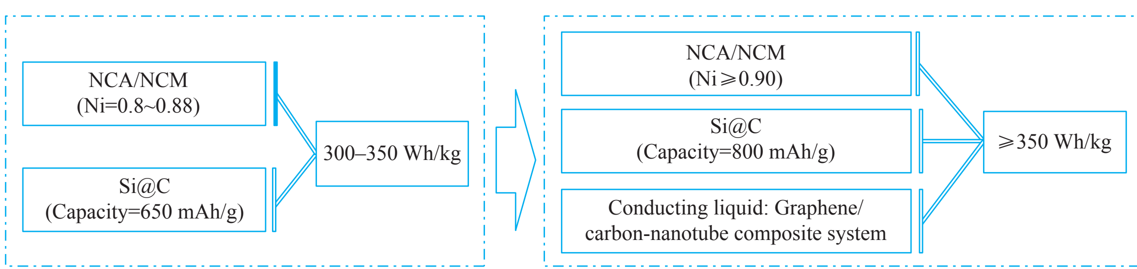

Fig. 1. Ternary battery technology routes for batteries with energy density greater than 300 Wh/kg.

power and high energy, the fuel cell has met the basic technological requirements for a modern vehicle in terms of power. As an electro-chemical device, the fuel cell has reached a higher level of chemical power than the secondary cell. The difference between a fuel cell and a secondary cell is its working principle; thus, a secondary cell is suitable for small- and medium-capacity power storage, whereas a fuel cell is suitable for large-capacity power storage.

All factors considered, in the next 5–10 years, it is unlikely that any of the new battery technologies mentioned above will be industrialized, and the lithium power battery will be used widely in the next few years.

Thus far, the production capacity of the high-end lithium power battery has been insufficient. The anode, cathode, and electrolyte material are controlled by companies in Japan. The lithium-battery manufacturing power of China is almost at an international standard in terms of power density; however, improvements are still required in terms of reliability and consistency.

In the fuel cell area, overseas vehicle manufacturers had plans for the industrialization of fuel cells long before China did, the development routes have been confirmed, and multi-nation co-engineering alignments have been formed. With major technological breakthroughs such as platinum catalysts, the industrialization of the FCV is imminent. However, the foundation of the FCV industry in China is relatively weak. With the majority of the key materials and components depending on imports, it is difficult to control the cost of an FCV engine, and its durability and environmental applicability still require improvement.

5 Basic technological routes of drive motor

5.1 Drive motor

The drive motor technologies for NEVs are relatively mature. The technologies of a motor system have met the requirements of various types of NEVs in the market. Several motor producers in China have realized a production capacity of more than 10 thousand; some of these products are exported to developed countries, some of which have met international standards.

The technological routes for the drive motor include an asynchronous motor and permanent magnet synchronous motor. The permanent magnet synchronous motor has become a mainstream technology owing to its features, such as its simple structure, small size, low weight, fast response, wide speed range, and precise positioning. Recently, the NEVs released in the majority of countries have used permanent magnet synchronous motors, except for some that use asynchronous motors such as Tesla. In 2016, 81.7% of the NEVs in China had permanent magnet synchronous motors, and 17.8% of the NEVs had asynchronous motors.

The future trend for the driving motor includes an increase in the watt density, promotion of permanent magnet synchronous motors, integration of a power driving system, and digitization of a vehicle-use electric control system [8].

5.2 Structure of hybrid power system

The hybrid vehicle today mainly comprises three hybrid power structures: extended-range, in-parallel, and in-series-and-parallel structures.

The extended-range structure charges the batteries though the engine, and the car is driven using only batteries as the energy source. In this manner, the engine can always work in an ideal environment with a high efficiency, and even under crowded urban working conditions, the fuel consumption remains low. However, in a high-speed working condition, owing to the layers of energy transmission, part of the power will be lost, and the fuel efficiency will drop. Such models include the BMW i3, and the Audi A1 e-tron.

In the in-parallel structure, an electric motor, battery set, and electric control system are included in a traditional car and are used to drive the car simultaneously. In this manner, the power is sufficiently used, and the car can run with either electric or hybrid power. However, when the car is in hybrid mode, a single motor cannot generate power and drive the car at the same time; the engine is unable to always work under perfect conditions, which results in a higher oil cost. Such models include the Mercedes-Benz 550 Plug-in and BYD Qin.

The in-series-and-parallel structure has two motors: one for driving and another for either driving or charging. Its main advantage is that under any working condition, the engine is able to work at a perfect rotation speed, thus minimizing the oil cost. However, the development barrier and manufacturing cost is high, thus limiting the promotion of this technology. Such models include the Toyota Prius plug-in and SAIC Roewe.

Presently, in the market, the in-parallel and in-series-and-parallel structures are popularly used in vehicles. Massively produced hybrid passenger cars in developed countries generally use a power-dividing, parallel-serial system in order to obtain a better transmission efficiency and prudent oil performances. The hybrid system products in China mainly use micro-hybrid and mild hybrid technologies. The upgradable products (e.g., PHEVs) are mostly expanded from the integrated starter and generator (IGS) structure. The PHEV products in the Chinese market mainly have in-parallel and in-series-and-parallel structures, but the performance of these is still far behind vehicles in the developed countries, especially in terms of the HEV engine, coupling device, systematic integration, and control systems.

6 Measures and suggestions

The development of NEVs in China and the world still faces problem that the technical characteristics of the traditional lithium battery are difficult to improve, while the new generation of battery technologies is underdeveloped. This means the driving range of NEVs is inferior to that of tradition vehicles. Moreover, the new battery technology system is, to some extent, subversive, and the fuel cell technology represents the ultimate level of vehicle-use clean energy, for which there is still a long way to go for us. China should put more effort into the development of related technologies, make use of development opportunities, and take a commanding position in the industry.

In allusion to the three key areas of electric vehicles, i.e., power batteries, plug-in hybrids, and fuel cells, China should organize corresponding innovation alignments: The National Power Battery Innovation Center (existing), National New Energy Vehicle Power System Research Center, and National Fuel Cell Technology Innovation Center should be assigned with a task paper and institutional constraints. The development resources and results of research of the related key technologies can thus be obtained more efficiently.

Objectives and goals: The objectives and goals include guiding and integrating the automotive and related industries, organizing collaborative research, and building an open and shared innovative platform. The R&D and engineering applications of the key common technologies should be accelerated. Advanced business modes including a modularized supply should be developed. High-value-added and knowledge-intensive components should be developed. The self-developing ability of the entire Chinese automobile industry should be optimized.

Research focus: The research focus should be on power batteries (new type of battery diaphragm, catalyst, and battery materials), power system (hybrid vehicle engine, hybrid vehicle coupling structure, IGBT, high speed reducer, and inverter integration) and fuel cells (voltaic pile, high performance membrane material, low platinum catalyst, and hydrogen production/storage/transportation).

Organization formed by related national departments and scientific research institutions, vehicle producers, component suppliers, industrial institutions, and academies with one leading member (from a third party institute in principle).

Operation mechanism: The related national departments will set out task papers, and the leading member will guide other members of the centers to fulfil the tasks, with shared results, data, patents, etc.

Capital requirements: Thirty percent of the annual research grant will be obtained from the government, and 70% will be obtained from the members themselves. Social capital, financial capital, public-private partnership (PPP), and other financing modes will be encouraged.

7 Conclusions

All considered, the development of NEVs is significant for China to resolve issues including energy security, environment conservation, and industrial transformation and upgrading. Thus far, the technological development of NEV products is still an on-going process. In the future, the industry will have to deal with a drop in subsidies and increasingly severe domestic and international competition. Only by maintaining an innovation-driven focus, can we make the most of the national technological innovation centers and increase the competitiveness of our product technologies.

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