Strategic Study of CAE 2019 Vol. 21 No. 3
DOI 10.15302/J-SSCAE-2019.03.005

Strategic Research on Promoting Coordinated Development of Refining and Automobile Industries

Cao Xianghong

China Petrochemical Corporation, Beijing 100127, China

Abstract: The rapid development of new energy vehicles such as electric vehicles and fuel cell vehicles has initiated the age of automobile power revolution. The internal combustion engine vehicle (ICEV) industry and fuel production industry have actively responded to the automobile power revolution by satisfying the latest requirement for emissions, upgrading the quality of oil products, and advancing the development of internal combustion engine technology. Although new energy vehicles have some advantages, they cannot comprehensively replace ICEVs in the short term. The use of gasoline-electric hybrid vehicles with high-efficiency internal combustion engines will significantly reduce the emission of carbon and other pollutants to levels that are in line with China's national conditions. By 2050, ICEVs, gasoline-electric hybrid vehicles, fuel cell vehicles, and pure electric vehicles will coexist based on their respective technological advantages. However, ICEVs will dominate the automobile market and the dependence of automobile power on liquid fuels will exceed 60%. Hence, the petroleum refining and automobile manufacturing industries should develop coordinately. This can be achieved by studying the combustion mechanism from a molecular perspective in internal combustion engines, exploring the relationship between fuel composition, distillation range, and particulate matter emissions, developing simplified models, and developing and promoting high-quality fuels and high-grade lubricants to adapt to the low-carbon and emission reduction requirements in the era of automotive power diversification.

Keywords: automobile power revolution; internal combustion engine technology; oil quality; coordinated development

1 New energy vehicles (NEVs) have initiated the vehicle power revolution

1.1 Development of electric vehicles (EVs)

In recent years, in a bid to reduce CO_2 emissions and improve air quality, several countries have introduced policies to promote the development of EVs. In addition, several countries have proposed a timetable for banning the sale of internal combustion engine vehicles (ICEVs) in a push to popularize. For example, the Netherlands and Norway plan to ban the sale of ICEVs by 2025 and France has specified 2040 as a deadline. In 2018, Hainan province of China announced that the sale of ICEVs would be prohibited by 2030. To prop up the development of EVs, the Chinese government has been carrying out a policy of high fiscal subsidy, and several municipal governments have adopted specific purchasing and driving policies for NEVs. In 2018, the government subsidies were reduced, and the "double scores" policy was implemented to set a higher demand for fuel economy level.

According to the statistics provided by the International Energy Agency (IEA) [1], compared to 2013, the world's EV population in 2017 increased by 2.5 times to approximately 3.11 million, while sales increased by more than 5.7 times to about 1.15 million. In China, the ownership grew by 38 times to 1.226 million and the sales increased by

Received date: May 6, 2019; **Revised date:** May 9, 2019
Corresponding author: Cao Xianghong, senior member of Science and Technology Committee of China Petrochemical Corporation. Major research field is petrochemical engineering. E-mail: weizhq@sinopec.com
Chinese version: Strategic Study of CAE 2019, 21 (3): 061–069
Cited item: Cao Xianghong. Strategic Research on Promoting Coordinated Development of Refining and Automobile Industries. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2019.03.005

3.8 times to 579 thousand, which is the highest ranking in terms of both worldwide. Figs. 1 and 2 depict the population and sales trends of EVs (including battery EVs and plug-in hybrid electric vehicles (PHEVs)), respectively, in China and abroad. This reveals that China is experiencing a "blowout-like" development in EVs from 2013 to 2017.

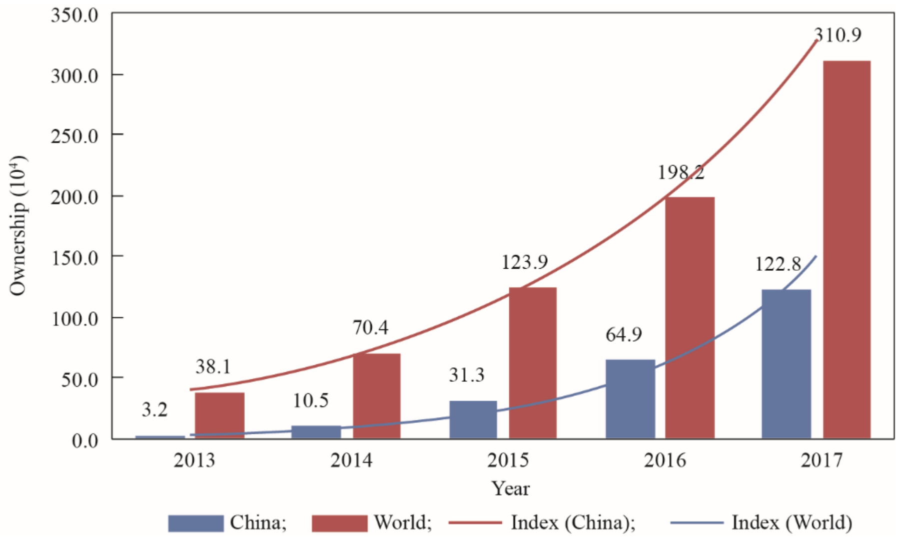

Fig. 1. EV population trend in China and abroad (2013–2017).

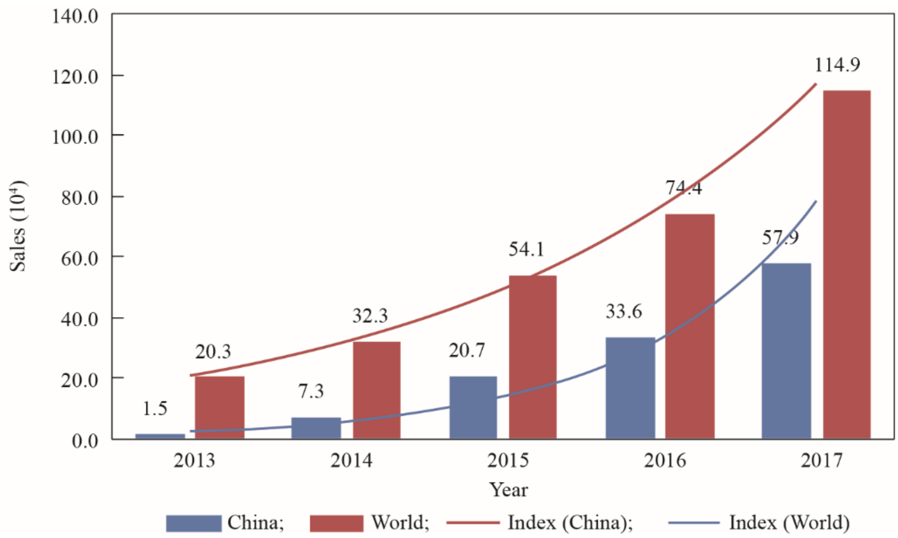

Fig. 2. EV sales trend in China and abroad (2013–2017).

1.2 Fuel cell vehicles (FCVs) are involved in the vehicle power revolution

Hydrogen fuel cell electric vehicles (HFEVs) are an important step towards the development of low-carbon vehicles in the future. HFEVs are currently entering the market and taking part in the vehicle power revolution. Since the 1980s, the European Union, USA, Japan, and South Korea have been investing large amounts of funds and manpower for research on HFEVs. Ballard Power Systems Inc., Mercedes-Benz, BMW AG, Honda Motors Co., Toyota Motor Corporation, General Motors Co., Hyundai Motor Co., and some other motor companies have developed their own FCVs that have been tested on road one after the another. Hyundai, Toyota, and Honda introduced fuel cell powered passenger cars in the market in 2013, 2014, and 2016, respectively.

In China, several research institutes, universities, and automobile companies such as the Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Tongji University, Tsinghua University, SAIC Motor Group, and Beiqi Foton have been carrying out FCV research at the same pace with global players. China has proposed to manufacture and sell up to 1 million FCVs and set up 1000 hydrogen refueling stations by 2030. Many cities like Shanghai, Beijing, Wuhan, Fushan, Yancheng, and Rugao, have successively carried out operating demonstration

DOI 10.15302/J-SSCAE-2019.03.005

of fuel cell buses and logistics vehicles. In addition, several hydrogen energy production industrial parks are under construction. From 2013 to 2017, 8451 HFEVs were sold around the world [2], among which 1901 were in China, accounting for 22.5 % of the total share. Passenger cars and buses constitute a dominant share of HFEVs overseas, while logistics and buses lead in China.

2 ICEV manufacturers and fuel suppliers actively respond to vehicle power revolution

2.1 Promulgation and enforcement of stringent emission standards for ICEVs

In December 2016, China promulgated the globally most stringent *Emission Limits and Method for Measuring Pollutant Emission from Lightweight Vehicles (Stage 6 in China)* that will come into effect from July 1, 2020. The State Council also issued a document calling for the implementation of the China 6A standard in key regions, the Pearl River delta, and Chengdu-Chongqing areas from July 2019. Automobile manufacturers are actively developing internal combustion engine technology to meet China 6 standard, and 65 auto companies have announced that 1216 car models will comply with the China 6B emission standard.

Table 1 and Table 2 shows a comparison of emission standards for gasoline and diesel vehicles specified in China 1 to China 6 and Euro I to Euro VI, indicating that Chinese emission standards for ICEVs are the most stringent in the world.

Table 1. Emission limits for gasoline vehicles (China 1–China 6 and Euro I–Euro VI).

Standard	Enforcement date	Emission limit (mg/km)						
		CO	THC	NMHC	NO_X	N_2O	PM	P[#/km]
Euro I	1992.7	2.72	–	*0.97	–	–	–	–
China1	2000.7	2.72	–	*0.97	–	–	–	–
Euro II	1996.1	2.2	–	*0.5	–	–	–	–
China 2	2005.7	2.2	–	*0.5	–	–	–	–
Euro III	2000.1	2.3	0.2	–	0.15	–	–	–
China 3	2008.7	2.3	0.2	–	0.15	–	–	–
Euro IV	2005.1	1.0	0.1	–	0.08	–	–	–
China4	2011.7	1.0	0.1	–	0.08	–	–	–
Euro V	2009.9	1.0	0.1	0.068	0.060	–	0.0045	–
China 5	2017.1	1.0	0.1	0.068	0.060	–	0.0045	–
Euro VIb	2014.9	1.0	0.1	0.068	0.060	–	0.0045	6×10^{11}
China 6A	2020.7	0.7	0.1	0.068	0.060	0.020	0.0045	6×10^{11}
Euro VId	2017.9	1.0	0.1	0.068	0.060	–	0.0045	6×10^{11}
China 6B	2023.7	0.5	0.05	0.035	0.035	0.020	0.0030	6×10^{11}

Notes: * HC+NO_X limits; THC: Total HC–total hydrocarbons; NMHC: non-methane HC; P[#/km]: particulate matters ([#/km] is the unit of measurement).

Table 2. Emission limits for diesel vehicles (China 1–China 6 and Euro I–Euro VI).

Standard	Enforcement date	Emission limit (mg/km)						
		CO	THC	NMHC	NO_X	HC+NO_X	PM	P[#/km]
Euro I	1992.7	2.72	–	–	–	0.97	0.14	–
China 1	2000.7	2.72				0.97/1.36	0.14/0.20	
Euro II	1996.1	1.0	–	–	–	0.7/0.9	0.08/0.10	–
China 2	2005.7	1.0				0.7/0.9	0.08/0.10	
Euro III	2000.1	0.64	–	–	0.50	0.56	0.05	–
China 3	2008.7	0.64			0.50	0.56	0.05	
Euro IV	2005.1	0.50	–	–	0.25	0.30	0.025	–
National 4	2011.7	0.50			0.25	0.30	0.025	
Euro V	2009.1	0.50	–	–	0.18	0.23	0.005	6×10^{11}
China 5	2017.1	0.50			0.18	0.23	0.005	
Euro VIb	2014.9	0.50	–	–	0.080	0.17	0.0045	6×10^{11}
* China 6A	2020.7	0.70	0.1	0.068	0.060	**0.020	0.0045	6×10^{11}
* China 6B	2023.7	0.5	0.05	0.035	0.035	**0.020	0.0030	6×10^{11}

*The pollutant emission limit in the stage of China 6 standard follows the fuel neutrality principle, i.e., same limit for both gasoline and diesel vehicle.

**N_2O limit.

2.2 China's high quality automotive fuel

Upgrading the quality of gasoline and diesel fuel is an important measure for reducing pollutant emissions from ICEVs. China took 19 years to upgrade its fuel quality from leaded gasoline to China 6A standards. In 2016, the

Chinese government issued automotive gasoline and diesel standards for Stage 6 (GB17930-2016 and GB19147-2016). The gasoline standards to be implemented were divided in two phases i.e., 6A and 6B. The China 6A standard had to come into force all over the country from January 1, 2019, and the China 6B standard to be implemented nationwide from January 1, 2023. The main quality indicators of China's China 6 standards for gasoline and diesel fuel are the same as in Europe, while some of them are stricter than that of Europe, the United States of America, and Japan as shown in Table 3 and Table 4.

2.3 Improvement in internal combustion engine technology

Improving engine thermal efficiency is a major measure to reduce fuel consumption in ICEVs and lower pollutant emission. The world has witnessed continuous development of new technologies such as advanced combustion, high supercharge and small-scale reinforcement, multi-variable and multi-system intelligent control of internal combustion engines, waste heat recovery, intelligent stop of cylinders, charge transit between different cylinders, and in-cylinder water injection. Some of these technologies are being utilized successfully. Gasoline engines with thermal efficiency of 41% are being produced at commercial scale. Peak thermal efficiency of gasoline engine measured in the laboratory has reached over 51%, and diesel engine exceeds 55% [3–5]. The thermal efficiency of an independently developed Chinese multi-pulse fuel injection technology that has a characteristic of high mixing rate is high at 45.5%. Diesel engines, with its pollutant emission meeting the China 6B limit, have been developed successfully. Weichai Group announced at SAECCE 2018 that diesel vehicles with more than 50% thermal efficiency will be mass-produced and released in the market in 2020. The internal combustion engine industry worldwide is now committed in achieving an effective thermal efficiency of 60 %.

Table 3. Comparison of main technical indicators of automotive gasoline standards between China 6, Europe, USA and Japan standards.

Item		China 6A/6B	Euro VI	USA	Japan
RON	Min	89/92/95	95	–	89/96
MON	Min	–	85	–	–
Antiknock index	Min	84/87/90	–	87/89/91	–
S content, ($mg\cdot kg^{-1}$)	Max	10	10	10	10
Benzene (%)	Max	0.8	1.0	–	1.0
Olefins (%)	Max	18/15	18	–	–
Aromatics (%)	Max	35	35	–	–
T50 (°C)	No greater than	110	46–71(E100)	71–121	110
T90 (°C)	No greater than	190	≥75(E150)	190	180
End point of distillation (°C)	No greater than	205	210	225	220

Note: RON: research octane number; MON: motor octane number.

Table 4. Comparison of main technical indicators of automotive diesel standards between China 6, Europe, USA, and Japan standards.

Item		China 6	Euro VI	USA	Japan
Cetane number	Min	51/49/47	51/49/47	40	50/45
Cetane index	Min	46/43	46/43	40	50/45
S content ($mg\cdot kg^{-1}$)	Max	10	10	15	10
PAH content (%)	Max	7	8	–	–
Lubricity (μm)	Max	460	460	520	–
Flash point (°C)	Min	60/50/45	55	52	50/45
T50 (°C)	Max	300	<65 (E250)	–	–
T90 (°C)	Max	355	>85(E350)	282–338	360/350/330
T95 (°C)	Max	360	360	–	–
Total contaminant content ($mg\cdot kg^{-1}$)	Max	24	24	–	–
Density ($kg\cdot m^{-3}$)		810–845/790–840	820–845	–	860 max

DOI 10.15302/J-SSCAE-2019.03.005

Hybrid electric vehicles (HEV) lead the future transition and development of ICEVs. Fueled by gasoline or diesel, HEV is driven by an internal combustion engine or electric motor or both simultaneously under different working conditions. As a result, the internal combustion engine is always running in the domain of highest efficiency, along with the recovery of energy generated during deceleration and braking to reduce fuel consumption and pollutant emission by more than 30% [6]. Fig. 3 shows a comparison between emission limits stipulated in Euro V and China 6B standard and the emission limits achieved by Toyota HEV. The emission of pollutants from Toyota HEV is lesser than that specified by the Euro V and China 6B standards. HEV does not change consumer driving habit or require charging. It takes full advantage of existing refining capability and infrastructure and does not increase social investment or carbon emission. It is one of the measures in the automobile power revolution with instant effect of emission reduction that is also in line with China's national conditions.

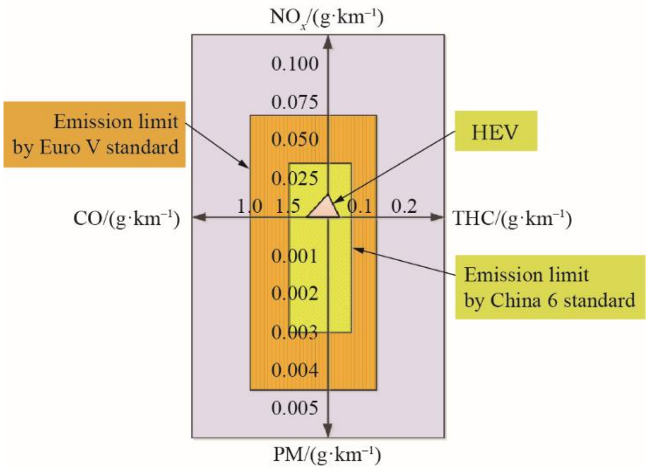

Fig. 3. Schematic diagram of pollutant emission from HEV.

3 Oil consumption trend during automobile power diversification in China

3.1 NEV has a long way to go to replace ICEVs

The primary advantage of EV is zero emission of carbon or pollutants. However, in the whole life cycle, the CO_2 emission of EVs is closely related to the energy structure of power generation in the country [7]. In countries where the share of fossil energy in power generation is higher than 50%, EVs do not have obvious advantages over ICEVs in terms of CO_2 emissions. In countries where the percentage is higher than 80%, pure electric vehicles emit more CO_2 than internal combustion engines. According to a study conducted by University of Tokyo, Japan, the emission of pollutants such as NO_X, PM, and SO_X in the full-life cycle of EVs in Japan is higher than that of gasoline vehicles. As the curb weight of EVs is 30% higher than that of ICEVs with the same load capacity. The PM emission generated through friction between the wheels and the road while driving is more compared to ICEVs and the emissions of total PM_{10} and $PM_{2.5}$ from EVs are not less than those from the ICEVs [8]. According to the coal consumption index of ultra-supercritical power generation in China, the CO_2 emission and fuel consumption per 100 km of EVs are equivalent to that of 7.15 L gasoline cars. Presently, the fuel consumption of advanced ICEV and HEV is lower than a 7.15 L gasoline car (Fig. 4).

In the course of China's EV development, the high dependence on imported lithium, cobalt and other battery materials will create new resource safety risks. At present, the dependence on imported lithium and cobalt for manufacturing batteries in China exceeds 70 % and 80 %, respectively. In the past three years, the world has witnessed soaring prices of lithium and cobalt with the development of EVs. The rapid growth of EV production will further increase the price of lithium and cobalt, which may raise the cost of EVs to an unbearable level. The growth of EV population in China will also lead to an increase in spent batteries. It is estimated that by 2020, about 1.7×10^5 t of batteries will be scrapped in China. However, there is no mature, reliable or environmental friendly technology for battery recycling [9,10]. The adoption of fast charging technology has shortened the charging time with a great impact on the smooth operation of transformer, power distribution system, and the power grid. The population of China is quite concentrated and most of the new residential buildings are multi-story. This increases the difficulty in constructing charging piles, which in turn crucially restricts the promotion of EVs in China.

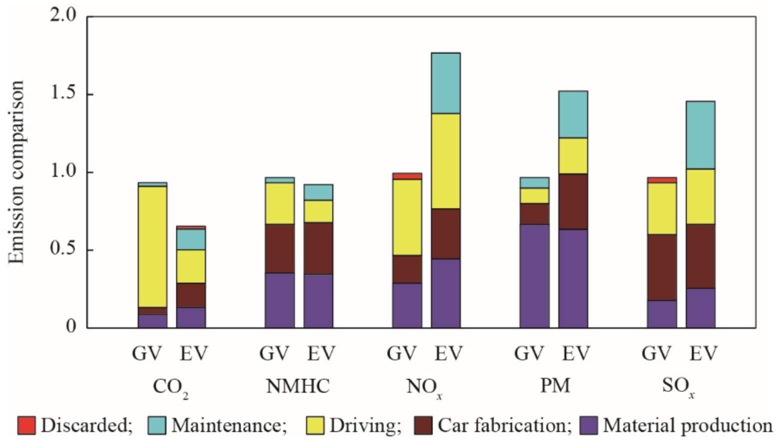

Fig. 4. Complete life cycle pollutant emission comparison between EV and ICEV.

The progress of FCVs is mainly constrained by factors such as manufacturing cost, durability, and reliability of the battery. The development of fuel cells in China lags behind that of other advanced countries [3], and the key fuel cell materials such as the catalyst, proton exchange membrane, carbon cloth/paper, membrane electrodes, sealant, and bipolar plate are mainly imported. Therefore, it has been difficult to form a complete fuel cell stack production chain thus far. The performance of indigenous Chinese batteries is lower than the advanced international ones; comparatively, the battery life is approximately 40% lesser and platinum loading of the catalyst is approximately 5 times higher in terms of the amount of platinum catalyst used for the indigenous batteries. This results in the low power density of the fuel cell stack and high production cost. Furthermore, the technical support is insufficient for the commercial production of 70 MPa hydrogen storage tank with valves and other associated equipment.

Hence, EVs, HFCVs and other NEVs cannot completely replace ICEVs in a short term.

3.2 Vehicle power diversification is the development trend, and internal combustion engine power will keep the leading role

Internationally renowned automobile enterprises, oil exploitation and refining companies, and energy and financial research institutions are constantly studying the automobile power revolution to determine a way to cope with the automobile power revolution. Fig. 5 shows the prediction trend of EV development from 2020–2040 made by different research institutions. The conclusions of the studies are quite different.

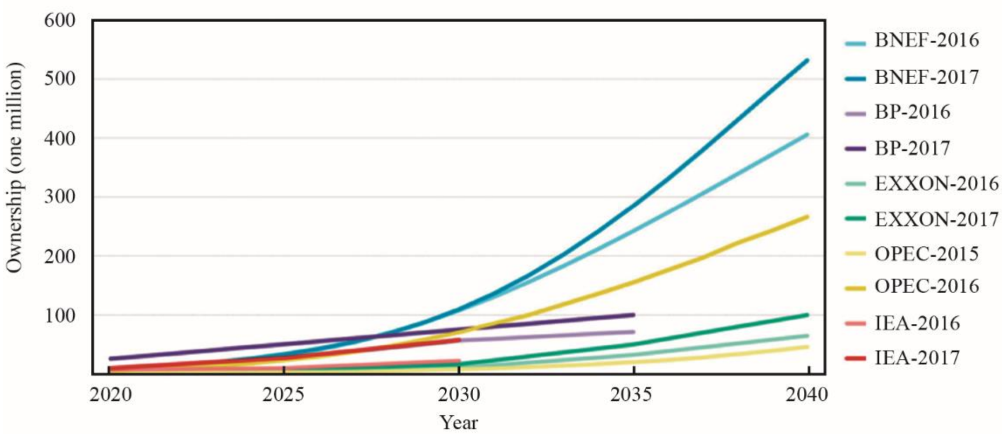

Fig. 5. Trend forecast of EV development made by different research institutions.

Source: BNEF

Technologies for HEVs, PHEVs, FCVs and EVs have their advantages as shown in Fig. 6. Each type occupies a corresponding market based on their technical characteristics. In future, the production, sale, and market share of HEVs, EVs, and FCVs will gradually increase. However, ICEVs will still dominate.

DOI 10.15302/J-SSCAE-2019.03.005

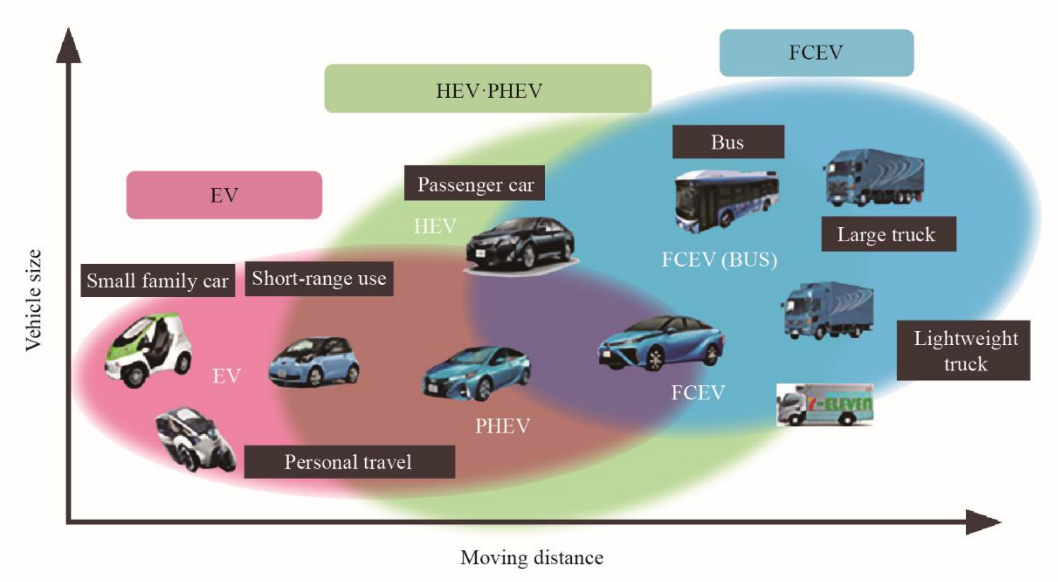

Fig. 6. Vehicle power evaluation diagram.

3.3 Forecast of trend and structure of automotive fuel consumption in China

In 2018, the car population per 1000 people in China was 173, much lower than the level of 500–800 in developed countries. With economic development, the car population in China continues to grow. According to national conditions, China will develop intercity high-speed railways and urban public transportation at a prodigious rate. Hence, the car population per 1000 persons will not touch that of developed countries. It is estimated that the car population will reach 260–280 million and 380–400 million by 2020 and 2030 respectively. By 2040 this number might reach 480–500 million with the national average car population per 1000 people increasing to approximately 350. In 2018, the total ownership of vehicles in China was 240 million, among which NEVs accounted for 1.09 %. However, in future the number of NEVs is bound to increase gradually. With the improvement in internal combustion engine technology, the development of HEVs and NEVs will affect the consumption of automotive fuel. By 2030, NEVs are expected to not significantly affect the consumption of liquid fuel. Up to 90% of cars will rely on liquid fuel by 2040, and by 2050 it will be more than 60%.

Fig. 7 shows the changes in China's automotive fuel consumption from 2005 to 2017. The diesel consumption in China grew rapidly from 2005 to 2015, reaching a peak of 1.73×10^8 t/a in 2015, and plateaued from 2016 onwards. Gasoline consumption is still growing steadily and is expected to peak around 1.70×10^8 t/a by 2025

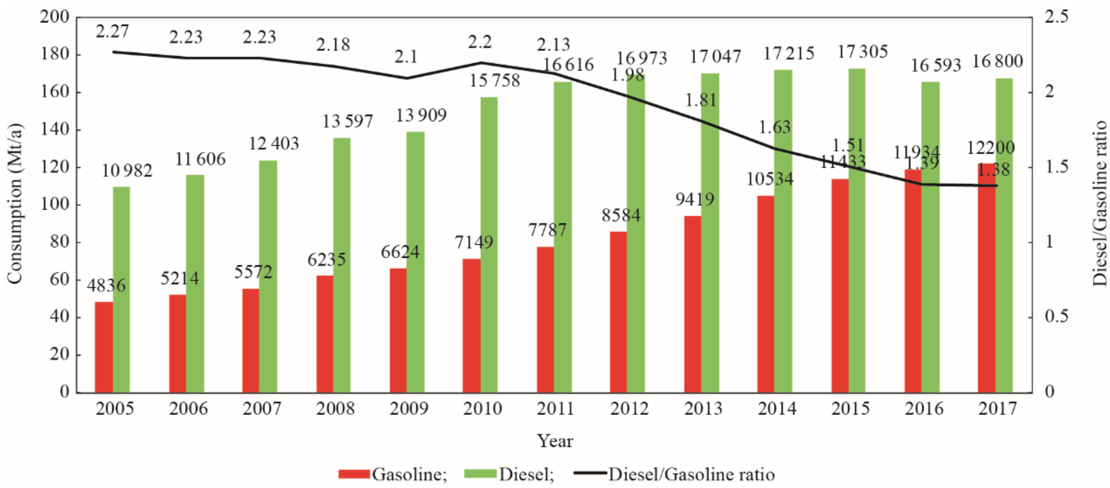

Fig. 7. Changes in China's automotive fuel consumption structure from 2005–2017.

4 Suggestions for the coordinated development of refining and automotive industry

4.1 Study on molecular-level fuel combustion mechanism in internal combustion engines

The internal combustion engine is a complex reactor where fuel reacts with air to convert chemical energy into mechanical energy through thermal energy. The transfer of fuel mass and energy in the reactor needs to be completed instantly at high speed with high efficiency in order to achieve full combustion and to reduce side reactions causing the formation of CO, THC, PM, and carbon deposition. Research on the combustion mechanism in internal combustion engine is the foundation for fuel composition optimization, innovation in the internal combustion engine structure, reaction pathway control, prevention of abnormal combustion reactions (such as detonation and pre-ignition), thermal efficiency improvement, low-carbon and low-pollutant emissions, and developing new internal combustion engines.

The composition of gasoline and diesel is very complicated. Gasoline is composed of hydrocarbon molecules consisting of 5 to 11 carbon atoms that can form more than 360 hydrocarbon molecules such as normal hydrocarbons, isomeric hydrocarbons, cycloalkanes, and monocyclic aromatic hydrocarbons with short side alkyl chains. Diesel is composed of hydrocarbons consisting of 12 to 20 carbon atoms, including normal hydrocarbons, isomeric hydrocarbons, long side-chain cycloalkanes, long side-chain monocyclic aromatic hydrocarbons, bicyclic aromatic hydrocarbons, and tricyclic aromatic hydrocarbons. Upon entering the engine cylinders, the fuel should be completely vaporized and mixed with the air in a very short period. As the boiling point, flash point, vaporization heat, and combustion heat of different hydrocarbon molecules differ remarkably, the vaporization rate and oxygen-mixing rate are quite different between the molecules. Hence, the process of combustion reaction between different hydrocarbon molecules and oxygen also differs.

Based on the results of molecular-level analysis and characterization of gasoline and diesel, the combustion mechanism in internal combustion engine is understood from the molecular perspective. This knowledge should guide the development of clean and efficient internal combustion engine theoretically, and help us obtain the molecular structure and composition of hydrocarbons fuels to ensure clean and efficient combustion reactions in the engine. These researches can theoretically lead the optimization of fuel composition and distillation range, targeting the advancement of molecular-level oil refining theory and technology.

4.2 Study on the model of correlation between automotive fuel composition and particulate matter emission

The limit on particulate matter emission is the core index for upgrading vehicle emission standards. Stage 6 requires the particulate matter number (PN) to be 6×10^{11}#/km. Fuel composition is an important factor affecting PM emissions. Honda Motor Company’s particulate mass index (PM index) can predict the influence of fuel composition in particulate emission trend from a model perspective, and has been verified in some vehicle fuel research projects and bench scale tests. In order to guide the optimization of liquid fuel composition, a simplified PM index model was developed that could link PM index with distillation range parameters and standardize the indexes. Based on several studies, Toyota Motor Corporation and other car companies proposed that gasoline standards should introduce a limit value on T70, while European car companies proposed T90 instead.

The content of heavy aromatics has a significant effect on particulate matter emission. Therefore, controlling the PM index by limiting the distillation range of liquid fuel can control the content of heavy aromatics in gasoline. It is necessary for Chinese oil enterprises to cooperate with automobile companies and learn from overseas research achievements, understand the relationship between fuel composition and PM, develop simple models, and lay a solid foundation for the establishment of China’s National 7 vehicle fuel standard.

4.3 Development of high-quality fuel

Automotive fuels in the future should be clean enough to support near-zero emissions from internal combustion engines (without negative impact on the atmosphere) and help automobile manufacturing enterprises improve engine efficiency, reduce fuel consumption and carbon emissions. According to current understanding, automobile gasoline is required to be free from C9+ aromatics, and increase the research octane number (RON). Taking into consideration the needs for good startability and drivability of vehicle, evaporation and emission of automotive fuel, the Reid vapor pressure (RVP) value of automotive gasoline should be regulated according to the conditions of different regions/seasons, and meanwhile, the automotive diesel fuel is required to contain less polycyclic aromatics.

In future, the oil refining industry should pay attention to general oil processing flow scheme for upgrading products quality and concurrently develop and produce high-quality automotive fuel. Firstly, it is necessary to

DOI 10.15302/J-SSCAE-2019.03.005

improve RON of gasoline. Grades such as RON 89 gasoline and RON 92 gasoline should be abolished as soon as possible. The supply of RON 95 gasoline should be decreased gradually while boosting the production of gasoline with a RON higher than 98. Secondly, it is important to optimize the distillation range of gasoline by decreasing T50 temperature from 110℃ to less than 105℃, and adding a limit value on T70 or T90. Thirdly, to reduce the content of polycyclic aromatic hydrocarbons (PAH) in diesel fuel from 7 v% to a lower level. A well-known foreign automobile manufacturing company has put forward a proposal on improving gasoline efficiency by raising the gasoline RON without mandatory limit on gasoline MON. The olefin in gasoline improves RON, therefore the limit for that can be moderated. Their new research is quite different from conventional understanding and may not be accepted in China in a short term. However, abiding by the principle of clean emission and high efficiency, an in-depth study on the influence of gasoline RON, olefin and aromatic content on both emissions and internal combustion engine efficiency should be carried out to lay the foundation for drafting new gasoline standards on a scientific basis.

4.4 Development of new specification fuel

With a target of 60 % engine thermal efficiency, the internal combustion engine industry is actively developing advanced technologies such as gasoline compression combustion (GCI), dual-fuel reactivity controlled compression ignition (RCCI), gasoline/diesel highly premixed charge combustion (HPCC), homogeneous charge compression ignition (HCCI) combustion, and appropriate and highly-stratified gasoline direct-injection compression ignition (GDCI), etc. [4]. These technologies should be matched with new specifications of automotive fuels. For example, after carrying out gasoline compression combustion research, Gautown Kalghatgi, et al., have proposed new fuel specifications [11,12] as shown in Table 5 for mass production and promotion of compression-ignition internal combustion engines. The refining industry should cooperate with the automotive industry to understand the influence of composition, distillation range and other quality indicators on thermal efficiency and emissions to help formulate new fuel specifications. Based on available research results, mass production and popularization of gasoline compression-ignition internal combustion engines will shoot up the consumption of low-octane gasoline, helping refineries produce more gasoline with 98+ RON for current gasoline engines.

Table 5. Performance indicators of new fuel for GCI.

Quality item	Value	Quality item	Value	Quality item	Value
RON	70–85	IBP (℃)	28	Aromatic content (v%)	<35
Cetane number	<27	EBP (℃)	250	Sulfur content ($mg·kg^{-1}$)	<10
Density (15℃) ($kg·L^{-1}$)	0.72–0.8	Olefin content (v%)	<18	Benzene content (v%)	<1

Faced with the development of novel internal combustion engines, the oil refining industry and automotive manufacturing industry should jointly form an innovation team to study new combustion technology related to the internal combustion engine and take initiative in R&D of new fuel specifications to set standards for new fuel on timely basis. The oil refining industry should simultaneously develop, process, and optimize the configuration for new fuel specifications.

4.5 Development of high-grade lubricating oil

To reduce the fuel consumption of an engine, friction loss should also be reduced. With the structural improvement of moving parts in high-efficiency internal combustion engines, and material surface modification, refining industry should correspondently develop technologies for associated lubricating base oils and additives. The consumption growth of high-grade lubricating oils for automobiles has become the main impetus to all high-grade lubricants in China. With the increase in high-efficiency and low-emission ICEVs, oil-refining enterprises should speed up the readjustment of lubricating oil products to raise the production of high-grade lubricating oils for ICEVs.

5 Conclusions

NEVs such as EVs and HFCVs have initiated vehicle power revolution, entering into an era of automobile power diversification. Due to technological constraints, resources, and markets, the development of EVs and FCVs will be a gradual and prolonged process. There remains large space for improving the thermal efficiency of internal combustion engines, while the HEVs equipped with high-efficiency internal combustion engines can greatly reduce pollutant and carbon emissions that are in line with China's national conditions. In the coming decades, internal combustion engine will maintain its dominance in the automobile power market, and the dependence of automobile on liquid fuel will account for over 60% by 2050. China's diesel fuel consumption has entered a peak plateau period, and the automotive gasoline consumption is expected to reach its peak by 2025. To meet the requirements for clean emission and high-efficiency ICEVs, the coordinated development between oil refining industry and automobile industry to produce high-quality automotive fuels and lubricants should be promoted. Meanwhile, to cope with R&D and mass production of novel internal combustion engines, we should consistently develop fuels of new specifications.

References

[1] International Energy Agency. Global EV outlook 2018 [R]. Paris: International Energy Agency, 2018.

[2] Information Trends LLC. Hydrogen fuel cell vehicles—A global analysis [R]. Washington D.C.: Information Trends LLC, 2018.

[3] Editorial Department of China Journal of Highway and Transport. Review on China's automotive engineering research progress: 2017 [J]. China Journal of Highway and Transport, 2017, 30(6): 1–197. Chinese.

[4] Su W H, Zhang Z J, Liu R L, et al. Development trend for technology of vehicle internal combustion engine [J]. Strategic Study of CAE, 2018, 20(1): 97–103. Chinese.

[5] Zhao F Q. Rational assessment of the challenges, potentials and opportunities of internal combustion engines [N]. China Automotive News, 2019-03-07(004). Chinese.

[6] Krishna V S, Hari O B, Dheerendra S. A comprehensive review on hybrid electric vehicles: Architectures and components [J]. Journal of Modern Transportation, 2019, doi.org/10.1007/s40534-019-0184-3.

[7] Hu X G. Advances in battery technologies for electric vehicles [M]. Beijing: Chemical Industry Press, 2018. Chinese.

[8] Timmers V R J H, Achten P A J. Non-exhaust PM emissions from electric vehicles [J]. Atmospheric Environment, 2016, 134: 10–17.

[9] Zhang X X, Wang Y Y, Liu Y, et al. Recent progress in disposal and recycling of spent lithium-ion batteries [J]. Chemical Industry and Engineering Progress, 2016, 35(12): 4026–4032. Chinese.

[10] Zheng X H, Zhu Z W, Lin X, et al. A mini-review on metal recycling from spent lithium ion batteries [J]. Engineering, 2018 (4): 361–370.

[11] Kalghatgi G T. The outlook for transport fuels: Part 1 [J]. Petroleum Technology Quarterly, 2016 (Q1): 23–31.

[12] Kalghatgi G T, Gosling C, Wier M J. The outlook for transport fuels: Part 2 [J]. Petroleum Technology Quarterly, 2016 (Q2): 17–23.