Clean Techn Environ Policy (2016) 18:7–15
DOI 10.1007/s10098-015-1019-5

PERSPECTIVE

Technology strategy to meet China's 5 L/100 km fuel consumption target for passenger vehicles in 2020

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Received: 12 May 2015 / Accepted: 28 July 2015 / Published online: 11 August 2015

Abstract In an effort to solve the growing energy and environmental issues, China launched the fuel consumption regulation, which requires the fleet average fuel consumption of new passenger vehicles to reach 5 L/100 km in 2020. The technology strategy to meet the regulation target has become a major concern for the Chinese as well as global automotive manufacturers. This paper aims to systematically and critically appraise the technology strategy from two perspectives, namely the 'energy-saving' and 'new energy' strategies. Our analysis indicates that conventional powertrain still has great potential for energy conservation. Potential from existing engines should continue to be explored. The developing of transmission system should be more fuel efficiency oriented. Vehicles that use lightweight materials to conserve energy should be fully explored. From the system perspective, the assembly and overall design of vehicles need to be optimized. New energy vehicles are yet capable of competing with conventional vehicles. They face the challenges of power generation transformation, battery technology immaturity, and lack of charging infrastructures. Hybrid electric vehicles are the appropriate embodiment of technological transition from conventional vehicles to new energy vehicles.

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Keywords Fuel consumption regulation · Technology strategy · Conventional vehicle · New energy vehicle · Hybrid electric vehicle

Abbreviations

AT	Automatic transmission
BEV	Battery electric vehicle
CVT	Continuously variable transmission
DCT	Dual clutch transmission
DI	Direct injection
EPS	Electrical power steering
EU	European Union
FCV	Fuel cell vehicle
HEV	Hybrid electric vehicle
ICCT	International council on clean transportation
IEA	International energy agency
ISG	Integrated starter generator
ITS	Intelligent transportation system
MIIT	Ministry of industry and information technology
MPG	Mile per gallon
PHEV	Plug-in hybrid electric vehicle
PM	Particulate matter
REEV	Range-extended electric vehicle
TDI	Turbocharge direct injection
VVL	Variable valve lift
VVT	Variable valve timing

Introduction

Passenger transportation system evolves as social-economic factors change. Over the past decade, China's economy has been growing in high speed. At the same time, China's urbanization rate increased significantly. Under such a circumstance, significant changes happened

Table 1 China's historical registered vehicle population

Unit: million	2005	2006	2007	2008	2009	2010	2011	2012	2013
Passenger vehicles	19.2	24.0	29.6	36.0	45.9	58.6	72.0	86.8	103.1
Buses	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.6	2.5
Trucks	9.6	9.9	10.5	11.3	13.7	16.0	17.9	18.9	20.1
Others	0.7	0.9	1.1	1.3	0.7	0.8	0.9	1.0	1.0
Total	31.6	37.0	43.6	51.0	62.8	78.0	93.6	109.3	126.7

to both the scale and structure of China's passenger transportation system. On the scale aspect, China's passenger transport volume increased from 1.2 trillion passenger-km in 2000 to 2.8 trillion passenger-km in 2013, with an annual growth rate of 6.4 %. On the structure aspect, the demand for private transport increased significantly, which was reflected in the booming passenger vehicle market. In 2014, total vehicle sales reached over 23 million, in which 20 million were passenger vehicles (CAAM 2014). Even with a conservative estimation of 4.5 % annual growth rate in vehicle sales, China's vehicle market will achieve 30 million sales in 2020 (Hao et al. 2011b). In addition, the implementation of relevant government policies may help increase the oversea sales to exceed 5 million. China's historical registered vehicle population is shown in Table 1 (NBS 2015).

China is rapidly entering the society where vehicles are one main form of transportation. For example, the share of vehicle travel out of total urban travel in Beijing increased from 23.2 % in 2000 to 32.6 % in 2012. During the same period, the share of public transport (including transit bus and urban rail) increased from 26.5 to 44.0 % (BTRC 2013). As a result, it is facing a series of challenges in transportation sector, with energy and environment as the most severe challenges (Hao et al. 2014b, 2015). Over the past few years, many cities and regions have experienced long-time chemical smog or haze, severely affecting the lives of local residents. Particulate matter (PM) is gradually becoming a focus of wide concerns for the entire society. According to official figures, nitrous oxides and PM emissions from vehicles occupy over 90 % of atmospheric pollution for each of the substance. In case of hydrocarbons and carbon monoxide, the emission levels exceed 70 % for each of the substance (MEP 2014). Since the environmental capacity to absorb these pollutants is limited, environmental protection will become an increasingly important assessment criterion for the automotive manufacturing industry (Chen et al. 2013; Schepper et al. 2014). Energy supply is the key limiting factor for automotive industry in China (Hao et al. 2011a). According to official statistics, China's reliance on imported oil is increasing. In 2014, China's dependence rate on oil import reached 59.6 % (NBS 2015). It is estimated that by 2030, the dependence rate on oil import will exceed 70 %.

To solve the social issues related to the increasing vehicle ownership, China has implemented a series of policy measures. These include a cap on fuel consumption, regulation on emission, implementation of policy incentives for the purchasing of new energy vehicles, pushing the development of low carbon fuel, and strategy to prioritize road development for public transportations, such as buses (Hao et al. 2014a). Among these measures, the policy concerning a cap on vehicle fuel consumption has had the greatest impact on the automotive manufacturing industry in China. What strategic technical innovation can be used to satisfy the newly updated regulation has become a key concern for the Chinese and international automotive manufacturers. This paper focuses on this key concern by systematically evaluating the technical strategies that could be implemented to meet the 5 L/100 km target by 2020.

China's passenger vehicle fuel consumption regulation

From a broad international perspective, the European Union (EU) has created the most robust and stringent regulations on vehicle CO_2 emission in the world. The regulation stipulates that CO_2 emission level for new passenger cars need to achieve 130 and 95 g/km by 2015 and 2021 respectively. This is a fall of 18 and 40 %, respectively, compared to the level in 2007 (EC 2014). In 2011, Japan also issued new regulation on energy consumption for passenger vehicles. The regulation requires that new passenger vehicles should reach the level of 20.3 km/L by 2020, which is equivalent to the EU emission regulation of 105 g CO_2/km, improving fuel efficiency by 24.1 % compared to 2009 (METI 2011). Moreover, in 2012, the US issued new regulation on energy consumption, requiring new cars and pick-up trucks to reach fuel economy level of 54.5 mile per gallon (MPG), which is equivalent to the EU emission regulation of 107 g CO_2/km. Some developing countries also implemented fuel consumption regulations (Mohammadnejad et al. 2014). The global comparison of vehicle fuel consumption regulations is illustrated in Fig. 1 (EPA 2012; ICCT 2014).

In 2013, the Ministry of Industry and Information Technology (MIIT) issued the guideline on calculating

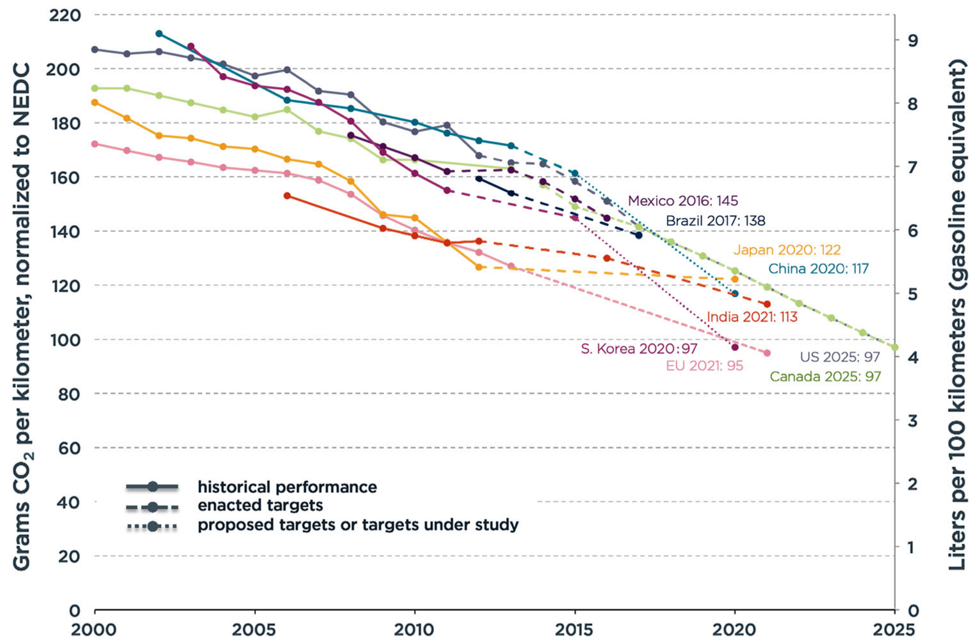


Fig. 1 Global comparison of passenger vehicle fuel consumption regulation

average fuel consumption of passenger vehicles for automotive manufacturers, requiring Chinese vehicle manufacturers to reduce the average fuel consumption of passenger vehicles to 6.9 L/100 km by 2015, with a further reduction to 5 L/100 km by 2020 (MIIT 2013). Currently, the government has already organized expert groups to research and discuss this topic. The above requirements will most likely be implemented in the form of official legislation. However, the targets are quite difficult to achieve. In 2012, Chinese automotive manufacturers reported an average fuel consumption of 7.38 L/100 km, in which joint venture companies reported 7.42 L/100 km and China's self-owned companies reported 7.3 L/100 km (iCET 2013). Given that China's self-owned automotive manufacturers produced smaller models, and that joint venture companies have extensive technical expertise, it is clear that Chinese manufacturers face a greater challenge. According to this policy, all manufacturers have to reduce average fuel consumption by 5 % each year in order to achieve the target of 5 L/100 km required. This contrasts sharply with the levels of change seen between 2006 and 2012, when the average fall in fuel consumption is only 1.3 %, including 2012, when the fall is 2.3 % (iCET 2013). Therefore, this is not an easy target to achieve even for joint venture companies.

Apart from more stringent regulatory standards, the new regulation also places different emphasis on different vehicles. The fourth phase of fuel consumption regulation is particularly strict on large vehicles. Although the target average fuel consumption compared to the third phase was reduced by 30 %, vehicles with curb weight greater than 2500 kg was given a target reduction rate of 36.5 %, making it even more difficult to achieve the required standard, as illustrated in Fig. 2.

Looking beyond 2020, the fuel consumption regulation will become tougher from both the global and Chinese perspective. Predictions based on estimates by the International Energy Agency (IEA) and other relevant organizations suggest that the average passenger vehicle fuel consumption in 2025 and 2030 will fall and reach 3.7 L/100 km and 2.7 L/100 km, respectively, as illustrated in Fig. 3 (IEA 2012).

Technology strategy to achieve the 5 L/100 km target

Overarching strategy

The strategy needed to cope with the challenges of energy conservation and environmental protection requires a variety of approaches (Sellitto et al. 2015). However, there is only one fundamental key to this, technology improvement. Only by advancing technology, can we overcome the challenges posed by energy conservation and environmental protection. To solve the current energy problem, we need to apply both the 'energy-saving' and 'new energy' approaches. The energy-saving approach implies improvement and optimization of existing technologies. The new energy approach implies the identification of new power sources, as illustrated in Fig. 4.

The energy-saving and new energy approaches are not contradictory. Both are equally important for achieving the ultimate objective. Automotive manufacturers need to pay

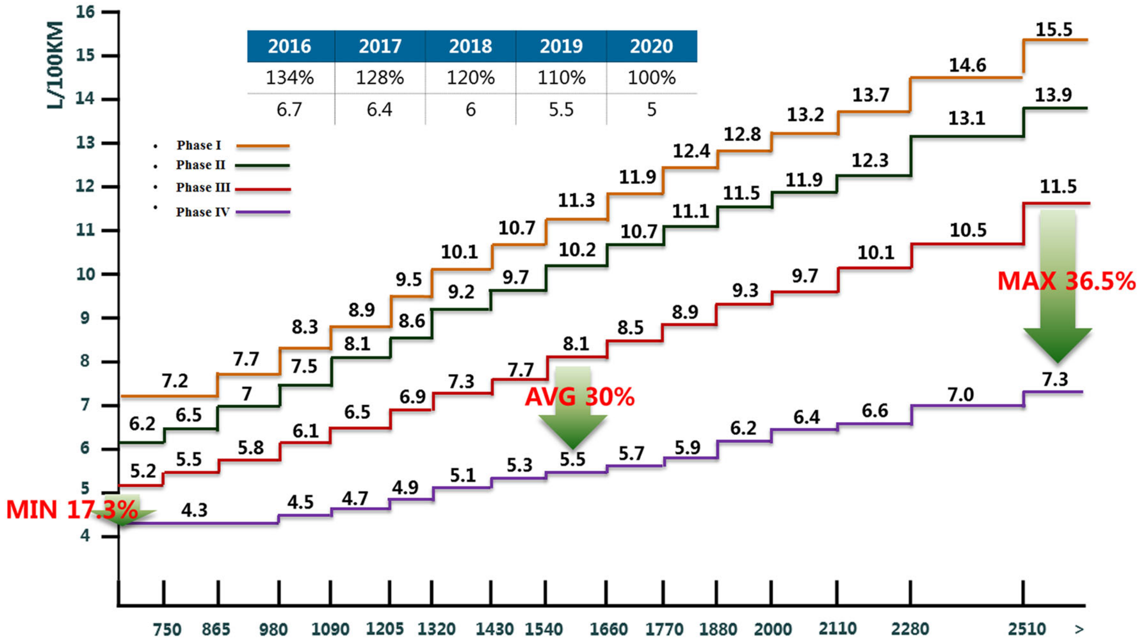


Fig. 2 Chinese passenger vehicle fuel consumption regulation comparisons at different phases

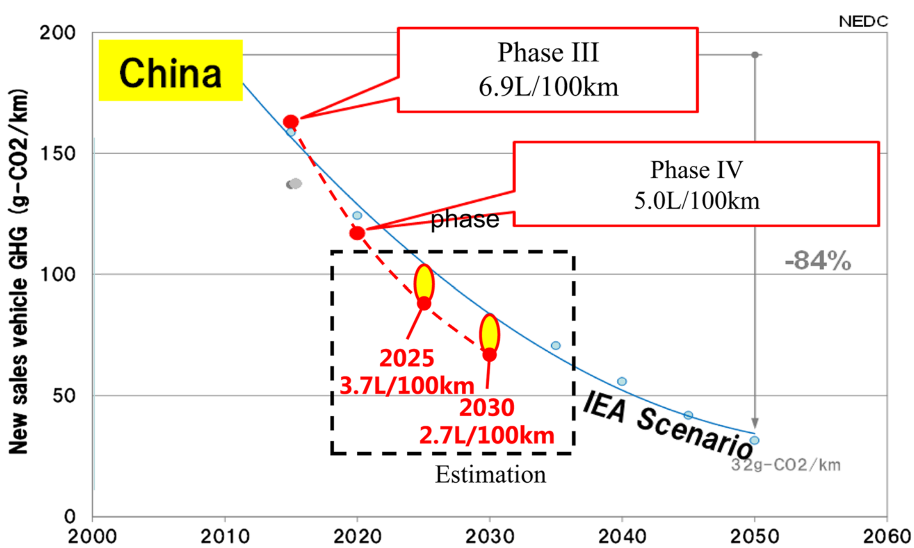


Fig. 3 Prospect of future Chinese passenger vehicle fuel consumption regulation

higher attention to energy-saving technologies, while appropriately distribute energy-saving and new energy technologies development efforts within the enterprise. The national and large scale research institutions, however, must focus on new energy technologies. Even though there have been continuous debates on the benefits and costs of new energy and conventional propulsion technologies, the transition from conventional propulsion technology to new energy technology is a general trend that is likely to continue. The advances in engine development will provide valuable time for new energy-based propulsion systems to become better established, while the rapid advancement of the new energy system will enable existing engine technology to exhibit greater effects in particular areas, stimulating advances in each other. Only in this way, can we guarantee sufficient motivation for the motor industry to strive for innovation. If we continue to argue between the new energy system and the conventional propulsion system, this will ultimately inhibit the advancement of technology.

As Fig. 5 illustrates, energy-saving technology is a systematic engineering. Specifically, in terms of conventional vehicles, this means engine optimization, gear box optimization, and a combination of the two. By achieving

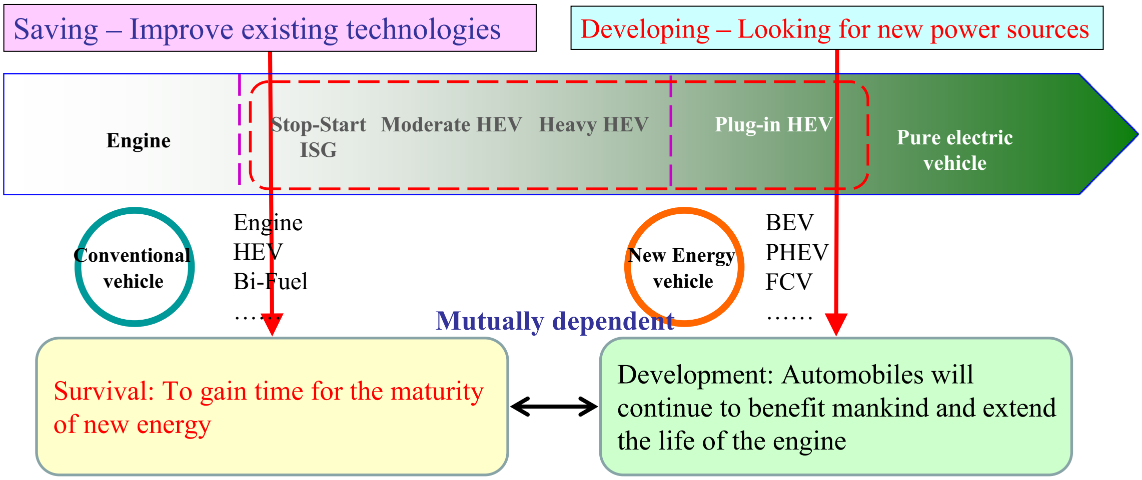


Fig. 4 Technological characterizations of vehicles based on 'Developing' and 'Saving' strategy classification

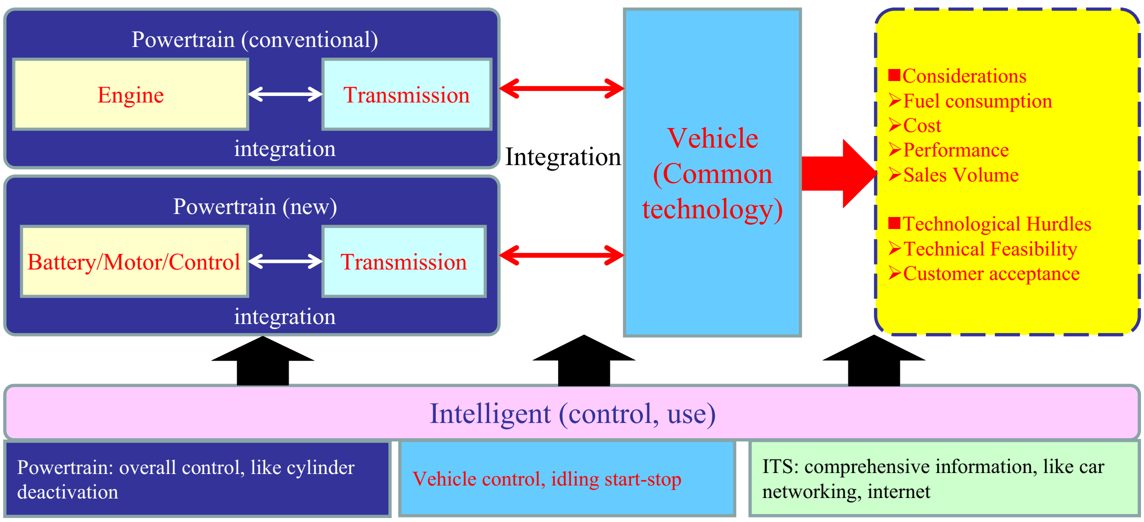


Fig. 5 Energy-saving engineering systems for vehicles

overall optimization, this will lead to satisfying fuel consumption, cost, and performance targets. On the other hand, for new energy vehicles, one should focus instead on battery—motor—electronic control systems optimization, gear box optimization, and the combination of the two. Control and use of intelligent technology forms a constant thread throughout the system. For example, intelligent traffic system can be realized by using information technology to form an internet of vehicles.

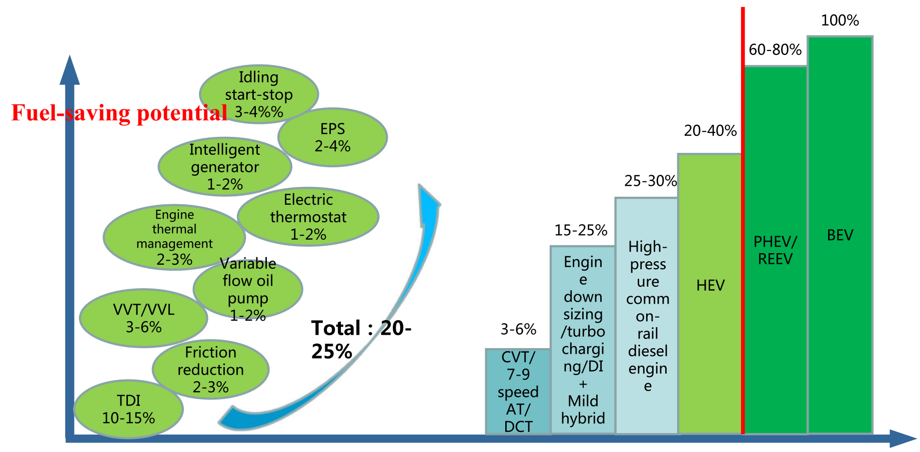
Energy-saving technology

When regarding energy-saving technologies, there is significant scope for efficiency improvement in conventional propulsion systems. First of all, we can perform comprehensive optimization of the engine, as illustrated in Fig. 6. There is still a significant gap between world-leading engine manufacturers and China's domestic engine manufacturers. Given the current level of engine development, with some technical input and investment, there is still approximately 15 % of improvement potential for China's engine manufacturers.

Secondly, according to official statistics, further development potential remains in foreign engine manufacturers. If optimization in variable control can be further improved, it is possible that a further 15 % development capacity might be achieved. The above statements imply that for Chinese engine manufacturers, there is 30 % of engine efficiency improvement potential remaining to be explored.

Thirdly, fuel diversification for conventional engine technology will develop. The possibility of using alternative sources of fuel, such as biofuel, natural gas, and

Fig. 6 Fuel-saving potential of vehicle engines



liquefied natural gas continue to exist. The development of alternative fuel will continue to extend the life of conventional engines.

Finally, the marketing of diesel engines can be improved further in China. Despite the fact that diesel engine is at a disadvantage in terms of its emission standard, the advantage of its ability to save between 30 and 40 % fuel is a fact that cannot be ignored. Although China cannot rapidly expand the share of diesel engines within the engine market in the same way as that in Europe, diesel use will increase as a general trend under normal conditions of market development. Some of the existing data suggested that as the sales of gasoline cars increase significantly, huge changes have already occurred in terms of gasoline to diesel consumption ratio, providing space for expansion of diesel cars. Overall, technological breakthroughs in engine development, renovations in alternative fuel, and the introduction of diesel cars in the market will ensure that the engine will survive globally for another 30–40 years.

Energy-saving technologies also include development of the gear box. Traditionally, the development of the gear box focused mainly in two areas; the first was the realization of automatic gear box, which improved driving comfort; the second was cutting down on cost to an affordable level for consumers. However, following a new round of gear box development and technical specification selection, the focus of gear box development must be on energy-saving. Only by selecting the right technical specification, can we expect significant energy-saving effects from gear box development.

Energy-saving must be considered from the system assembly perspective. Use weight reduction as an example, a reduction of 10 % in vehicle weight translated into a reduction of 6–7 % in fuel consumption (Cheah 2010). The fuel-saving method based on weight reduction is illustrated in Fig. 7. Moreover, the effect of weight reduction becomes more significant with the application of new

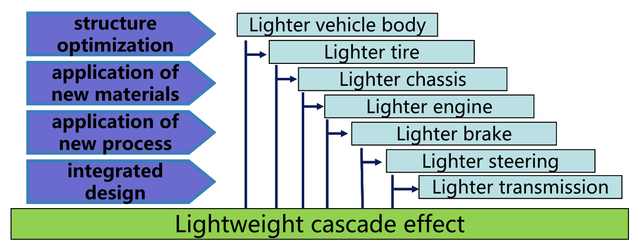


Fig. 7 Fuel-saving measures based on weight reduction

energy technologies. Given a vehicle weighing 1500 kg with an additional 300 kg battery installed, the effect of weight reduction technology can be easily envisaged. Other common ways to increase energy efficiency include wind drag reduction, the use of fuel-efficient tires, intelligent air conditioning system, electric power steering, etc. These energy-saving measures are fundamental not only to conventional propulsion systems, but also for new energy systems. Their importance will not diminish with the application of new energy systems. It is in fact more important than ever because if these other measures are not maintained, the energy saved by using the new energy system will be wasted on inefficiencies of these other measures. A reduction of 15 % in engine energy consumption in principle would reach the efficiency limitation of Carnot Cycle. But we know that technological advances in tires can have 1 % energy-saving effect, a 0.02 % reduction in drag reduces energy consumption by 1 % (NRC 2011). Therefore, the future of energy-saving and environmental protection requires that we do not miss a single energy-saving emission reducing technology. Only by accumulating every single energy-saving measure, can we hope to achieve our overall energy-saving target.

In addition, during the development of energy-saving technologies, the role of system integration demands high attention in order to maximize the energy-saving effect. For example, the effective integration of engine and gear box, standardized complementarity between engine assembly and system assembly. Although system integration cannot optimize the vehicle in every aspect, the automotive manufacturer must know where the breakthrough may occur. The current need for energy-saving technology continues to remain strong above everything else in the sector. For example, acceleration performance is often used as an advertising gimmick. But in reality, apart from niche markets, ordinary customers under normal circumstances will not have the opportunity to experience the actual impact of this technology. Fuel consumption and emission problems must be resolved through modification of the system. Doing so will not only bring benefit to the automotive manufacturers, but also provide real experiences of technology to consumers.

New energy technology

The concept of new energy technology has many different interpretations. According to MIIT, new energy vehicles include plug-in hybrid electric vehicle, full electric vehicles (excluding lead acid battery powered), and fuel cell vehicles. Further analysis of the new energy vehicle technology must remain critical and objective (Teixeira et al. 2015). First of all, because of the special conditions in China in terms of its generation structures, the premise for developing new energy vehicles is clean power. Without reform of the generation system, the rationale for developing electric vehicles would not exist. Secondly, conventional energy-saving technologies and new energy vehicles are closely linked. Dedicated gear box and engines for new energy vehicles rely on conventional engine as basis for their development. Weight reduction energy-saving technology has enormous significance for both conventional vehicle and new energy vehicles. Therefore, we must not ignore conventional energy-saving measures, and attempt to integrate them together instead.

It took over 100 years for conventional engines to develop to the level we know today. It is impossible for new energy technology to replace it overnight, so this process is likely to take a long time. Currently, the breakthrough for new energy vehicle technology is yet to occur. In particular, the future of electric vehicles may never become a reality if significant advances in battery technology do not occur. Although methods are improving in overcoming the limitations of the technology and the cost involved, these problems remain unresolved. Therefore, conventional engines will likely continue to dominate in the next 10–20 years. Despite having many advantages, electric vehicles still require decades of development. During this transition process, the market share that new energy technology occupies will steadily increase over time.

Charging facility and infrastructure is another limitation for the development of new energy vehicles (Majumdar et al. 2015). Currently, charging infrastructure development is lagging behind, making it difficult to charge electric vehicles, inhibiting its use and wider distribution. In terms of charging times, even with fast charging, current charging technology require no less than 20 min (Capasso and Veneri 2015). This will inevitably be difficult for consumers to accept. In addition, this implies that charging stations require large areas of land. The key to solving the above problems lies in finding an appropriate business model for these new energy vehicles and accelerating the construction of charging facility and infrastructure.

There are a few questions regarding the validity of the new energy vehicles. Firstly, electric vehicles are yet sufficiently advanced to achieve the level required for mass production. The criteria required for mass production, however, remain unclear. If the market share can reach approximately 3 %, then this means it is already a commercialized business, offering the prospect of further growth. There are already many models of new energy vehicles on the market. Given that China has over 23 million vehicles sales per year, even if new energy vehicles occupy 5 % of the market, then this translates into 1.1 million vehicles. In the past, we have seen internal combustion engine undergoing a lengthy period of development before becoming upscaling to industrial levels. The same patience must be given to new energy vehicles in terms of time.

Secondly, the functionality of the electric vehicles differs significantly from the conventional vehicles. Conventional vehicles have the advantages of higher driving range, better acceleration, durability, and low cost. It can function under extreme conditions, such as high temperatures, low temperatures, high altitudes etc. It is unreasonable to expect new energy vehicles to reach this level at this stage. Conventional and new energy vehicles are developing at different stages. The characteristics of the two are different and should not be simply compared.

In the future, the choice of transportation model should depend on different localities, as illustrated in Fig. 8. In terms of locality, moving about the area inside the city means the distance traveled will be short, the area of movement is restricted. Hence short distance low-cost electric vehicles should widely be used. For people living in the distal townships, it is also more appropriate to use short distance low-cost electric vehicles. As for people living in the suburbs, who need to travel in and out of the city and the townships, they will need long distance transportation and so conventional vehicles will be a more appropriate option.

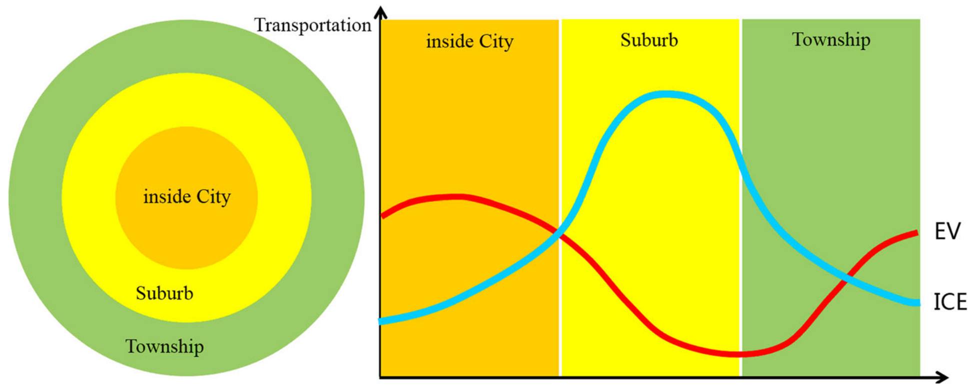


Fig. 8 Appropriate methods of transportation under different locations

Crossover technology: hybrid electric vehicle

Hybrid electric vehicle is the bridge between conventional vehicle and new energy vehicle. It can be used to overcome flaws in the conventional vehicles, and exploit the potential of new energy technologies. However, currently, this is being overlooked in China, even despised.

Before battery and motor can be perfected, hybrid technology is the most eligible system during the transition from conventional vehicle to electric vehicle. Hybrid technologies can be further divided into multiple technology categories that differ both in fuel consumption and costs. These include idling start-stop technology, mild hybrid, medium hybrid, and heavy hybrid. There is significant development potential for idling start-stop technology in China because of its low-cost and well-proven performance; light hybrid and medium hybrid also have large development potentials, due to the expansion of various applications particularly for small and medium-sized cars. Heavy hybrid system is highly complex, with increasingly higher cost.

Conventional, hybrid, plug-in hybrid, and full electric vehicles will exhibit different market trends and occupy different shares of the market as time passes. When electric vehicle reaches significant share of the market in certain areas, its mileage capacity will be noticed, driving demand for electric generators, and hence, plug-in hybrid will in turn develop. Eventually, electric vehicles will become the mainstay of transportation, but the process of achieving this may take at least 50 years.

Conclusive remarks

This paper aims to systematically and critically appraise the technical innovation and strategies needed to achieve China's 5 L/100 km fuel consumption target for passenger vehicles in 2020. The analysis is based on two perspectives, namely the energy-saving and new energy perspectives. Our analysis suggests that conventional powertrain still has great potential for energy conservation. Potential from existing engines should continue to be explored. The developing of transmission system should be more fuel efficiency oriented. Vehicles that use lightweight materials to conserve energy should be fully explored. From the system perspective, the assembly and overall design of vehicles need to be optimized. New energy vehicles are yet capable of competing with conventional vehicles. They face the challenges of power generation transformation, battery technology immaturity, and lack of charging infrastructures. Hybrid electric vehicles are the appropriate embodiment of technological transition from conventional vehicles to new energy vehicles.

Acknowledgments This study is sponsored by the National Natural Science Foundation of China (71403142), the Automotive Energy-saving Technologies Evaluation and Related Policy Measures Research ([2013]506). The authors would like to thank the anonymous reviewers for their reviews and comments.

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