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Fuel-efficiency technology trend assessment for LDVs in China: Vehicle technology

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1 Background

Fuel-consumption standards drive down China's use of fuel by the on-road sector and encourage the uptake of advanced vehicle-efficiency technologies. Understanding the need for a policy roadmap and long-term strategies to provide certainty for long-term fuel consumption, technology advancement, and potential compliance costs for manufacturers, China is looking ahead to advance post-2020 standards for light-duty vehicles.

In its "Made in China 2025" strategic initiative (MIIT, 2015), China set a 2025 fleet efficiency target of 4 L/100 km for passenger cars, a 20% decrease from the 2020 target of 5 L/100 km. In the Technology Roadmap for Energy Saving and New Energy Vehicles published by the Society of Automotive Engineers of China (SAE China, 2016), a 2030 fleet efficiency target of 3.2 L/100 km was set. To evaluate whether and how these targets can be met, it is essential to understand what technologies will be available within the 2020-2030 timeframe and what the costs of applying those technologies in the Chinese market will be.

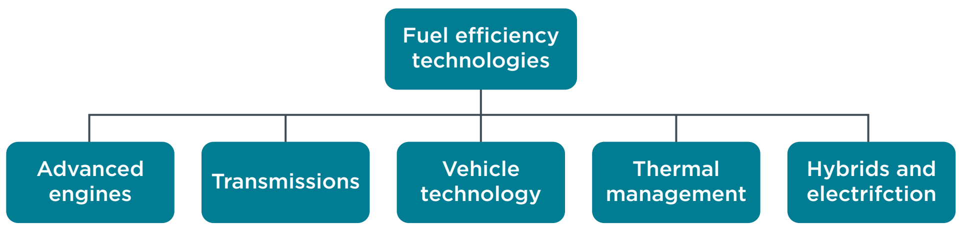

Figure 1 Categorization of fuel efficiency technologies in the briefing

This series of technical working papers aims to provide a comprehensive understanding of the current availability, effectiveness, and future market penetration of key fuel-efficiency technologies that manufacturers are likely to use in China by 2030. This information enables a more accurate, China-specific understanding of future technology pathways.

We group technologies into several categories: advanced engine, transmission, vehicle technologies, thermal management, and hybrids and electrification (Figure 1). The specific technologies we considered include those that are available today and others that are under development and expected to be in production in the next 5-10 years.

This research relies on information from publicly available sources, third-party databases, and information from the participating partners. Our approach includes:

- A detailed literature survey, including both Chinese and global regulatory documents, official announcements, and industry and academic reports.
- Analysis of databases from Polk and Segment Y.
- Conversations with manufacturers, tier one suppliers, research entities, and domestic and international experts.

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For each key technology, we discuss how it reduces passenger-car fuel consumption, its effectiveness in reducing fuel consumption, and its current level of application or potential application in the China market. Wherever applicable, we compare technology trends in China with those in the United States and the European Union to reflect potential technology pathways in the long term.

This working paper assesses technology progress and new developments in vehicle technologies, including lightweighting, active aerodynamics, and low rolling resistance tires.

2 Introduction

Among various technologies, lightweighting has been considered critical for improving vehicle energy efficiency. Vehicle weight reduction decreases the load on the vehicle, thus lowering the amount of fuel necessary to move it. Reducing weight directly lowers the power needed to accelerate the vehicle, decreases energy dissipated by the brakes, and lowers tire rolling resistance. It also has a secondary effect on fuel consumption by allowing engine downsizing and brake and suspension lightweighting while maintaining constant performance. For every 1 kg of primary mass reduction, the estimated secondary mass reduction ranges from 0.5 kg to 1.25 kg (Isenstadt et al., 2016).

Studies have indicated that a 10% weight reduction can decrease fuel consumption by 5% without downsizing the engine and by 6%–8% if the engine is downsized to maintain constant performance.

Light-weighting technologies include component substitution with advanced materials and material processing, which could improve fuel efficiency 1%–5%. Integrated vehicle redesign including parts consolidation, improved manufacturing processes, and holistic optimization could result in 5%–10% improvement (ICCT, 2013). Over the past two decades, Chinese manufacturers increasingly shifted traditional materials toward high-strength steel, aluminum, magnesium, and plastics and polymer composites to reduce vehicle mass.

The application of lightweighting technology is especially important for electric vehicles because lower curb weight reduces the energy needed to propel the vehicle. This in turn allows for use of a smaller battery to maintain the same driving range. The cost savings from shrinking the battery at least partially compensate for the increased cost of light-weight materials.

Active aerodynamics and low rolling resistance tires also reduce fuel consumption. Similar to lightweighting, these technologies are important for both conventional and electric vehicles.

3 Current status

3.1 LIGHTWEIGHTING

In general, China's lightweighting technology development is shifting from focusing only on materials to also considering integrated mass-optimization design.

Lightweighting materials include high strength steel (HSS), advanced high strength steel (AHSS), aluminum alloy, magnesium alloy, and plastic and polymer composites. Different lightweighting materials are at different stages of development.

HSS/AHSS

Steel is still the main material in Chinese cars. In 2009, average HSS use on body-in-white (BIW), or the steel structure of the vehicle before painting and addition of other parts, was less than 20% per vehicle (Fan, 2009). Nowadays, many new models claim BIW with 50%–70% HSS. Automotive steels can be classified in several ways. The definition of HSS in the United States is steel with yield strength equal or higher than 480 megapascals (MPa). But the definition of HSS by Chinese OEMs includes a range from 180 MPa to 780 MPa (Table 1). Baoshan Iron & Steel Co. Ltd., the largest steel company in China, has developed a line of HSS among which those materials with yield strengths below 600 MPa are more broadly commercialized than those above. Meanwhile, there is increased use of press hardening steel (PHS) on recent models in China. For example:

- The application of HSS on the Chery Tiggo 7 is 60% of the BIW, including 8% AHSS. PHS is applied on six key parts of the vehicle body, including the A and B pillars, and delivers a bending rigidity of as much as 21,000 Nm/Deg (Chery International, 2018a).
- The 2015 BAIC Senova X55 applies 68% HSS in BIW, including 8% AHSS. PHS is applied on 11 parts, with a tensile strength of more than 1,500 MPa (China Daily, 2015).
- The average yield strength of HSS applied in Great Wall vehicles is more than 300 MPa. The Great Wall H2 and H8 models feature HSS on more than 60% of BIW. The A pillar of the H2 adopts PHS of 1,500 MPa. The H7 applies HSS to 68% of BIW, 12% of which is PHS. The rear bumper uses aluminum alloy to further reduce weight (Havel, 2017).
- The 2016 FAW Magotan applies more than 81% of HSS to BIW. The

use of PHS accounts for 27% of BIW, 11 percentage points than the previous model (Autohome, 2016).

Aluminum

The development of aluminum began to accelerate with the ninth five-year-plan beginning in 1996, when China encouraged and financed research on aluminum materials and casting technology. By now, the production of casting aluminum should satisfy the needs of the car industry. Plenty of domestic manufacturers have applied aluminum alloy in components such as wheels and cylinder head covers on models since the 1990s, when the average aluminum used per car ranged from 40 kg to 80 kg. In 2015, the average usage of aluminum was 105 kg per vehicle. As shown in Figure 2, die casting is the major manufacturing process for aluminum parts on vehicles, followed by casting and flat-rolled (Du, 2016).

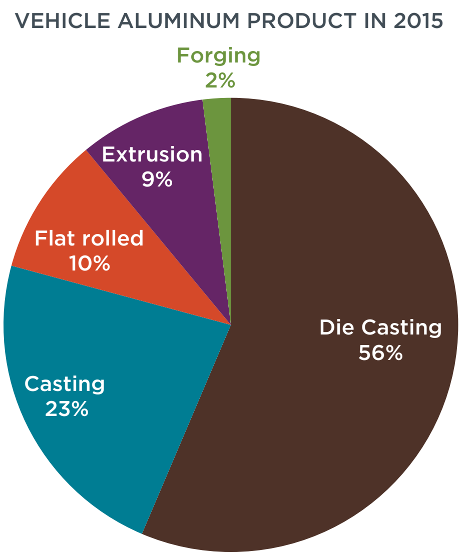

Figure 2 Chinese vehicle aluminum product by manufacturing type in 2015 (Du, 2016)

There is emerging use of significant aluminum application on BIW of domestically manufactured vehicles.

Table 1 definition comparison of several categories of steel between China and the Unites States.

	Yield strength range (megapascals, MPa)	
	China	**United States**
Iron and mild steel	150-210	Less than 480
High-strength steel (HSS)	210-550	480 and above
Advanced high-strength steel (AHSS)	550 and above	780 and above
Press hardened steel (PHS)	1,100-1,300	

- The Fengshen E30L, a battery-electric vehicle introduced by Dongfeng in 2014, applied an all-aluminum BIW. The weight of BIW was 145 kg, 75 kg less than the estimated weight if the BIW were made of conventional steel (DFMC, 2015).
- In 2016, the Chery Jaguar Land Rover Changshu Plant launched a purpose-built aluminum body shop with Novelis, a U.S.-based global company, as its local supplier. With the new plant, Chery Jaguar Land Rover Automotive adopted an all-aluminum body for the domestically manufactured Jaguar XFL, the first Jaguar model customized to the China market. The model, launched in 2016, featured a BIW of 75% aluminum. The body adopted customized RC5752 high-strength aluminum alloy, which is designed to contain up to 75% recycled material. The crumple zone adopted AC300 T61 high-strength aluminum alloy, which has the advantages of high strength and high energy absorption. In addition, 72% of the aluminum body is connected by self-pierce riveting and adhesive joining technology, which make body connection strength two to three times stronger than simple riveting (Chery Jaguar Land Rover, 2018).
- The Chery eQ1, a mini-battery electric vehicle introduced in 2017, uses high-strength magnesium aluminum alloy for as much as 93% of its body (Chery International, 2018b). The Chery eQ1 is 24% lighter than its predecessor, the Chery eQ. As a result, the battery capacity of the Chery eQ1 is 4 kWh smaller than that of the Chery eQ while maintaining a similar driving range (Chery EV, 2018). Compared with a steel structure, the aluminum BIW increases cost by 50%, or 2,500–3,000 RMB. But the cost saving from reduced battery capacity could be as high as 2,000–3,000 RMB per kWh (Fu, 2017).
- NIO, a Chinese electric vehicle startup, launched an SUV model ES8 that adopts a 96.4% aluminum BIW and an aluminum chassis. The aluminum alloy is aerospace grade 7003 series, enabling a torsional stiffness of 44,140 Nm/Deg. The BIW weight is 335 kg, 13.6% of the vehicle's total curb weight (Song, 2017). Novelis is the supplier of the ES8's body-in-white (Labat, 2017), while Magna is the supplier of aluminum front sub-frame and rear cradle (Magna, 2017).
- BYD is applying lightweighting technologies by system. The automaker adopted aluminum-magnesium alloy for the multi-road rear suspension of the Tang and Song models and for the front and rear suspension of the Qin100 (Sina, 2017).

Magnesium alloy

With support from the Ministry of Science and Technology, 100 manufacturers are capable of die-casting magnesium alloy for transmission housings, pedal brackets, instrument panels, steering wheels, torque converters, and other parts, supplying domestic and foreign manufacturers. The application of cast magnesium alloy for domestic models is limited to a couple of parts, mainly concentrated on dashboard frames or steering wheel frames. There are few applications of wrought magnesium alloy, despite its great potential for door frames, trunk lids, and engine covers. Today, the average magnesium use per vehicle is less than 1.5 kg (SAE China, 2017).

Plastics and polymer composites

In general, use of plastics on domestic cars varies from 50 kg to 110 kg, which is close to the world average. Plastics are mostly seen in interior components and increasingly replace exterior non-structural components.

Chinese manufacturers have limited capacity for supplying most polymer composites. Nearly 90% of the long fiber-reinforced thermoplastic applied on domestic cars is imported.

A study showed that as the average curb weight of passenger cars was reduced by 2%–6% through the use of lightweighting technologies from 2014 to 2020, the cost per vehicle increase by 1,000 RMB to 3,000 RMB (Hao, Wang, Li, Liu, & Zhao, 2017). In a recent evaluation by the U.S. Environmental Protection Agency, lightweighting resulted in 5%–10% cost saving across all vehicle segments (EPA, 2016).

Lightweighting by Chinese manufacturers are not fully reflected in the weight of the vehicle fleet. In fact, average curb weight rose 11% from 2010 to 2015 (Figure 3).

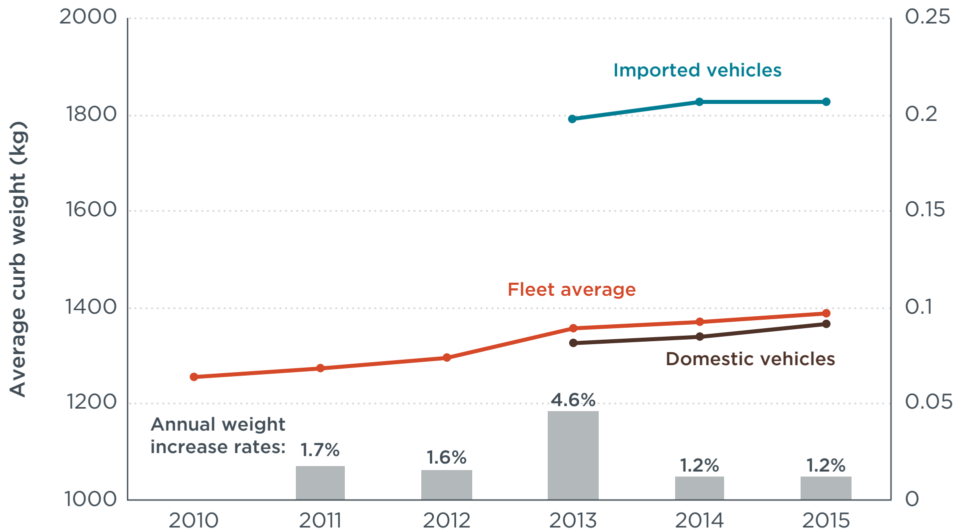

Figure 3 Fleet average curb weight of passenger cars in China from 2010 to 2015

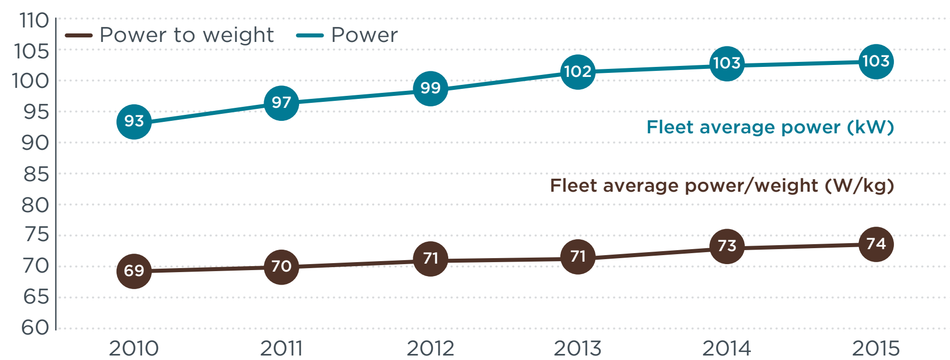

Figure 4 Fleet average power and power to weight ratio, 2010-2015

There are several possible reasons for this:

- Lightweighting is not fully incentivized under the existing stepped, weight-based fuel-consumption standards. Vehicles that reduce curb weight are subject to more-stringent targets, so manufacturers are not equally incentivized to adopt lightweighting technologies as a way to comply with fuel-consumption standards (He & Yang, 2014). In addition, the stepped fuel-consumption targets create several gaming opportunities that allow manufacturers to make minor modifications that shift vehicles into weight classes with higher fuel-consumption targets, or hold off on the use of lightweighting technologies to keep vehicle models on the preferred side of fuel-consumption targets (Hao, Wang, Li, Liu, & Zhao, 2016).
- Weight reductions from applying lightweighting are most likely offset by higher demand for performance and upscale features. From 2010 to 2015, the average power of the vehicle fleet increased by 19% (Figure 4). The ratio of power to weight also rose. Additional weight increases may

come from interior technologies for improving driver and passenger comfort.

- The market structure changed toward larger cars and SUVs. Demand for larger vehicles and SUVs rose in the past decade. Figure 5 shows a significant decline in the market share of mini and small vehicles, or segments A and B. Meanwhile, SUVs surged from less than 5% of sales in 2005 to 10% by 2010 and 40% in 2017 (CAAM, 2018).

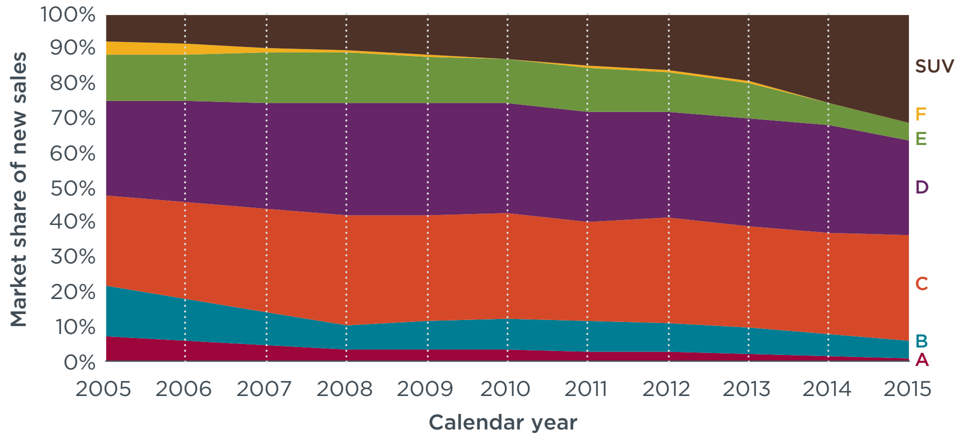

Figure 5 Market penetration by segment from 2005 to 2015

3.2 ACTIVE AERODYNAMICS AND LOW ROLLING RESISTANCE TIRES

In additional to design improvements to reduce aerodynamic drag, an emerging technology is active grille shutters (AGS). AGS is a mainstream technology that improves aerodynamics at high speeds by mechanically actuating flaps that control radiator airflow to reduce drag. In addition to reducing aerodynamic losses, AGS technology can be considered an active thermal management technology. Because grille shutters can control airflow based on powertrain thermal needs, they can assist in rapid engine and transmission warm-up and reduce friction losses during cold engine start. The AGS technology of the Ford Focus reduces fuel consumption by 0.15–0.2 L/100 km at 120 km/h. When the AGS is totally closed, drag is lowered by 7.8%, resulting in as much as a 2% reduction in CO_2 emissions at 120 km/h (Autohome, 2012). The EPA provides off-cycle credits for active aerodynamics technologies assuming that a 3% reduction in drag coefficient can reduce fuel consumption by around 0.3%. Note that the benefit from aerodynamic technologies might not be the same in China if a lot of driving occurs at lower speeds than on the five U.S. test cycles. A more precise estimate of the benefit of such technology in China requires consideration of the China driving condition and test cycles. Active grille shutters have a higher benefit to cost ratio compared with other technologies in ITB's evaluation (ITB, 2017).

Active grille shutters have already been implemented in China by some joint ventures with European and American partners. Chang'an Ford introduced AGS on its 2012 Focus and later on its Kuga models. GAC-FCA introduced a domestically produced 2016 Cherokee that included AGS on most versions. Other examples include the BMW 530i and the Buick Lacrosse eAssist.

The main supplier of AGS in China is Bodun Group, which accounted for 70% of the market in 2016. Roechling Automotive, one of the biggest global suppliers of AGS, opened a new plant in Shenyang in 2015 and is ramping up production.

Lower rolling resistance tires reduce frictional losses associated with the energy dissipated mainly in the deformation of the tires under load, thereby improving fuel economy and reducing CO_2 emissions. The EPA estimated that tires with a 10% reduction in rolling resistance can lower fuel consumption by 1.9%, and tires that offer a 20% reduction will lower fuel consumption by additional 2%, for a total of 3.9%.

This study did not collect detailed information on application of low rolling resistance tires in China. The China Society of Automotive Engineers in its *Technology Roadmap for Energy Saving and New-Energy Vehicles* lists developing low rolling resistance tires among goals for 2020, suggesting that this technology is still at an early stage in China (SAE China, 2016). In the United States, the EPA assumed that tires with 10% lower rolling resistance have been available since 2007 and exceeded 90% penetration by 2017. Tires with 20% percent less rolling resistance have been available since 2017. We would assume a similar penetration growth path and fuel consumption impact on passenger vehicles in China but with a delayed timeline compared with the United States.

4 Further development pathways

In its *Energy Saving and New-Energy Vehicle Technology Roadmap*, SAE China set a goal of reducing curb weight from 2015 levels by 10% by 2020, 20% by 2025, and 35% by 2030 (SAE China, 2016). This mass reduction target would be achieved through increased application of lightweighting (Table 2) and mass-optimization design.

To achieve this goal, it is equally important to maintain a relatively stable fleet structure. SAE China (2016) also proposed a vision for increasing sales of compact vehicles or smaller cars in China from 2020 to 2030. Without a policy slowdown or even reversal of the existing trend of increasing market share for larger vehicles, achieving the proposed weight reduction will be unlikely.

There is a trend of increased adoption of AGS in China as manufacturers are already deploying the technology on coming new models. According to suppliers, there is an increase in the number of manufacturers that plan to apply AGS on production vehicles from 2018 to 2021. The SAE China technology roadmap set a target of improving aerodynamics by 10% from 2015 to 2030 (SAE China, 2017). The roadmap also indicated developing low rolling resistance tires by 2020, optimizing tire structure and size by 2025, and improving rubber formulas by 2030.

Table 2 Lightweighting material application target set in the Energy Saving and New-Energy Vehicle Technology Roadmap (SAE China, 2016)

	By 2020	By 2025	By 2030
HSS/AHSS/PHS	50% AHSS>600 MPa	30% of BIW with AHSS>900 MPa	Some application of PHS>2000 MPa
Aluminum	190 kg/vehicle	250 kg/vehicle	350 kg/vehicle
Magnesium	15 kg/vehicle	25 kg/vehicle	45 kg/vehicle
Carbon fiber reinforced polymer composites	Some application	2%/vehicle	5%/vehicle

5 Summary

Figure 6 summarizes the key vehicle technologies discussed in this working paper. The adoption status of each technology in China is marked before the name of each technology. The start sign in front of active grille shutter indicates that it is a technology applied on only a couple of models in China. A blue question mark indicates technologies without sufficient market penetration information. We have seen increasing application of lightweighting technologies in China, but it is challenging to estimate the level of lightweighting achievement for the entire fleet. The application of low rolling resistance tires on passenger vehicles is still at an early stage.

The percentages following each technology summarizes its potential for reducing fuel consumption. In most cases, the potential is compared with baseline vehicles without the specified technologies. The number represents an average impact or an impact range considering the differences in baseline vehicle segment, specifications, and other factors.

Based on the application status of advanced technologies in China, we group the technologies into three categories:

Commercialized technologies. Technologies that are already adopted on at least several production models in China and could be applied widely in the fleet.

Emerging technologies. Technologies that are available on passenger cars sold in the Chinese market but only on a couple of models, such as

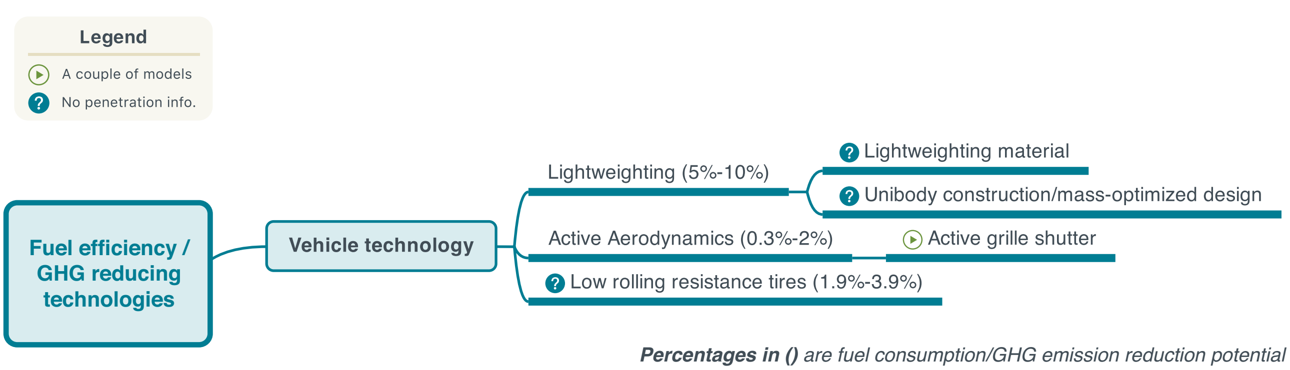

Figure 6 Vehicle technology map for passenger cars in China

variants of flagship models or luxury models that target high-end users.

Underdeveloped technologies. Technologies that have been adopted in other markets but are not yet available on cars produced in China, or technologies that have been announced by manufacturers or suppliers and are likely to be adopted on production passenger cars in the near future.

Table 2 lists the vehicle technologies under each category based on our definition. For lightweighting technology and low rolling resistance tires, we use the level of weight reduction and rolling resistance reduction to differentiate development phases. This information is used for estimating fuel-saving potential of all efficiency technologies in the summary of this series of working papers.

Table 2 Vehicle technologies at different development stages in China

Commercialized technologies	Emerging technologies	Underdeveloped technologies
• Lightweighting — 10% weight reduction • Low rolling resistance tires (5%)	• Lightweighting — 20% weight reduction • Low rolling resistance tires (10%) • Active aerodynamics	• Lightweighting — 30% weight reduction • Low rolling resistance tires (20%)

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