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MARKET ANALYSIS AND FUEL EFFICIENCY TECHNOLOGY POTENTIAL OF HEAVY-DUTY VEHICLES IN CHINA

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EXECUTIVE SUMMARY

China is the world's largest heavy-duty vehicle (HDV) market and second-largest consumer of fuel for HDVs (Sharpe and Muncrief, 2015). The HDV fleet will increase fuel consumption at a rate of 3% a year from 2012 to 2040, which amounts to 34% of China's total increase in transportation-sector energy consumption over that period (U.S. EIA, 2016). Although HDVs account for about 10% of the on-road vehicle fleet in China, they use about 50% of the on-road fuel because of higher annual per-vehicle fuel consumption than passenger autos, reflecting their greater size and longer distances traveled.

Policymakers in China are working to implement regulations and other measures to reduce fuel consumption and carbon dioxide (CO_2) emissions from the HDV sector. China is one of four nations that have implemented fuel consumption standards for HDVs, a key measure for ensuring reductions. China imposed fuel consumption standards in 2011 and has proposed progressively more stringent standards extending until 2019 for new type approvals and until 2021 for all new vehicles. The rules will reduce fuel consumption by 18%–29% for new HDVs, depending on vehicle segment. There will still be a significant need to further address HDV fuel consumption in China to meet the country's long-term targets. For regulators to make well-informed decisions on measures to reduce fuel consumption, it is necessary to have a detailed understanding of the HDV market and the potential for vehicle technology improvement.

This study examines the HDV market in China and investigates the potential for currently sold vehicles to reduce fuel consumption through the adoption of known efficiency technologies. For this study, we obtained and analyzed 8 years of HDV registration data in China. We extracted information on registered models, including model year, vehicle manufacturer, engine manufacturer, and various vehicle and engine technical specifications. Based on the results of this analysis and additional data and using vehicle simulation software, we specified and modeled two representative, top-selling 2015 baseline vehicles: a tractor-trailer and a rigid delivery truck. Technology packages were then established to represent applicable technologies that are either currently commercialized or forecast to become available during 2020–2030. The potential for reductions in baseline vehicle fuel consumption from phasing in these technology packages was then modeled to determine the technology potential for new HDVs in China.

Figure ES1 shows the potential for lowering tractor-trailer fuel use substantially more than mandated by China's currently proposed Stage 3 fuel consumption standards. The Stage 3 standards would reduce new tractor-trailer fuel consumption by about 3% a year until 2020. After 2020, China could further reduce fuel consumption by 21% through the application of technologies used in the U.S. Phase 2 HDV GHG regulation, such as engine efficiency improvements, low rolling resistance tires, and tractor-trailer aerodynamics. China could lower HDV fuel use by a total of almost 45% from the 2020 level by also applying in-development technologies that are expected to be commercially available in the 2025–2030 timeframe, such as waste heat recovery, integrated tractor-trailer aerodynamic designs, and hybridized powertrains.

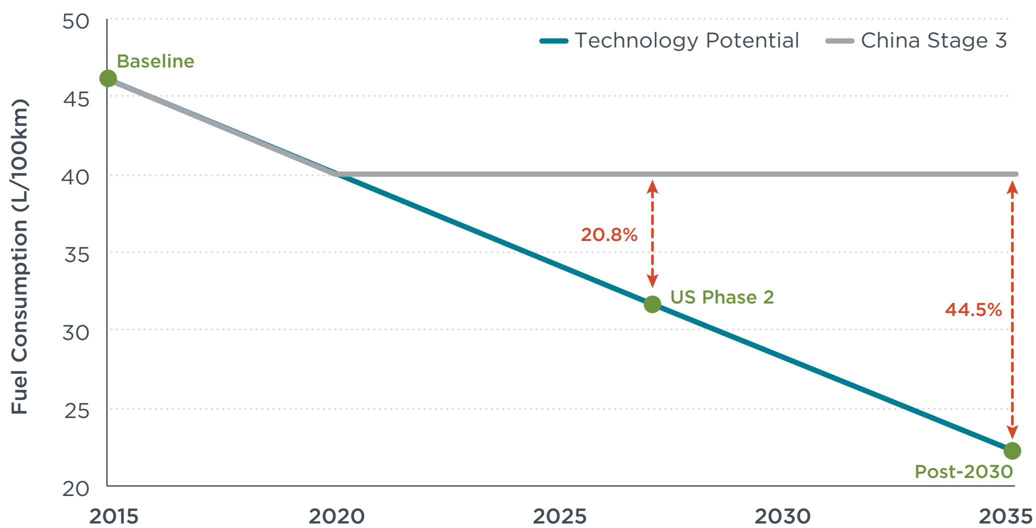

Figure ES1. Comparison of fuel consumption between Stage 3 and predicted potential: tractor-trailers

This report also found several characteristics and trends of the HDV market in China that are relevant to future policymaking:

» **Regulated and unregulated segments:** The current fuel consumption standards regulate six HDV segments—tractors, rigid trucks (including straight trucks and dump trucks), specialized delivery vehicles, coaches, and city buses. These represent 85% of the HDV market. About 15% of HDVs are not covered by the fuel consumption standards. These include alternative-fuel vehicles and specialized vocational vehicles. The market share of these vehicles is predicted to expand. Trailers, which represent significant fuel saving opportunities in other markets, are also not covered by the fuel consumption standards.

» **Long-haul freight vehicles:** In China, tractor-trailers are not the only means of on-road long-haul freight transport, in contrast with other markets such as the U.S. and the EU. Tractor-trailers and large straight trucks both move long-haul freight in China. Tractor trucks account for 21% of China's HDV market, compared with 23% in the U.S. and 26% in the EU. The contrast is even sharper in the 15 tonnes or greater category. Chinese sales of non-tractor trucks are almost three times those of tractors in that category. In the EU, the two types sell about the same, and in the U.S., tractor sales are three times non-tractor sales (Sharpe and Muncrief, 2015). The box or curtain-side style of semi-trailer, popular for long-haul freight in the U.S. and the EU, is not nearly so common in China, where stake trailers are the most-used type. These trailers use welded beams to form the frame but do not fully cover the top or the sides. Also, the "drop-and-hook" capabilities of trailers are not fully utilized.

» **Vehicle manufacturers:** With more than 460 vehicle makers, China's HDV market is more highly fragmented than the consolidated large Western markets. The top 10 Chinese manufacturers represent less than 70% of the market. In the U.S., the top five producers account for 70%, and in the EU, 91%. China's tractor market consists of seven primary manufacturers with a combined share of more than 90% and about 20 smaller producers whose aggregate market share reached 10% in 2014, up from 4% in 2007. The rigid, or non-articulated, truck market consists of more than

70 manufacturers. Among engine makers, the top seven hold 99% of the tractor market and 95% of rigid truck market.

- **Vehicle and engine specifications and trends:** Tractors increased in size over the 8 years analyzed, with median tractor-trailer gross combination weight (GCW) going from 41.2 tonnes in 2007 to 45.5 tonnes in 2014. Tractor engines gained in displacement and power from an average of 9.1 L and 228 kW in 2007 to 10.1 L and 250 kW in 2014. However, engines' displacement and power were still lower than in the EU and the U.S., where average displacements were between 13 L and 15 L and typical engine power levels ranged between 300 kW and 450 kW. Rigid trucks' gross vehicle weights (GVWs) increased, moving toward regulatory maximums, such as 16 tonnes for two-axle configurations. The typical drivetrain configuration for straight trucks had two axles, whereas the typical configuration for dump trucks, which carry heavier loads and are used in construction and mining operations, included three or four axles. The most common GVWs were 16 tonnes for straight trucks and 25–31 tonnes for dump trucks. Dump trucks' engines have higher displacement and power than rigid trucks' engines.

The findings from this study lead to several recommendations for future policies to reduce China's HDV fuel consumption. If China's currently proposed standards are implemented effectively, there will be significant reductions over the next few years. However, China needs to make additional advances for its HDV market to match that of the U.S. on technology and efficiency. There is potential to significantly further lower fuel consumption by new vehicles using known technologies. More stringent standards based on these technologies with longer lead times could ensure that manufacturers apply advanced technologies effectively.

In addition, the freight-hauling fleet in China is not using the most efficient vehicle logistics as compared with the U.S. and the EU. Policymakers should consider policies or incentives to encourage the use of tractor-trailers and the use of box-style trailers and their drop-and-hook capabilities to improve efficiency. This could reduce empty miles driven, incidence of overloading, and the number of vehicles on the road, allowing for a more modern national logistics system.

Finally, China's current HDV fuel consumption standards do not fully cover the HDV market, leaving 15% of all new HDVs unregulated. The trailers, which by themselves can have a large impact on fuel consumption, are also unregulated unlike in the U.S. China could obtain further reductions in HDV fuel consumption by extending its regulatory framework to include these segments. These represent some of the opportunities for China to significantly improve the efficiency of its on-road freight system over the next 15–20 years.

1. INTRODUCTION

China is the world's largest heavy-duty vehicle (HDV) market and the second-largest user of HDV fuel (Sharpe and Muncrief, 2015). China is projected to have the largest regional increase in use of transportation energy from 2012–2040, with an annual increase of 3% in HDV fuel consumption (U.S. EIA, 2016). As China uses more energy for transportation, the nation becomes more dependent on fuel imports, increasing risks associated with energy security and sustainability (Institute for 21st Century Energy, 2016). Since the end of 2013, China has been the world's largest net oil importer (U.S. EIA, 2015).

China classifies vehicles with gross vehicle weights of more than 3,500 kg as HDVs. Although this category accounted for 10.4% of vehicle sales in 2012, HDVs consumed nearly half of total fuel used on roads because of their larger payloads and the long distances they travel (CATARC, 2013). China is one of four nations worldwide that have implemented standards to reduce fuel consumption and carbon dioxide (CO_2) emissions.

The Chinese government so far has issued three stages of standards for new HDVs. The first stage, "Industry Standard," was implemented in mid-2012 for type approval of new models and in mid-2014 for all vehicles (MIIT, 2011). The standard covers three common segments of HDVs—tractors, straight trucks, and coach buses. The second stage, "National Standard," went into effect in mid-2014 for type approval of new models and in mid-2015 for all models (AQSIQ & SAC, 2014). The National Standard incorporates city buses and dump trucks and tightens fuel consumption limits for tractors, straight trucks, and coach buses by an average of 10.5%–14.5%, depending on vehicle category, compared with limits under the Industry Standard (Delgado, 2016). The proposal for Stage 3 was released for public comment in April 2016 (AQSIQ & SAC, 2016a). This draft inherits the same scope as the second stage and tightens vehicle consumption limits by an average of 12.5%–15.9%, depending on vehicle category (Delgado, 2016). The new standard is scheduled to take effect July 1, 2019, for new type approvals and July 1, 2021, for all vehicles. Significantly, this will be done in parallel with China VI HDV emissions standards, scheduled to go into effect in 2019 for new type approvals and 2020 for all vehicles (MEP, 2016).

We conducted this study for three reasons. First, the proposed Stage 3 standards in China aim to close the fuel-efficiency gap with more-advanced markets, such as Japan and the U.S., while reducing fuel consumption and CO_2 emissions. With this study, we intend to analyze the current characteristics of the fleet and compare it with fleets in other markets to identify efficiency improvement pathways. Second, the fuel consumption standards in China have been in effect since 2012, making preliminary market trends worth exploring. Third, the study aims to identify regulatory issues and provide recommendations for the proposed Stage 3 standards.

Our goal is to inform future HDV fuel-efficiency policy-making in China with an independent data analysis. This paper provides a baseline analysis of the HDV fleet in China using the latest market data and assesses the technology potential for reducing HDV fuel consumption from 2020–2030. Our comprehensive review and analysis of HDV registration data explores the HDV market's historical trends and current market and vehicle characteristics. Vehicle simulation modeling defines baseline fuel consumption and evaluates the potential of future efficiency technologies.

This paper's market analysis is based on HDV registration data in mainland China collected by IHS Automotive[1]. The database includes records of vehicles heavier than 4,536 kg from 2007–2014. The database includes detailed specifications and number of vehicles registered per province each year. Vehicles weighing between 3,500 kg and 4,536 kg are categorized as HDVs by the fuel-efficiency standards but are not included in this analysis due to data unavailability. Overall, the data on China's HDV fleet rates as good for completeness, validity, and accuracy. The data was preprocessed to remove invalid or factually incorrect data points. After data cleaning, the key vehicle characteristics for each vehicle segment have a validity rate, or ratio of number of valid data points to total data points, greater than 99.4%.

1 Content supplied by IHS Global SA;

2. MARKET SNAPSHOT AND TRENDS IN CHINA

2.1 HDV MARKET OVERVIEW

HDV market snapshot

There are 34 provincial-level administrative units in mainland China: 23 provinces, four directly controlled municipalities (Beijing, Tianjin, Shanghai, and Chongqing), five autonomous regions, and two special administrative regions. Vehicle ownership is highly dependent on regional economic and cultural development. Figures 1 and 2 show the average HDV registrations from 2007–2014 and 2014 registrations by province or municipality in mainland China. Historically, the market has centered on Beijing and Guangdong Province. Provinces around the country's perimeter, such as Heilongjiang and Xinjiang, also show relatively higher HDV registration. This is most likely a result of increasing freight movement across borders with Russia, Mongolia, and other neighboring countries. Economic growth applies continued upward pressure on freight volumes. Most recently, the growing logistics sector in southeastern China has led to an increase in the number of provinces with HDV registrations higher than 3% of the total, as shown in Figure 2.

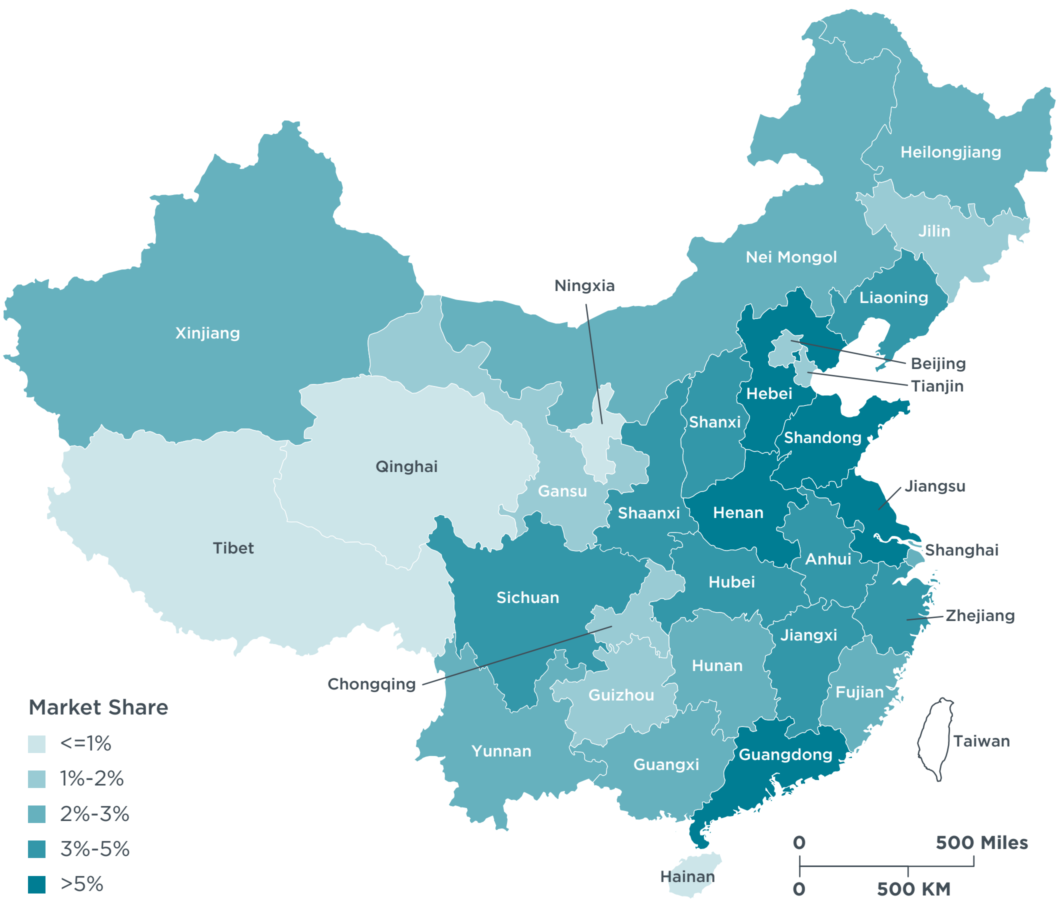

Figure 1. Total HDV registration by province in mainland China, 2007–2014

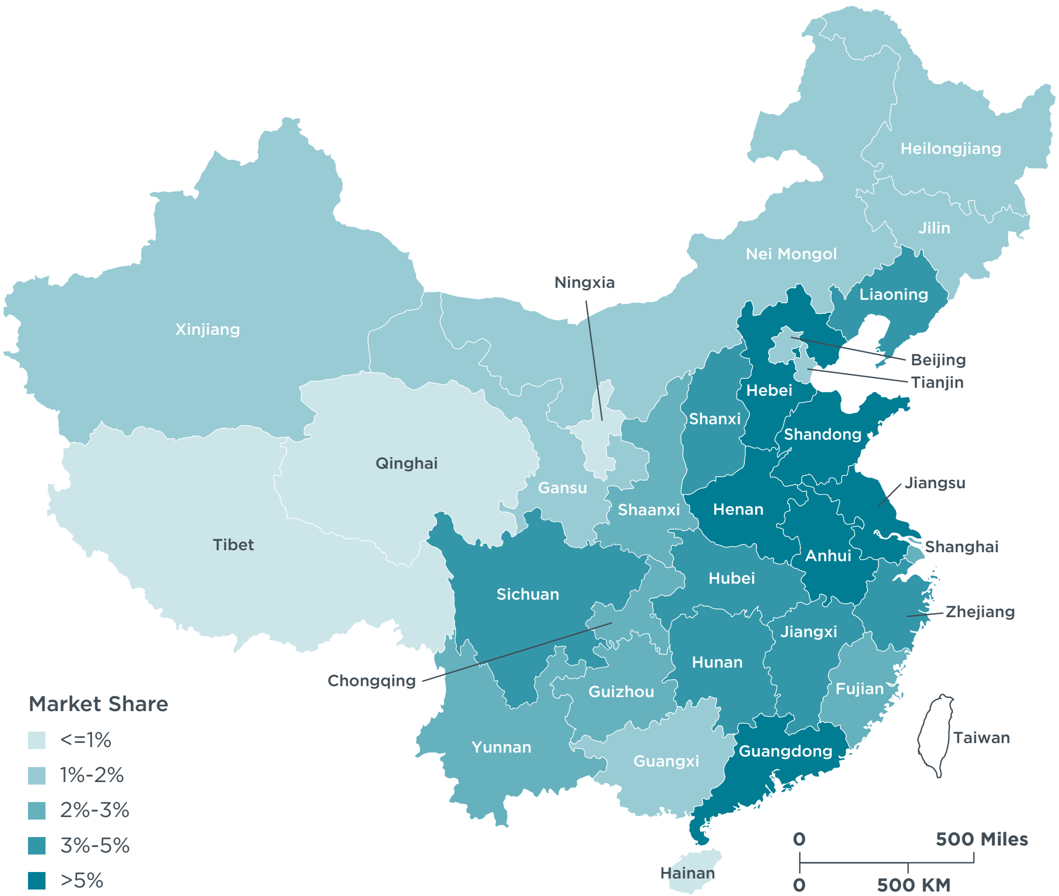

Figure 2. HDV registration by province in mainland China, 2014

New HDV registrations surged between 2008 and 2010, then declined for 2 years (Figure 3). After that, registrations jumped 26% in 2013 and fell 13% in 2014. Even after the declines, which are indicative of excess capacity or economic downturns, HDV registrations in 2014 were 40% higher than in 2007, indicating an average annual increase of 5.7%.

The market breakdown by vehicle segment in Figure 3 is based on vehicle categories defined in the National Standard fuel consumption regime. Specialized vehicles account for 30%, the biggest share of the HDV market. These vehicles are categorized into two sub-types not shown in Figure 3: delivery vehicles and vocational vehicles (NTCAS, 2009). Specialized vocational vehicles conduct work to serve a specific purpose besides transport of goods and are excluded from fuel efficiency regulations. Specialized delivery vehicles are customized to deliver specific types of goods, such as concrete, garbage, and natural gas, and are regulated based on the closest body type when compared with the five other regulated segments. Dump trucks and straight trucks are both rigid trucks, with the cab and truck body integrated on a single chassis. All rigid trucks that are not either dump trucks or specialized vehicles are classified under the "straight truck" segment.

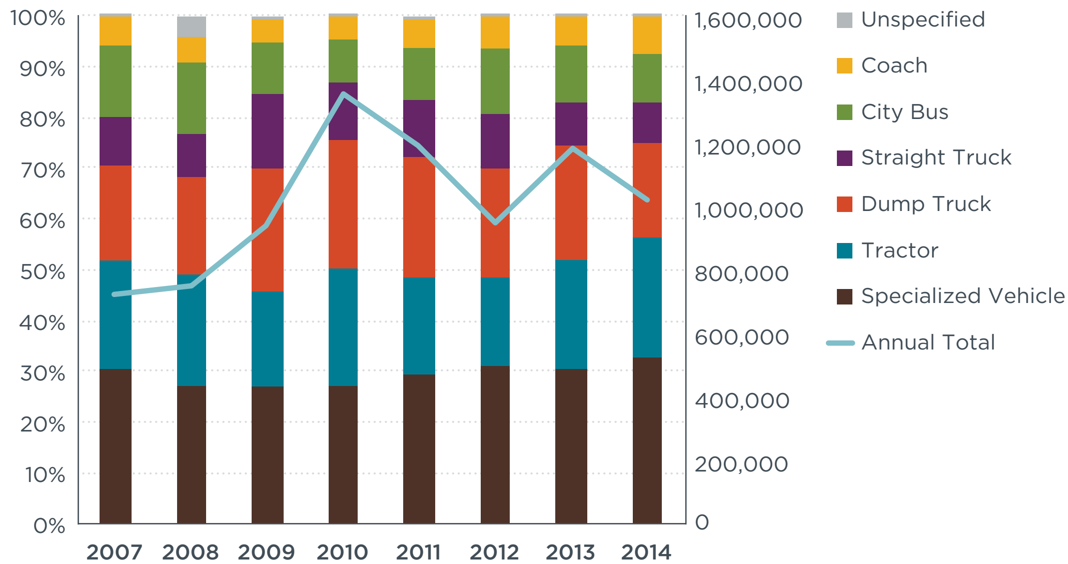

Figure 3. Historical trend of HDV registration count and market breakdown by vehicle segment in China, 2007–2014

Figure 4 shows the annual new registration breakdown of trucks with GVW larger than 15 metric tons[2] (equivalent to U.S. Class 8) for 2007–2014. Tractor trucks' share increased from 32% in 2011 to 37% in 2014. Continuous economic growth demands and promotes improvements in the logistics industry. Operators switch to larger trucks and drop-and-hook trailer operations that improve freight efficiency. However, China's 37% share of tractors in weight classes above 15 tonnes was much smaller than in the U.S., with 75%, and the EU, with 50% (Sharpe and Muncrief, 2015). Tractor-trailers are more efficient than large rigid trucks and large, progressive operators switch to them for long haul freight transportation. The low share of tractors might be indicative of owner-operators and small trucking companies not being able to afford tractors, or being unaware of their fuel consumption benefits. Dump trucks are prevalent in the Chinese market because of the relative importance of construction and mining. The decline in dump truck sales from 31% in 2011 to 25% in 2014 can be attributed to shrinking demand for coal transportation (Zhang, 2016).

2 Metric ton or tonne is the unit used in Chinese regulations. 1 tonne = 1,000 kilograms = 1.10 short tons = 2,200 lbs.

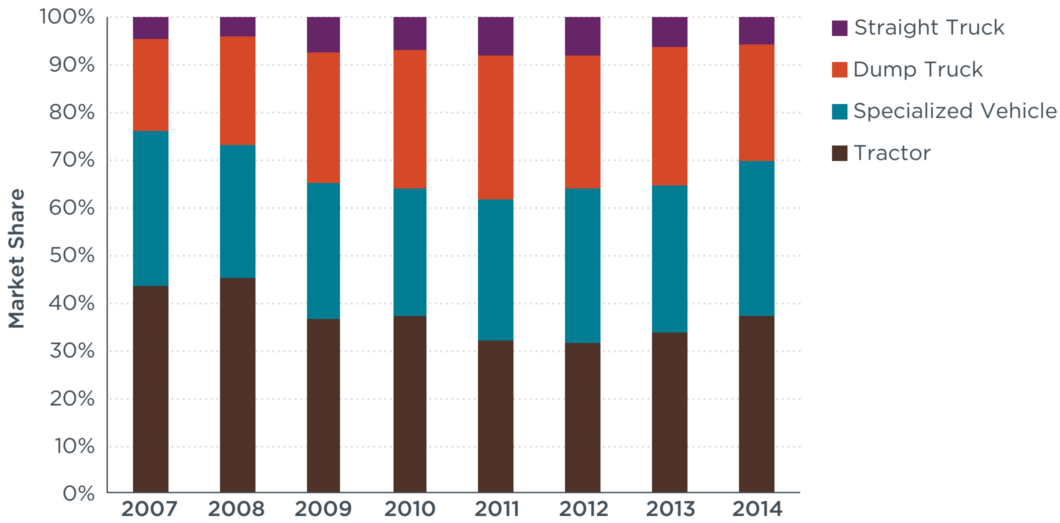

Figure 4. Breakdown of registration of trucks heavier than 15 tonnes in China, 2007–2014

The Chinese HDV market is much less consolidated than other major markets. Figure 5 shows truck manufacturers by market share in five leading markets. In China, the aggregate market share of the top five manufacturers is about 50%, while in the EU, the top five account for 91%; in the U.S., 70%; in Brazil, 90%; and in India, 93%. The aggregate share of the 10 top-selling manufacturers in China is less than 70%, with the remainder covered by more than 450 smaller companies.

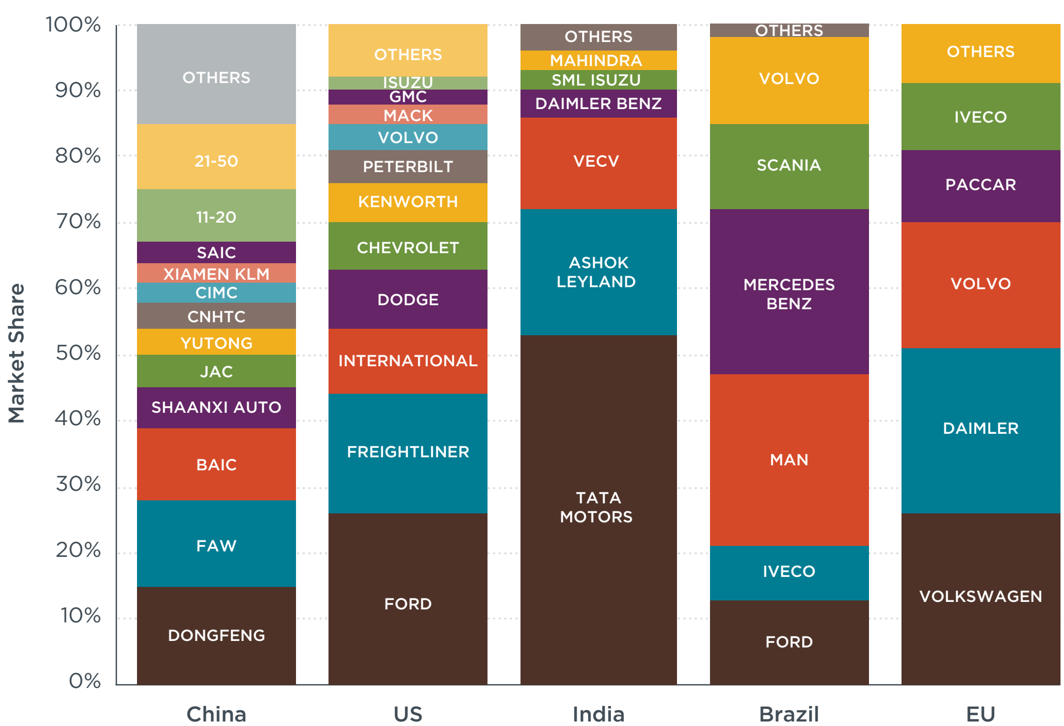

Figure 5. HDV manufacturer breakdown of main global markets in 2014.

Source: Muncrief and Sharpe (2015), Sharpe (2015).

Note: China market column names 10 largest manufacturers and shows combined market shares for those ranked 11–20, for those ranked 21–50, and for all others.

Table 1 ranks the annual registrations of the 10 best-selling manufacturers and their aggregate market share from 2007–2014. The three market leaders are Dongfeng Auto, FAW, and BAIC.

Table 1. Annual ranking of HDV registrations by manufacturer in China, 2007–2014

		Annual Registration Count Ranking								2007–2014 Market Share
		2007	2008	2009	2010	2011	2012	2013	2014	
Vehicle Manufacturer	DONGFENG AUTO	2	1	2	2	1	1	1	1	18.3%
	FAW	1	2	1	1	2	2	2	2	16.6%
	BAIC	3	3	3	3	3	3	3	3	12.5%
	JAC	5	6	5	6	4	4	4	5	5.5%
	SHAANXI AUTO	6	5	6	5	5	6	5	4	5.1%
	CNHTC	4	4	4	4	6	8	7	7	5.1%
	YUTONG	9	9	8	8	7	5	6	6	3.6%
	XIAMEN KLM MOTOR	7	7	7	7	8	7	8	8	3.4%
	SAIC	8	8	9	9	9	10	9	9	2.8%
	ZOOMLION	10	10	10	10	10	9	10	10	1.6%
Top 10 Market Share		73.3%	74.4%	72.2%	74.1%	73.2%	74.0%	76.3%	77.5%	74.4%

Scope of Fuel Consumption Standards

As shown in Figure 6, China's proposed Stage 3 fuel consumption standards would cover about 85% of the HDV market, based on 2014 data. The standards apply to HDVs with gross vehicle weights of more than 3,500 kg in six segments: straight trucks, dump trucks, tractors, specialized delivery vehicles, coach buses, and city buses. Only vehicles with diesel or gasoline engines must comply with the standard. Exempted are specialized vocational vehicles (4.6%) and HDVs that use alternative fuels (10.8%).

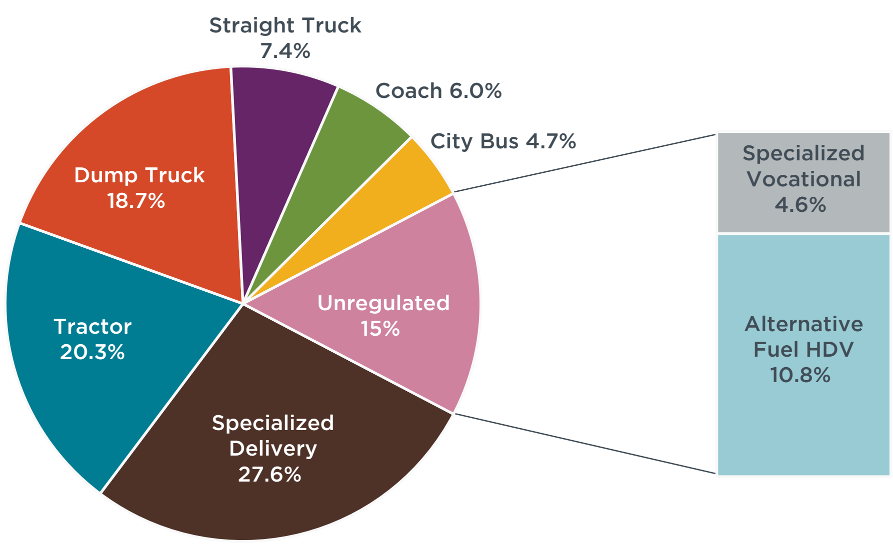

Figure 6. HDV registration by vehicle segment and fuel type in China, 2014

Fuel consumption limits under the standards are based on gross combination weight (GCW) for tractor trucks and gross vehicle weight (GVW) for the other segments. The rules impose a consumption limit on all HDVs within a given weight range or bin. Tables 2–4 show the reductions in fuel consumption, or stringency, of the Stage 3 standards compared with Stage 2. The tables also specify 2014 market share by vehicle segment and weight bin for tractor trucks, rigid trucks, and buses. Specialized delivery vehicles are regulated based on the fuel consumption limits for dump trucks if they have a hydraulic lift system or straight trucks if they do not. In Table 3, the market shares of straight trucks and dump trucks include specialized delivery vehicles.

The most stringent targets apply to city buses weighing 3.5–4.5 tonnes, with tightening of 17.9%. The most lenient targets are for coaches with GVW of 14.5–16.5 tonnes, tightened by 10.7%. Regulated HDVs are not evenly distributed among weight bins. For example, 60.9% of tractors are in the 46–49 tonnes bin.

Table 2. Market share and stringency of fuel consumption limits by weight bin for China's Stage 3 standards compared with Stage 2: tractor trucks, 2014

GCW Bin (tonnes)	Stringency	Market Share
3.5–18	15.2%	0.0%
18–27	15.3%	0.3%
27–35	15.8%	2.4%
35–40	15.0%	5.6%
40–43	15.5%	13.2%
43–46	15.6%	17.1%
46–49	14.9%	60.9%
>49	15.6%	0.4%
Weighted Average Stringency	**15.1%**	

Table 3. Market share and stringency of fuel consumption limits by weight bin for China's Stage 3 standards compared with Stage 2: rigid trucks, including specialized delivery vehicles, 2014

GVW Bin (tonnes)	Straight Trucks		Dump Trucks	
	Stringency	Market Share	Stringency	Market Share
3.5–4.5	11.5%	0.0%	13.3%	0.0%
4.5–5.5	12.9%	1.7%	15.6%	0.9%
5.5–7	13.8%	1.9%	14.3%	5.1%
7–8.5	14.2%	8.9%	14.6%	2.4%
8.5–10.5	14.9%	6.9%	15.2%	2.0%
10.5–12.5	14.8%	4.9%	13.7%	7.5%
12.5–16	14.3%	36.1%	10.7%	7.6%
16–20	14.3%	0.5%	13.2%	0.7%
20–25	13.3%	19.8%	14.9%	39.6%
25–31	12.8%	19.3%	13.8%	34.3%
>31	15.4%	0.0%	15.3%	0.0%
Weighted Average Stringency	**13.8%**		**14.1%**	

Table 4. Market share and stringency of fuel consumption limits by weight bin for China's Stage 3 standards compared with Stage 2: buses, 2014

GVW Bin (tonnes)	Coaches		City Buses	
	Stringency	Market Share	Stringency	Market Share
3.5–4.5	15.2%	0.0%	17.9%	0.0%
4.5–5.5	14.8%	12.1%	16.1%	25.8%
5.5–7	11.3%	22.8%	16.0%	21.5%
7–8.5	12.1%	6.7%	14.4%	17.4%
8.5–10.5	13.5%	4.6%	13.8%	11.7%
10.5–12.5	11.5%	14.0%	14.2%	4.2%
12.5–14.5	11.2%	7.8%	16.4%	5.9%
14.5–16.5	10.7%	16.4%	17.6%	10.2%
16.5–18	11.3%	15.4%	17.3%	3.2%
18–22	10.8%	0.1%	15.9%	0.0%
22–25	12.7%	0.2%	15.4%	0.0%
>25	15.3%	0.0%	15.3%	0.1%
Weighted Average Stringency	11.8%		15.6%	

The Stage 3 stringency analysis shows that city buses face the largest market share-weighted average reduction at 15.6%, followed by tractors at 15.1% (see Figure 7). The smallest reduction would apply to coaches, 11.8%. As in Table 3, Figure 7 includes specialized delivery vehicles in the straight truck and dump truck categories. Based on the 2014 data, the HDV fleet-wide weighted average stringency works out to 14.2%. This estimate is based on vehicle population and not actual fuel consumption, so it will not correspond precisely to reductions in fuel consumption that will be observed for the fleet. For example, tightening the limit for tractors by 1% is not the same as doing the same thing for city buses, because the tractor fleet consumes more fuel than city buses.

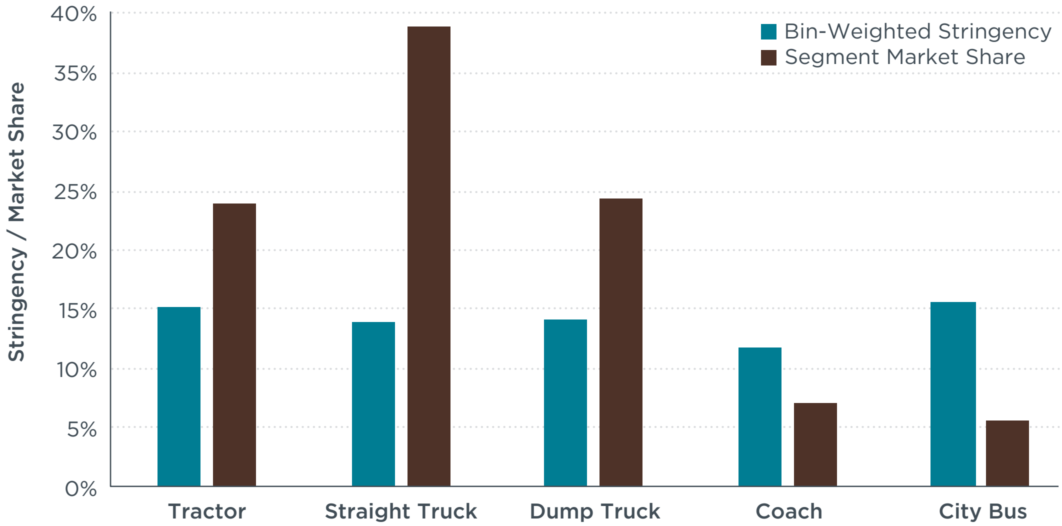

Figure 7. Regulated HDV bin-weighted stringency and market share by vehicle segment in China, 2014

Natural gas, hybrid-electric, and battery-electric vehicles account for almost all of the alternative-fuel HDVs today in China. As shown in Figure 8, 53% of city buses, 17% of coaches, and 16% of tractors in 2014 were in the alternative-fuel category to which fuel consumption standards do not apply. Natural gas is mainly used in city buses, coach buses, and long-haul tractors. Electric and hybrid architectures are mostly used in city buses. China is leading the global deployment of electric bus fleets, with more than 170,000 buses out of a global electric bus fleet estimated at 173,000. By 2020, China plans to have more than 200,000 electric buses circulating, drawing on a network of close to 4,000 charging stations dedicated to buses (IEA, 2016).

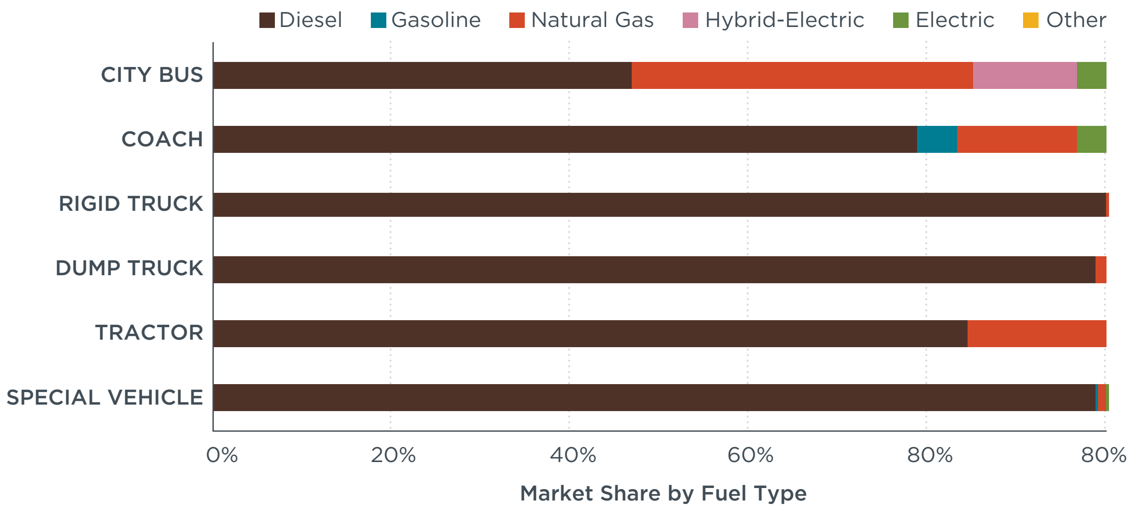

Figure 8. HDV market share by vehicle segment and fuel type in China, 2014

The market penetration of alternative-fuel vehicles has been growing steadily (see Figure 9). The fastest growing segment is the natural gas fleet, which expanded 10-fold from 2007–2014, or 144% a year. China's national and local governments promote natural gas vehicles as part of the nation's green transportation strategy (MOF & China MOT, 2011; Sichuan DRC et al., 2013). These vehicles do have air-quality advantages relative to diesel and gasoline. However, natural gas engines are inherently less efficient than diesel or gasoline engines. Moreover, natural gas is more than 90% methane, a potent greenhouse gas that notoriously leaks in significant volumes throughout the natural gas supply chain (Camuzeaux, Alvarez, Brooks, Browne, & Sterner, 2015; Clark et al., 2017; Delgado and Muncrief, 2015). Natural gas vehicles are currently excluded from the fuel-efficiency regulations, and if the growth trend continues, this could create a significant challenge for climate change mitigation.

The HDV market penetration of hybrid-electric vehicles grew at an average rate of 43% per year from 2007–2014. Government financial incentives encourage the purchase of so-called new energy vehicles including battery-electric, plug-in hybrid, and fuel cell vehicles. The incentives include subsidies, free license plates, and sales tax exemptions (MOF, MIIT, & NDRC, 2013; MOF, MIIT, & State Administration of Taxation of the People's Republic of China, 2014; U.S. EIA, 2014). Annual registrations of new energy HDVs increased from 121 in 2007 to 5,839 in 2014. This trend is expected to continue.

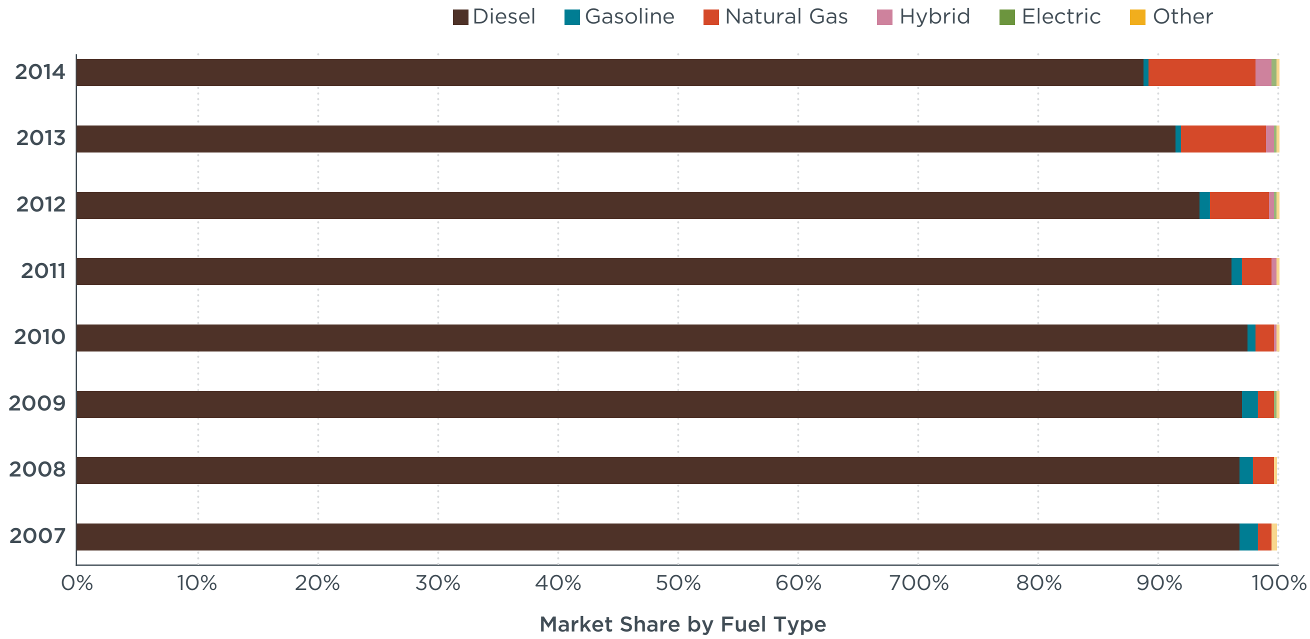

Figure 9. Historical trend of market share by fuel type in China

2.2 TRACTOR TRUCKS

Tractor trucks are used in combination with semi-trailers carrying payloads. In 2014, tractors accounted for 24% of the HDV market in China and are mostly used for long-haul freight.

Tractor Manufacturers

China's tractor segment was more consolidated from 2007–2014 than the rest of the HDV market. The seven market leaders—FAW, Dongfeng, BAIC, Shaanxi, CNHTC, CNGC, and CAMC—together acounted for more than 90% of the market (see Figure 10). However, as smaller manufacturers became more competitive, the domination of the top seven declined by almost 1% per year, from 96% in 2007 to 90% in 2014. The number of tractor makers increased from 18 to 26 during that time. Additional competition may stimulate technology gains (KPMG International, 2011). Domestic manufacturers have been continuosly making technological progress to comply with fuel consumption standards (AQSIQ & SAC, 2016b; CBU/CAR, 2015). In 2014, No. 2 Dongfeng, for example, invested $329 million to expand its technology center, featuring advanced engines and green vehicles (Shen and Kazunori, 2014).

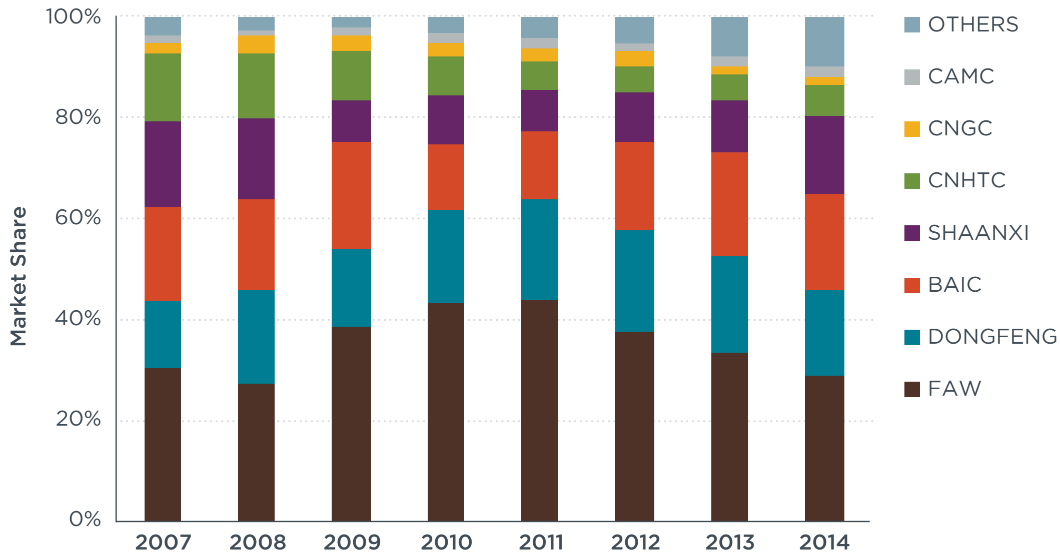

Figure 10. Historical trend of manufacturer market breakdown in China: tractor trucks, 2007–2014

Engine Manufacturers

Although there were 21 to 26 active tractor engine manufacturers from 2007–2014, the industry is even more consolidated than the tractor vehicle market. The seven biggest engine makers combined had 98.6% of the 2014 market, compared with 90% for the top seven tractor producers. Figure 11 shows the market breakdown of engine OEMs in China, 2007–2014.

Weichai Power is the main domestic engine supplier, accounting for almost half of the market and producing engines for all HDV segments. Some tractor makers also produce engines. FAW, the tractor market leader, is the second-largest engine supplier with about one quarter of the HDV engine market. Other relevant domestic players include Dongfeng with 8.2% and CNHTC with 6.7% of the 2014 engine market.

Another form of engine supply is the joint venture between foreign and domestic manufacturers. For example, Dongfeng, Shaanxi, and BAIC all have 50/50 joint ventures with the U.S. engine maker Cummins Inc. The joint venture structure is expected to add value for technology development, fuel efficiency improvement, and pollutant emissions reduction. Cummins, Inc. (2010) invested in local manufacturing of several key technologies, including turbochargers and filtration products. However, the relatively small market shares of joint ventures may reflect higher prices of the more technologically advanced engines, which influences purchasing decisions (KPMG International, 2011). The registration data shows that there are other engine joint ventures besides Cummins, such as Sichuan Hyundai. Because of their small market share, these joint ventures are included in the "others" category.

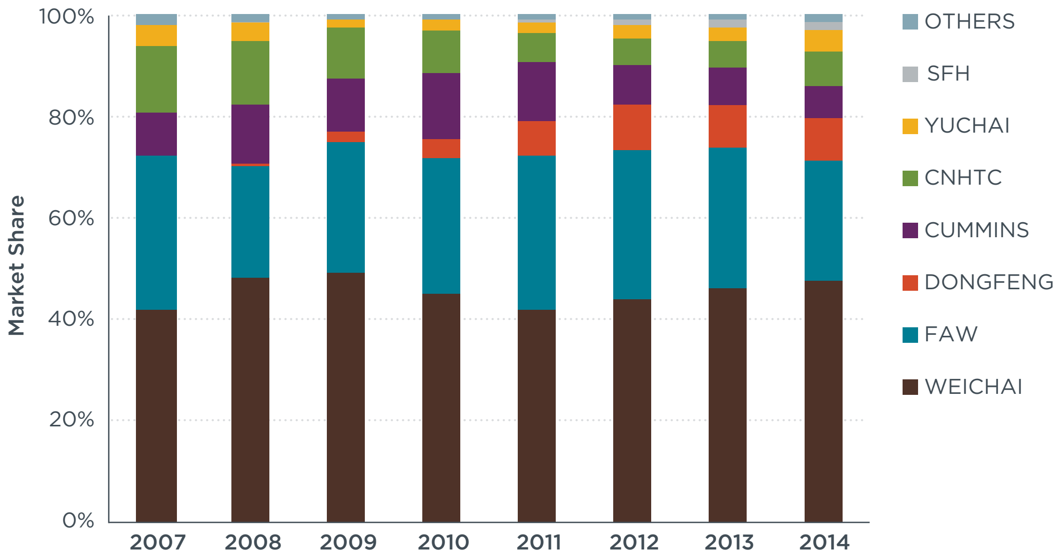

Figure 11. Historical trend of engine OEM market breakdown in China: tractor trucks, 2007–2014

Note: Cummins includes all joint ventures of domestic manufacturers with Cummins Inc.

Each tractor truck manufacturer forms its own constellation of engine suppliers. The main tractor producers and their engine makers in 2014 are listed in Table 5. Some of the largest tractor manufacturers produce their own engines. For example, FAW builds 75% of its own engines; Dongfeng, 29%; and CNHTC, 97%. Some tractor companies rely mainly on other engine suppliers. Weichai supplies 95% Shaanxi's engines, 96% of BAIC's, and 99% of CNGC's.

Table 5. Vehicle manufacturers and their engine suppliers in China in 2014: tractor trucks

		Engine Supplier							
		WEICHAI	**FAW**	**CUMMINS**	**CNHTC**	**DONGFENG**	**YUCHAI**	**SFH**	**OTHERS**
Vehicle Manufacturer	**FAW**	25%	75%						
	DONGFENG	11%		49%		29%	11%		
	BAIC	96%		4%					
	SHAANXI	95%		2%	2%				1%
	CNHTC	2%			97%		1%		
	CNGC	99%							1%
	CAMC	86%		3%	1%			1%	9%
	OTHERS	59%	1%		1%		12%	12%	15%
Engine Supplier Market Share		**45%**	**27%**	**10%**	**8%**	**5%**	**3%**	**1%**	**1%**

Gross Combination Weight

Tractor trucks' gross combination weight is the sum of the tractors' curb mass and towing capacity, or the maximum allowable weight of trailers, including trailer curb mass and payload. The fuel consumption limits are based on tractor truck GCW bins.

Tractor trucks' GCW and curb weight were not in the dataset used in this study, but their towing capacity was. To calculate tractor trucks' GCW, a reasonable estimate of tractor curb mass is necessary. In this study, curb mass was estimated by using the traction ratio, or the ratio of towing capacity to curb mass. We assumed the average traction ratio was 4.75, based on a previous study by Wang and Zhang (2015), which found that a traction ratio of 4.5–5.0 represented more than half of the 835 most recent tractor models in China. This value was checked against specifications of 194 new-model type approvals between 2014 and 2016 listed on the ChinaCar website, which showed that the average traction ratio was 4.74 (ChinaCar).

Therefore, we applied the traction ratio of 4.75 to the maximum towing capacity from our database to derive each tractor's curb mass first, and then added up the trailer's curb mass and towing capacity to calculate the tractor-trailer's GCW. For instance, a tractor capable of towing a 40-tonne trailer was estimated to have a curb mass of 8.4 tonnes, with a GCW of 48.4 tonnes. The results of this approach were consistent with values observed in some popular models in China.

Figure 12 shows the GCW trend of tractor trucks. The median GCW increased by 13%, from 41.2 tonnes in 2007 to 45.5 tonnes in 2014. The span between the first and third quartiles of GCW narrowed to 4.6 tonnes in 2014 from 13.3 tonnes in 2007. The average GCW increased by 10%. The share of tractor trucks with GCW greater than 40 tonnes increased from 60% in 2007 to 92% in 2014.

Most tractor truck GCWs concentrate at the maximum values allowed. In 2014, GCW distribution peaked at 49 tonnes, the upper GCW limit for six-axle tractor trucks (see Figure 13). Yellow vertical lines represent the maximum GCW limits determined by number of axles. The dashed lines are the limits of regulatory weight bins in the fuel consumption standards (AQSIQ & SAC, 2016a, 2016b). The most popular weight bin is 46–49 tonnes, which represents 60% of the tractor market. Within this GCW bin, more than 60% of vehicles are between 48 and 49 tonnes, within one tonne of the upper boundary. For tractors in the 43–46 tonnes GCW bin, representing 20% of the market, more than 45% are within 1 tonne of the upper GCW limit.

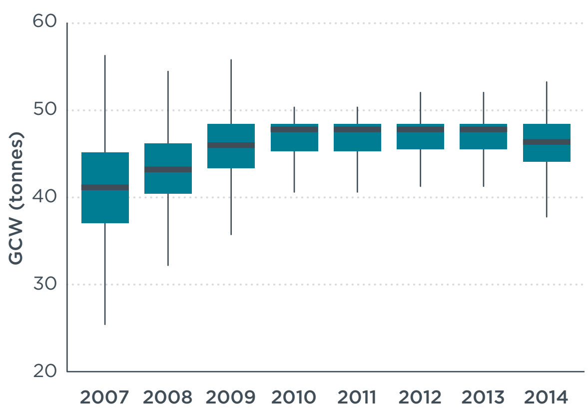

Figure 12. Historical trend of GCW in China: tractor trucks, 2007–2014[3]

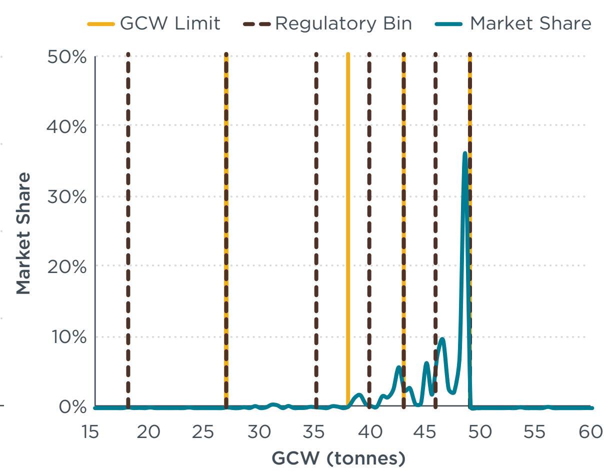

Figure 13. GCW distribution in China: tractor trucks, 2014

3 Box plot displays the distribution of data based on a five-number summary: minimum, first quartile, median, third quartile, and maximum. The central rectangle spans the first quartile to the third quartile. The line inside the rectangle shows the median. The "whiskers" above and below the box show the minimum and maximum values. The span between the first quartile and the third quartile is the interquartile range, or IQR. Outliers are not shown; outliers are either 3×IQR or more above the third quartile or 3×IQR or more below the first quartile.

Tractor-trailer overloading has been an issue in China for years, even though tractors' GCW is compatible with on-road vehicle weight limits based on number of axles (AQSIQ & SAC, 2016b). Overloading has caused reduced fuel economy and safety concerns related to brake failure and additional weight affecting truckers' ability to steer (Jun & Bensman, 2010). Regulations to reduce overloading have resulted in significant progress in ameliorating the problem (China MOT et al., 2016; MOT & MPS, 2016). In Beijing, the overloading rate of inspected vehicles was lower than 1% from 2006 to 2012 through enforcement of routine inspections of on-road vehicles (Beijing Transportation Research Center, 2013). In Zhuzhou City, fixed inspection stations and mobile inspection stops reduced the overloading rate from 7.1% in 2014 to 0.6% in 2015 (Rednet.cn). However, overloading remains a problem on many roads in China, spurring continued regulatory measures and collaboration between national and local governments to address it (Deng, Wang, & Yu, 2015; Dou, Zhang, & Hu, 2016; KPMG International, 2011; Xu, Zhang, Wang, & Zhang, 2016).

Driveline Configuration

The distribution of tractor driveline configurations went through significant changes from 2007–2014, shown in Figure 14. While three-axle tractors were the most common configuration, the percentage of tractors with two powered axles doubled to more than 60% from 2007–2010. Since then, tractors with a single powered axle have claimed a growing share of the market, accounting for more than half in 2014. (The figure uses industry parlance to denote driveline configuration in terms of number of wheel hubs. Thus, a three-axle tractor with six wheel hubs that sends power to two axles totaling four hubs is designated a 6x4. A three-axle tractor with a single drive axle is designated a 6x2, and so forth. Figure 14 excludes less common configurations, including 8x4, 8x2, and 4x4, which combined account for less than 0.1% of the market.)

Tractors with a single drive axle reduce weight and have fewer energy losses related to gearing and oil churning, and as a result may provide fuel consumption reductions of about 2.5% (NACFE, 2013). The potential drawback with single drive-axle configurations is reduced traction, although traction-enhanced systems still achieve about 2% fuel savings (U.S. EPA, 2016). The trend toward having only one driven axle might reflect road improvements that reduce difficult terrain conditions for tractors.

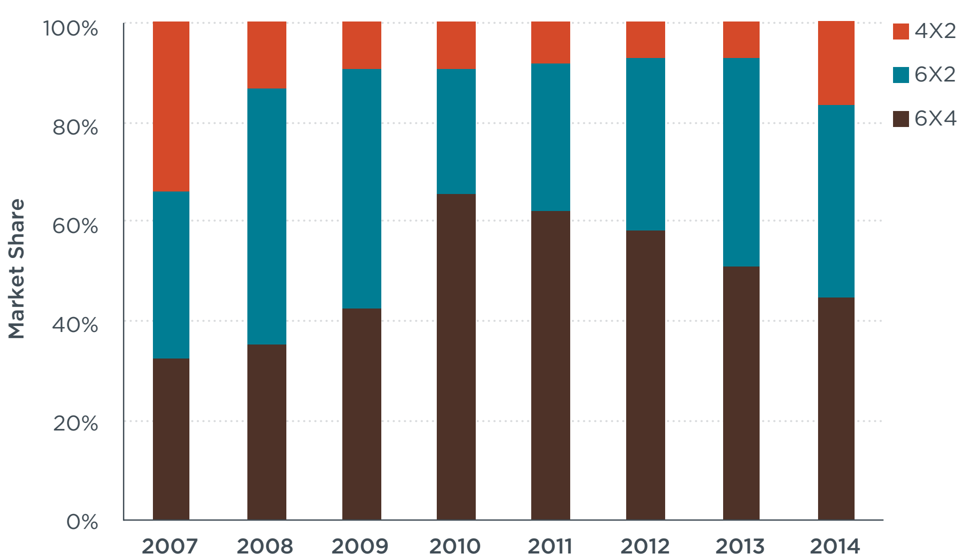

Figure 14. Historical trend of driveline configuration in China: tractor trucks, 2007–2014

Engine Displacement and Power

Tractor engines' displacement has increased steadily, as shown in Figure 15. The share of engines larger than 11 L climbed from 6% to 41% over the years studied. The average engine displacement increased 11% from 9.1 L in 2007 to 10.1 L in 2014. However, there is still a significant difference in tractor engine size between China and the U.S. and the EU. Only 1.4% of tractor engines in China exceeded 12 L, while typical engine displacements in the EU were 13 L and in the U.S., 15 L (Sharpe and Muncrief, 2015). The average ratio of engine displacement to GCW in 2014 was 0.22 L/t for tractors in China. In the EU, the average ratio was 0.32 L/ t while in the U.S., 0.41 L/t, or almost twice the China value.

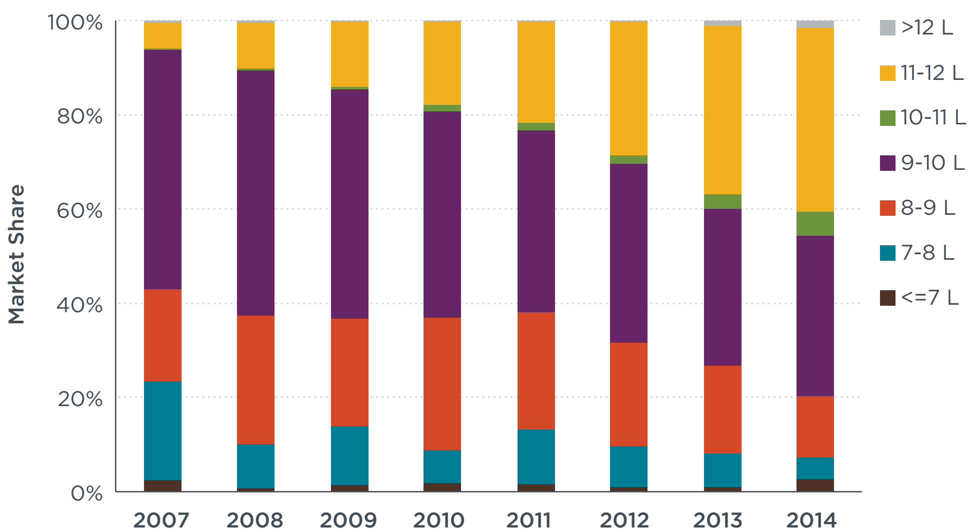

Figure 15. Historical trend of engine displacement in China: tractor trucks, 2007–2014

Consistent with the trend of increasing engine displacement, tractor engines' power climbed (see Figure 16). Average engine power increased 15% from 228 kW to 263 kW over the years studied. The share of engines with power ratings higher than 250 kW increased from 25% in 2007 to 56% in 2014. Fewer than 20% of engines rated at more than 300 kW. For comparison, typical tractor engine power in the EU and the U.S. was 300–350 kW.

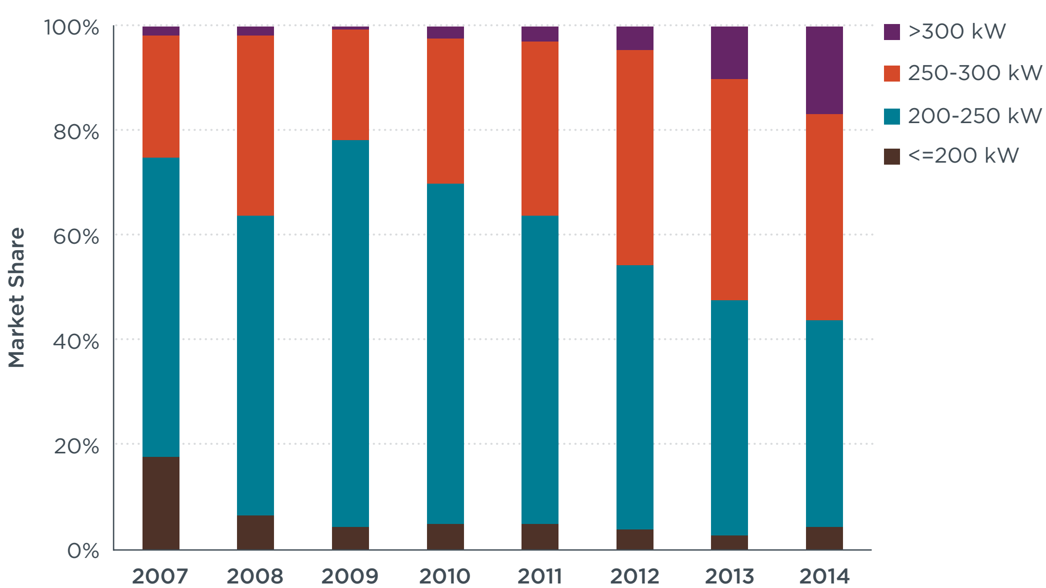

Figure 16. Historical trend of engine power in China: tractor trucks, 2007–2014

Trailers

In China, tractors and trailers are sold and registered separately. Even though trailers have an important impact on fuel consumption, they are not regulated in China's fuel consumption standards. In the 8 years of the study, the ratio of registered tractors to trailers was around 1:1. This implies that the drop-and-hook capability of trailers is not fully utilized, and most tractors always pull the same trailer. Logistics inefficiencies such as this and the relatively low use of tractor-trailers for long-haul transportation increase costs. Logistics costs in China as a percentage of GDP amount to 18%. In the U.S., such costs represent around 9% of GDP (Xiong, 2010). In recent years, China has been promoting more efficient freight transportation. For example, in 2014, 1,000 trucks from 20 logistics companies participated in a pilot program supported by China Green Freight Initiative to reduce freight fuel consumption by improving fleet management, vehicle technology, and eco-driving (China Energy Foundation, n.d.).

More than 90% of trailers in China have three axles, with the rest having two. Six-axle tractor-trailers, with three on the tractor and three on the trailer, are more common because they offer higher payloads. The GCW limit for a six-axle tractor-trailer is 49 tonnes, 14% higher than the 43-tonne limit for a five-axle combination. Transportation equipment maker CIMC had the largest trailer market share during 2007–2014, accounting for more than 15% of sales. In 2014, the aggregate market share of the top 10 manufacturers was 37%, with each trailer maker except CIMC accounting for less than 3%. More than 240 manufacturers make up the rest of the industry. In contrast with the U.S., where box-type trailers account for 68% of sales (Sharpe et al., 2013), stake and platform trailers make up more than half of the market in China (see Figure 17).

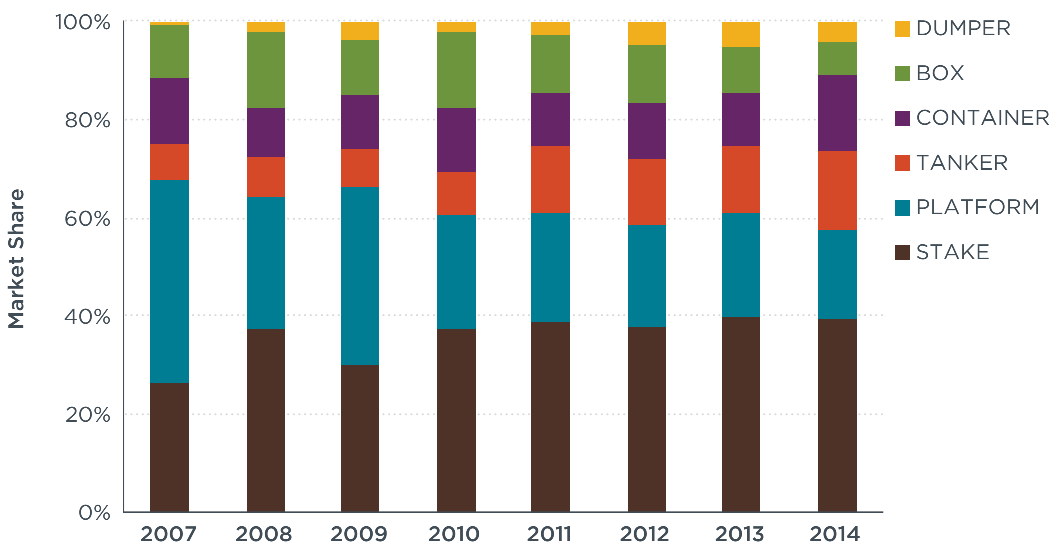

Figure 17. Historical trend of market share of trailers by body type in China, 2007–2014

Unlike box trailers, whose bodies are fully enclosed, stake trailers use welded beams to form a frame. Platform trailers have only a long bed without roof, sides, or doors. Like box trailers, stake trailers are used for long-distance transport of freight and bulk cargo. Platform trailers usually transport heavy and oversized cargo that normally would not fit into standard freight trailers, such as construction machinery, pipes, or steel. However, platform trailers can also carry freight containers. These two types of trailers both have higher load capacities than other body types (see Figure 18). The difference between the first and third quartiles of load capacity for stake trailers, 0.8 tonnes, is narrower than the 3.8-tonne interval for platform trailers. Stake trailers' average load capacity is 5% higher than that of platform trailers. The higher load capacity and lower curb weight may help explain the dominance of stake trailers in China. These vehicles are also less costly than box trailers, a high priority for purchase decision-makers. Some fuel-saving technologies might not be applicable to certain trailer types. For example, aerodynamics-enhancing boat tails are applicable for box type trailers but not for stake or platform trailers.

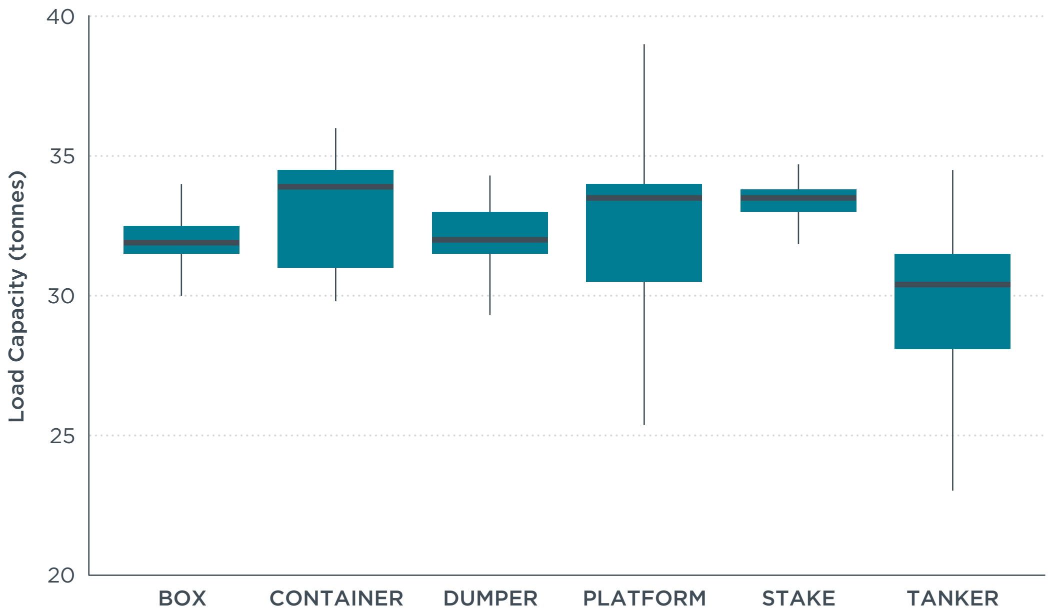

Figure 18. Trailer load capacities (maximum payload) by body type in China, 2014

The load capacity of trailers increased from 2007–2014, as shown in Figure 19. Average load capacity of all trailers rose 20.3% from 23.5 tonnes in 2007 to 31.8 tonnes in 2014. In 2014, 89.4% of trailers had a maximum payload of more than 30 tonnes. For stake trailers, average load capacity jumped 20.3% from 27.8 tonnes in 2007 to 32.9 tonnes in 2014, when 97% of stake trailers had maximum payloads of more than 30 tonnes.

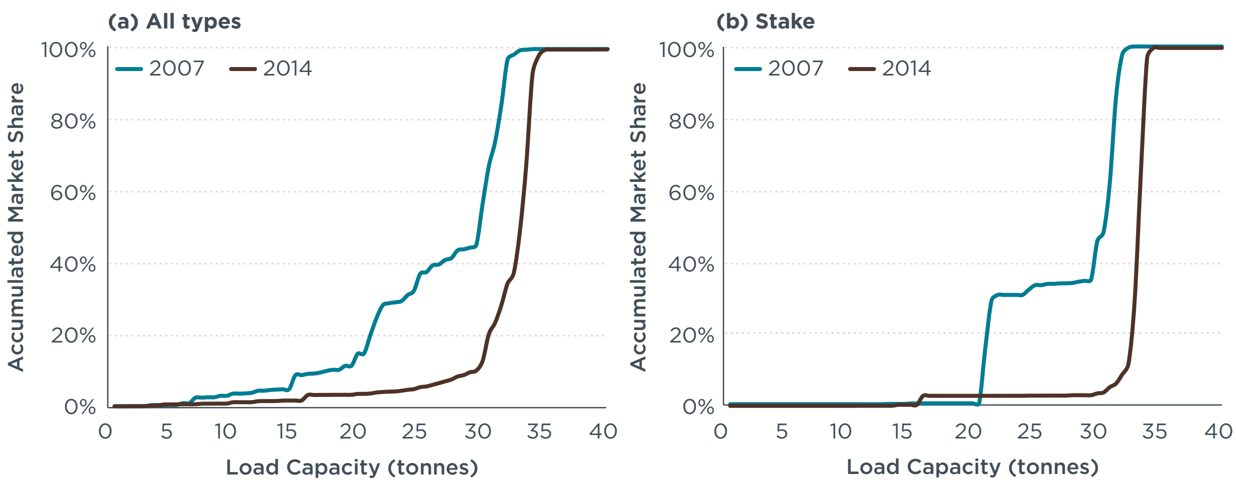

Figure 19. Trailer load capacity comparison in China, 2007 vs. 2014

Table 6 lists size and weight characteristics of 2014-registered trailers by type. The limits for three-axle trailers are 13m in length, 2.5m in width, and 4m in height (AQSIQ & SAC, 2004). This standard was in effect for 11 years. Regulators issued an updated standard in August 2016 (AQSIQ & SAC, 2016b). Under the new standard, the length limit for stake, tanker, platform, and dumper trailers remains 13 m. For box trailers the limit increases to 13.75 m, and for container trailers, to 13.95 m. The width limit of all trailer types increases to 2.55 m, except that the maximum width for trailers with refrigeration increases to 2.6 m. The maximum height limit remains unchanged at 4.0 m.

Table 6. General information on trailers in China, averaged by registration, 2014

Trailer Type	Payload (tonnes)	Length (m)	Width (m)	Height (m)	Market Share
Previous Regulatory Limits	NA[1]	13[2]	2.5[3]	4	NA
Updated Regulatory Limits	NA[1]	13[4]	2.55[5]	4	NA
Stake	32.9	12.7	2.5	3.4	40%
Tanker	28.9	11.7	2.5	3.9	16%
Platform	33.2	12.8	2.5	2.7	18%
Container	31.7	12.1	2.5	1.6[6]	16%
Box	30.1	13	2.5	3.6	7%
Dumper	31.1	10.6	2.5	3.2	4%

Notes:
[1] No payload limits
[2] Length limit for three-axle trailers
[3] Width limit for all trailers is 2.5 m, except close-body trailers (2.55 m)
[4] Length limit for all trailers is 13 m, except box trailers (13.75 m) and container trailers that load 45-ft containers (13.95 m)
[5] Width limit for all trailers is 2.55 m, except refrigerator trailers (2.6 m)
[6] The height of container trailers is measured by the trailer chassis. The total height will be greater with a container loaded on the trailer.

2.3 RIGID TRUCKS: STRAIGHT AND DUMP TRUCKS

Straight trucks and dump trucks are regulated as two separate vehicle segments in the fuel consumption standards. However, they are essentially rigid trucks with similar vehicle body type except that dump trucks have a hydraulic lifting system. In 2014, straight trucks represented 18.9% and dump trucks, 7.4% of the HDV market in China.

Rigid Truck Manufacturers

Market share trends for straight and dump trucks are shown in Figure 20. Both segments are dominated by the same five manufacturers: Dongfeng, BAIC, FAW, JAC, and SAIC. At the same time, the two categories are less consolidated than the tractor market. In 2014, newly registered rigid trucks came from 73 manufacturer groups. The aggregate market share of the five largest manufacturers increased over the study period, and the number of manufacturers decreased 25%, suggesting a slight trend toward consolidation. This trend did not appear in the total number of HDV manufacturers, which did not change significantly.

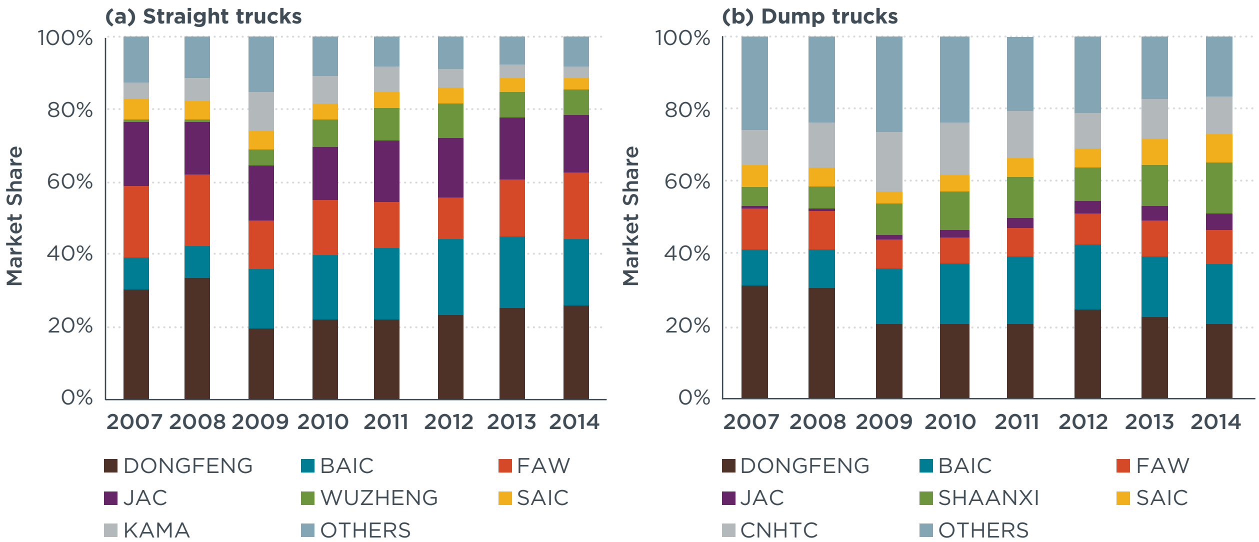

Figure 20. Historical trend of manufacturer market breakdown in China: rigid trucks, 2007–2014

Engine Manufacturers

From 2007–2014, there were 37 to 42 engine suppliers for straight trucks and 26 to 31 for dump trucks. The engine market trends are shown in Figure 21. In 2014, domestic manufacturers produced 83% of straight truck engines and 99% of dump truck engines. The remainder of the market was split among joint ventures involving Cummins.

The top three engine makers for straight trucks in 2014 were FAW with 28%, Yuchai with 20%, and Dongfeng with 16%. In the dump truck segment, Yuchai and Weichai have been responsible for more than 65% of sales since 2007. Yuchai was the top seller until 2012, then Weichai took the lead for 2013. Market share for the three top-selling makers of engines for dump trucks in 2014 were 41% for Weichai, 33% for Yuchai, and 11% for CNHTC.

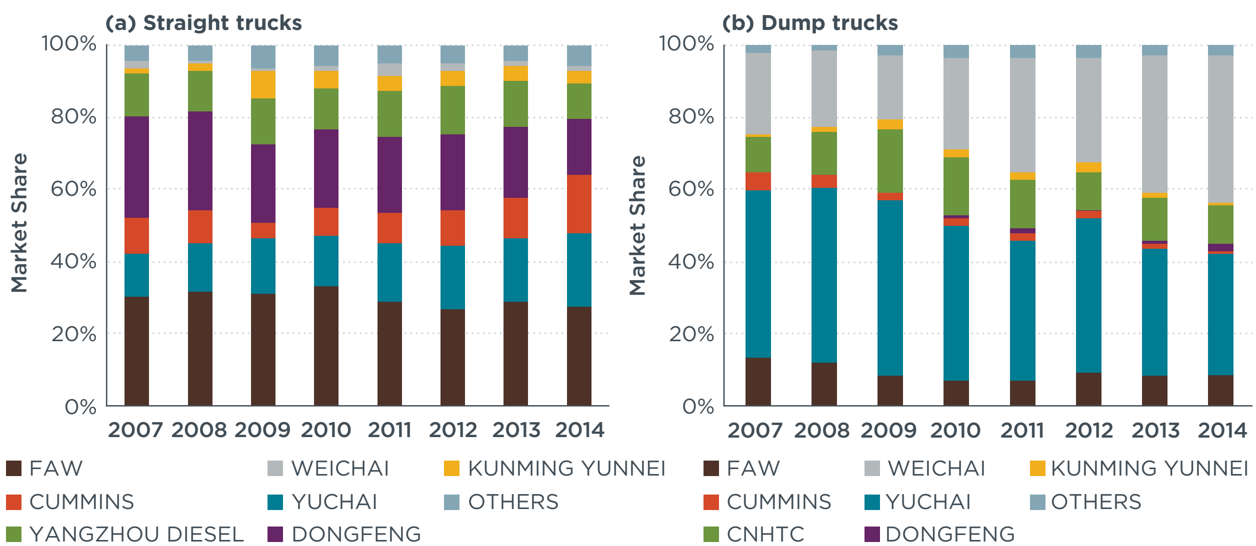

Figure 21. Historical trend of engine OEM market breakdown in China: rigid trucks, 2007–2014

Tables 7 and 8 show the main manufacturers of straight and dump trucks and their engine suppliers in 2014. The tables show that there is more diversity in combinations of engine and vehicle OEMs in the straight truck segment than in the dump truck segment. As an example, seven engine manufacturers account for 90% of BAIC's straight trucks, with the remaining 10% from smaller engine makers. However, for BAIC's dump trucks, three main engine manufacturers account for 96%, and the small manufacturers, 4%. One possible reason is that dump truck engines are typically more powerful than straight truck engines, and fewer producers specialize on such engines.

Table 7. Vehicle manufacturers and engine suppliers in 2014 in China: straight trucks

		Engine OEM							
		FAW	YUCHAI	CUMMINS	DONGFENG	YANGZHOU DIESEL	KUNMING YUNNEI	WEICHAI	OTHERS
Vehicle Manufacturer	DONGFENG		24%	39%	36%		1%		
	BAIC	3%	25%	26%	8%	21%	6%	1%	10%
	FAW	100%							
	JAC	18%	32%	7%	22%	12%		4%	5%
	WUZHENG	57%	15%		1%	20%	7%		
	SAIC		9%	2%	23%	49%	2%		15%
	KAMA	59%	18%			14%	9%		
	OTHERS	9%	25%	4%	7%	8%	11%	10%	26%
Engine OEM Market Share		**28%**	**20%**	**16%**	**16%**	**10%**	**3%**	**2%**	**5%**

Table 8. Vehicle manufacturers and engine suppliers in 2014 in China: dump trucks

		Engine OEM							
		FAW	YUCHAI	CUMMINS	DONGFENG	YANGZHOU DIESEL	KUNMING YUNNEI	WEICHAI	OTHERS
Vehicle Manufacturer	DONGFENG		80%	3%	9%			8%	
	BAIC		26%				3%	67%	4%
	FAW	78%	1%					21%	
	JAC	4%	24%			2%	2%	64%	4%
	SHAANXI		3%					97%	
	SAIC		11%					71%	18%
	CNHTC		5%			95%			
	OTHERS	7%	57%		1%	2%	3%	26%	4%
Engine OEM Market Share		**9%**	**33%**	**1%**	**2%**	**11%**	**1%**	**41%**	**3%**

Gross Vehicle Weight

Straight trucks' average GVW increased by 32% over the study period. Figure 22 shows box plots representing the GVW distribution from 2007–2014. The median GVW increased from 8.8 tonnes to 14.6 tonnes. The span between the first and third quartiles increased from 7 tonnes to 7.6 tonnes. Figure 23 shows GVW distribution of new straight trucks registered in 2014 by 0.5-tonne bins. The red solid lines show maximum legally allowed weights, determined by number of axles (AQSIQ & SAC, 2016b). For example, the maximum weight for two-axle straight trucks is 16 tonnes, which can be increased to 17 tonnes if the traction axle has two wheels on each side with air suspension. For simplicity, only the 16-tonne limit is shown.

The GVW peaks around 16 tonnes, 25 tonnes, and 31 tonnes closely correspond to the legally allowed maximums by weight class. The peak around 10 tonnes may relate to the highway tolling system in most provinces, where 10 tonnes and above trucks have increased road-use fees (Tianjin DRC, 2011).

Of straight trucks, 84% have two axles with a GVW limit of 16 tonnes, helping to explain the large peak in Figure 23 between 15 and 16 tonnes. Dashed lines in Figure 23 show the regulatory weight bins for fuel consumption limits. Straight trucks in the 12.5–16 tonne bin account for 46% of the market, representing the largest market share. In this bin, 72% of the straight trucks have GVW above 15 tonnes, the highest peak in Figure 23.

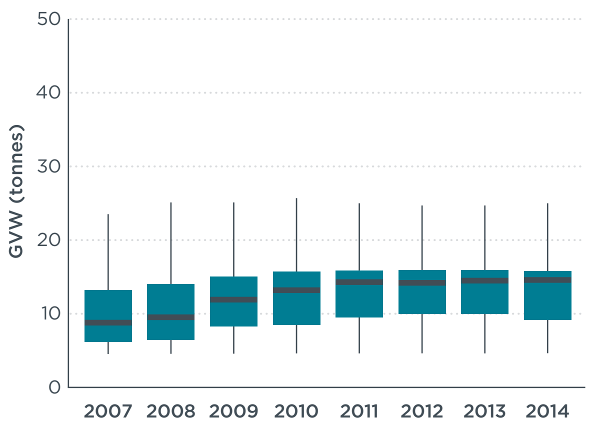

Figure 22. Historical trend of GVW in China: straight trucks, 2007–2014

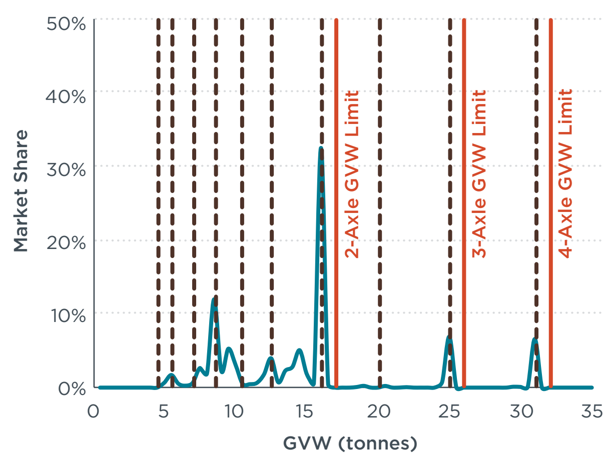

Figure 23. GVW distribution in China: straight trucks, 2014

Dump trucks' average GVW increased by 45% from 2007–2014. Figure 24 shows box plots representing GVW distribution year by year. Median GVW increased from 15 tonnes to 25 tonnes. In 2014, dump trucks were built within a much narrower GVW range than in previous years, perhaps an effect of the Stage 2 fuel efficiency regulations. The span between the first and third quartiles of dump trucks' GVW show a significant declining trend, from 17.6 tonnes in 2007 to 6.5 tonnes in 2014. This contrasts with straight trucks, where the span widened.

Dump truck GVWs are usually higher than those of straight trucks. More than two thirds of dump trucks have three or more axles with two traction axles, allowing them to operate on rough roads carrying heavy materials like sand and coal. Figure 25 shows that as with straight trucks, the most common GVWs correspond to the maximum allowed weights.

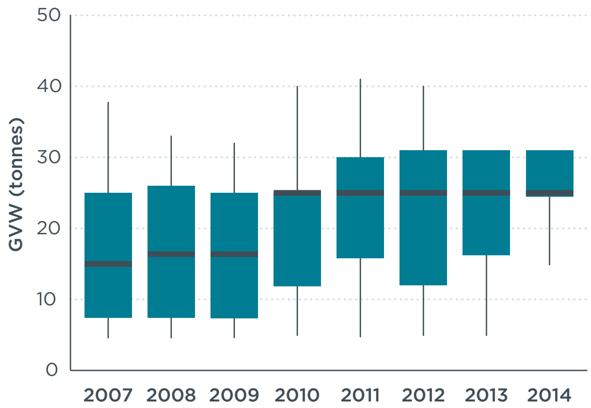

Figure 24. Historical trend of GVW in China: dump trucks, 2007–2014

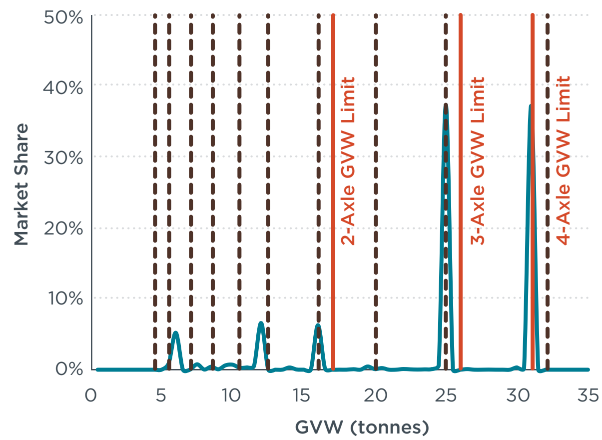

Figure 25. GVW distribution in China: dump trucks, 2014

Because of their lower curb weight, straight trucks show higher load capacities than dump trucks with similar driveline configurations. Figures 26a and 26b show the maximum payload distribution for different axle configurations for straight and dump trucks in 2014, by 0.5-tonne bins. The distribution of load capacity by number of axles has obvious peaks, especially around 13 tonnes for three-axle drivelines and 16 tonnes for four axles. In contrast, straight trucks' load capacities are more diverse.

The average load capacity for straight trucks is 7.6 tonnes for two axles, 14.9 tonnes for three axles, and 19.1 tonnes for four axles. For dump trucks, the averages are 5.0 tonnes for two axles, 12.5 tonnes for three axles, and 15.9 tonnes for four axles. As suggested before, this may relate to the additional curb weight for the dump trucks' hydraulic systems. Assuming the same maximum GVW, this reduces maximum payload. Nonetheless, the average fleet-wide load capacity for dump trucks is higher than for straight trucks. Three- and four-axle drivelines are dominant for dump trucks, representing 77% of the dump truck market in 2014. In straight trucks, two-axle configurations account for 84%.

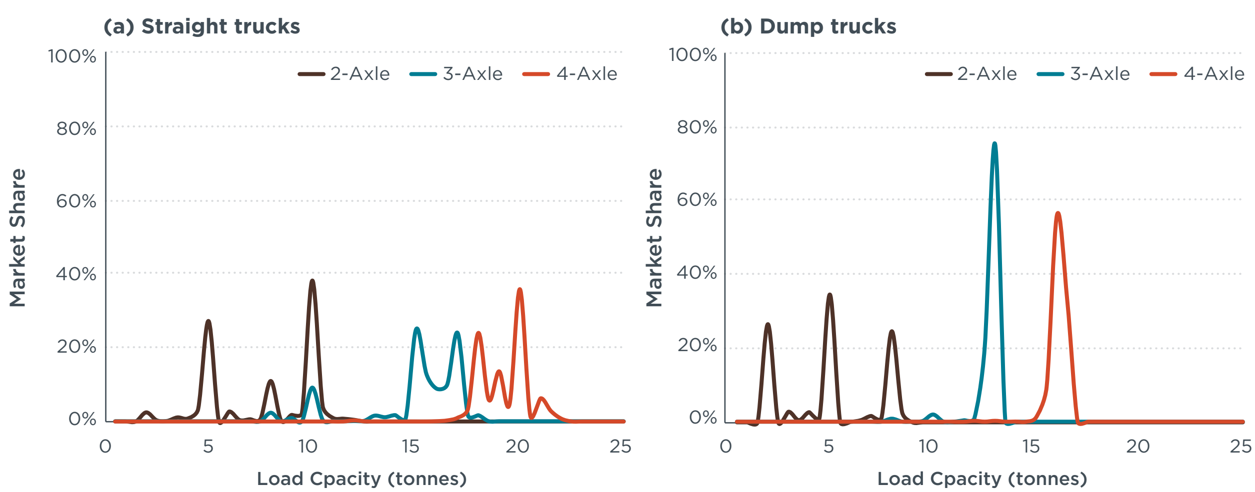

Figure 26. Load capacity distribution by number of axles in China: rigid trucks, 2014

Note: Distribution plots add up to 100% for each axle configuration (shown as one color).

Driveline Configuration

The dominant driveline configuration for straight trucks is 4x2, representing more than 80% of the market from 2007–2014 (see Figure 27a). Dump trucks commonly have more axles than straight trucks because of the need to transport larger payloads (see Figure 27b). The most common dump truck driveline configurations are 6x4 and 8x4, each representing about 35% of the 2014 market.

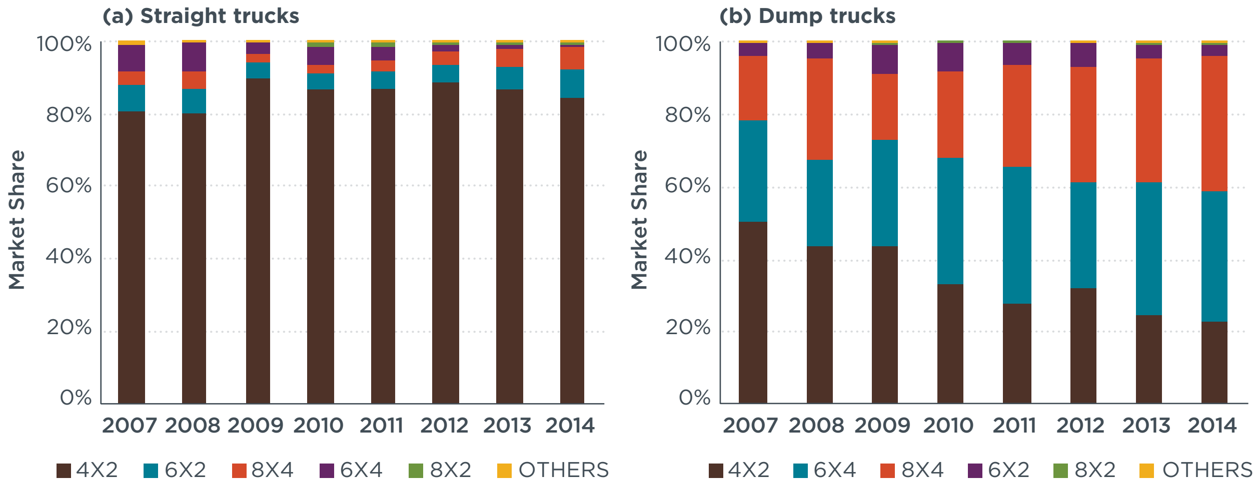

Figure 27. Historical trend of driveline configuration in China: rigid trucks, 2007–2014

Engine Displacement and Power

Dump trucks generally use larger engines than straight trucks. Average displacement in 2007–2014 was 7.8 L for dump trucks and 4.6 L for straight trucks. Engine displacement trends for straight and dump truck engines are shown in Figures 28a and 28b. The average engine displacement for straight trucks decreased 4% from 4.9 L in 2007 to 4.7 L in 2014. As for dump trucks, the average engine displacement climbed 15% from 7.3 L to 8.4 L, and the share of engines with a displacement larger than 8 L jumped from 38% in 2007 to 65% in 2014. Fewer than 0.3% of straight truck engines were larger than 10 L, and fewer than 0.1% of dump truck engines were larger than 12 L.

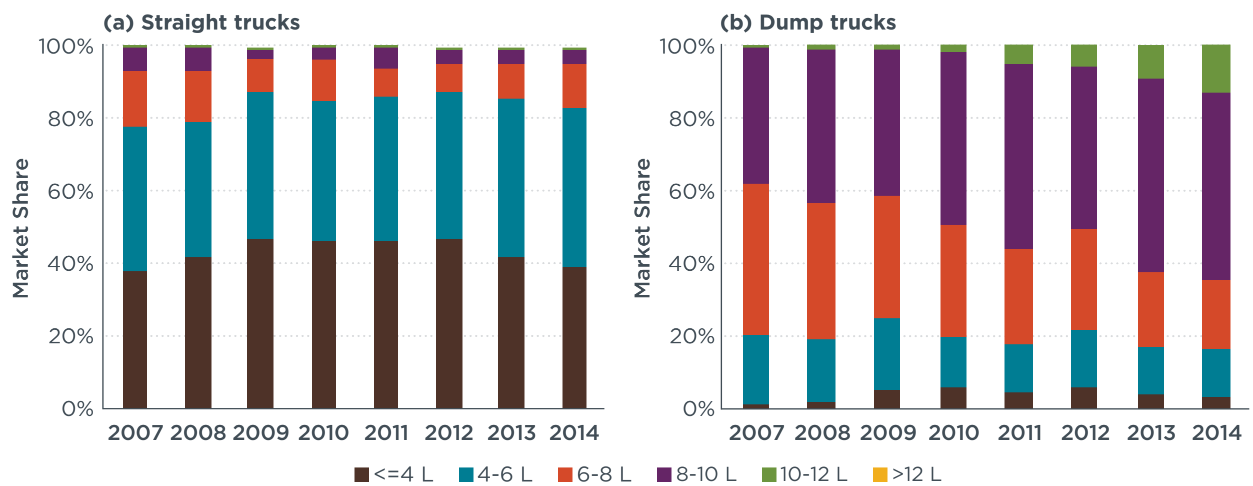

Figure 28. Historical trend of engine displacement in China: rigid trucks, 2007–2014

The average dump truck engine in 2007–2014 was rated at 186 kW, and the average straight truck engine, at 107 kW. Figures 29a and 29b show the trend of engine power for straight and dump truck engines. Both segments have moved toward using higher-power engines, especially dump trucks. Straight trucks' engine power increased 6% from 109 kW to 116 kW while engine power of dump trucks climbed 27% from 164 kW to 208 kW. The share of straight truck engines with power greater than 100 kW almost tripled from 17% in 2007 to 47% in 2014. As for dump trucks, the share of engines with power ratings higher than 200 kW more than doubled from 34% in 2007 to 76% in 2014.

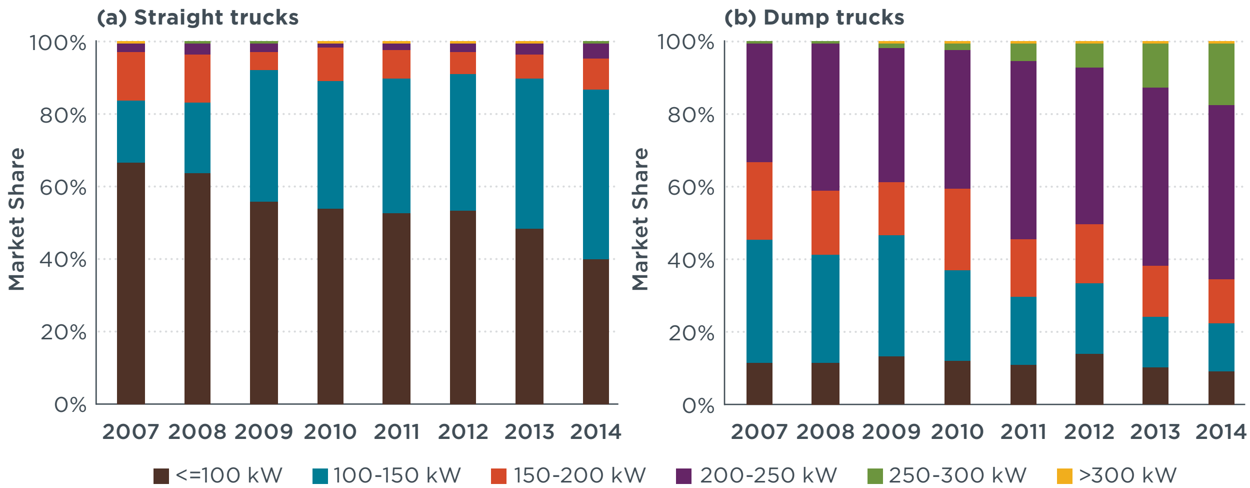

Figure 29. Historical trend of engine power in China: rigid trucks, 2007–2014

2.4 SPECIALIZED VEHICLES

Each of the two sub-types of specialized vehicles—delivery and vocational—split into six body types: stake, van, tanker, dumper, crane, and special structure (NTCAS, 2009). A specialized delivery vehicle is designed to transport a specific type of goods, such as flammable liquids, livestock, or seafood. Stake, van, and tanker are the three most common body types for these delivery vehicles, as shown in Figure 30. Common uses of vans are food trucks, communications vehicles, medical vehicles, mail, and cash carriers. Tankers are used for liquids or gases. Stake trucks are mainly for livestock and general goods.

Specialized vocational vehicles are designed for a specific type of work, such as pumping fluids, blowing snow, or lifting goods. Some examples are street sprinkler, asphalt-distributing tanker, and foam fire tanker. (A full list of specialized vocational vehicles is available in regulation GB/T 17350-2009.) Figures 30a and 30b show that cranes and special structure vehicles are the two main body types for specialized vocational vehicles.

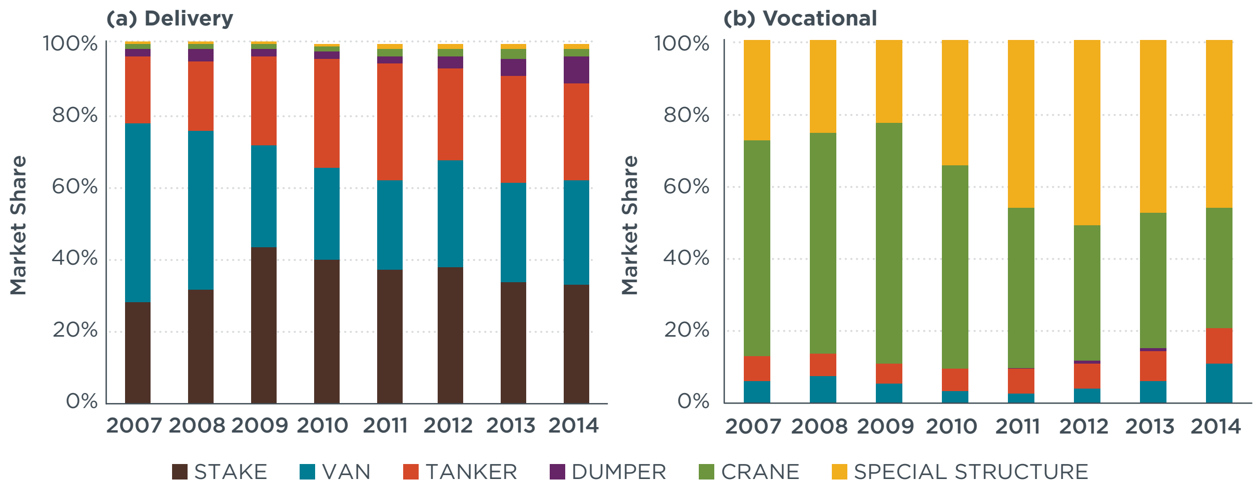

Figure 30. Historical trend of specialized vehicles annual registration in China by body-type, 2007–2014

Specialized delivery vehicles account for more than 80% of the combined specialized vehicle market (see Figure 31). The following sections focus on specialized delivery vehicles, which are covered by China's current efficiency regulations. In 2014, according to the fuel consumption standards categorization (NTCAS, 2009) and our market analysis, 93% of these vehicles were regulated as straight trucks and 7% as dump trucks, based on the similarity of body types. These vehicles are subject to the same limits as straight trucks and dump trucks. Specialized vocational vehicles account for less than 20% of all specialized vehicles and are not covered by the current fuel consumption standards.

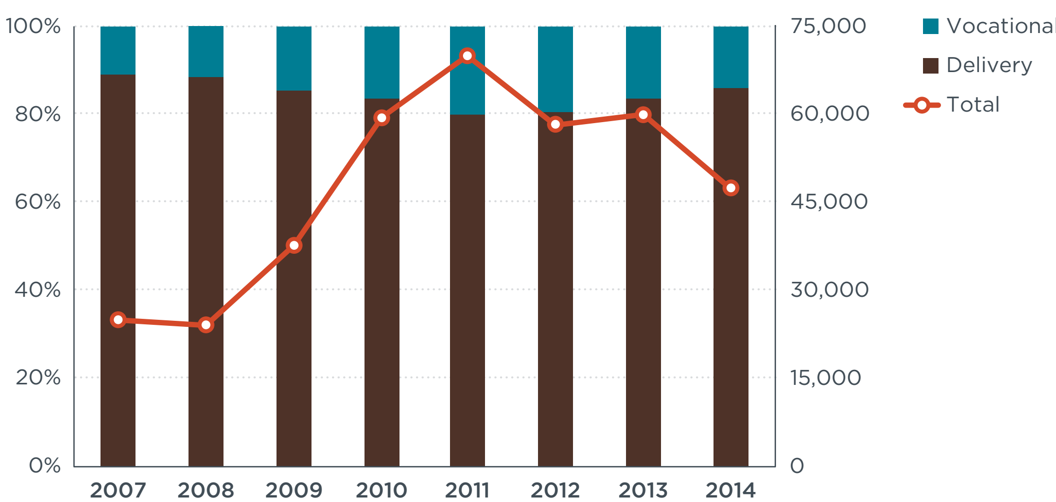

Figure 31. Historical trend of registration count of specialized vehicles China and market breakdown by sub-type, 2007–2014

Specialized Delivery Vehicle Manufacturers

The specialized delivery vehicle market is fractured among more than 250 producers. The seven largest manufacturers had 69%-73% of the market from 2007–2014 (see Figure 32). In 2014, the top seven had 71% of the market and the top 25, 90%. The remaining 10% was split among around 250 manufacturers. There was no significant consolidation trend. As in the tractor and rigid truck markets, the leaders were Dongfeng, FAW, and BAIC.

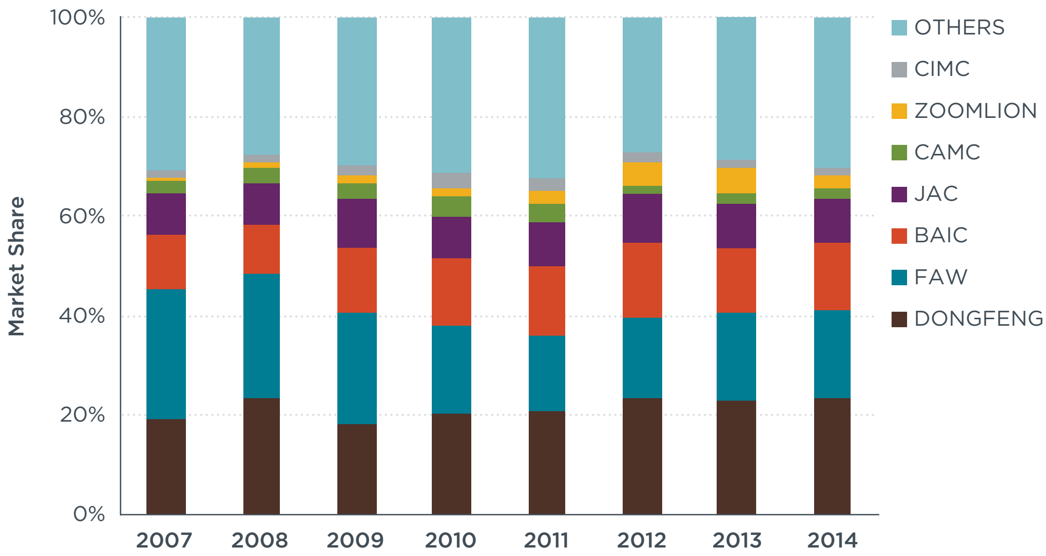

Figure 32. Historical trend of manufacturer market breakdown in China: specialized delivery vehicles, 2007–2014

Engine Manufacturers

The specialized delivery engine market consisted of 41 to 51 engine manufacturers during 2007–2014. Specialized delivery engine OEM market share trends are shown in Figure 33. The top seven manufacturers were responsible for 91% of sales in 2007 and 89% in 2014. FAW lost market share, falling from 34% in 2007 to 21% in 2014, while Cummins joint ventures gained share, climbing from 15% in 2007 to 22% in 2014. The "other" category consists of more than 30 engine OEMs, a number that generally held stable.

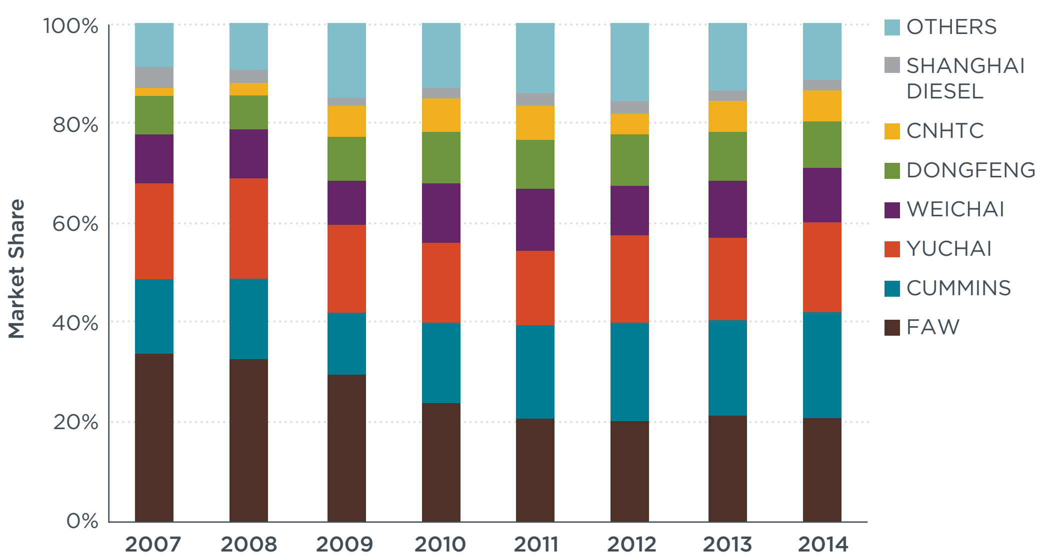

Figure 33. Historical trend of engine OEMs in China: specialized delivery vehicles, 2007–2014

Table 9 shows the principal manufacturers of specialized delivery vehicles and their engine suppliers. In contrast with the tractor and dump truck segments, where mostly domestic companies supply engines, joint ventures represented a substantial market share. Cummins joint ventures supplied 44% of Dongfeng engines and 34% BAIC motors in 2014. On the other hand, FAW built almost all of its own engines—97% in 2014. Nearly every vehicle manufacturer in this segment uses engines from the two biggest suppliers, Yuchai and Weichai.

Table 9. Vehicle manufacturers and engine suppliers in China: specialized delivery vehicles, 2014

		Engine OEM								Vehicle Market Share
		CUMMINS	FAW	YUCHAI	WEICHAI	DONGFENG	CNHTC	SHANGHAI DIESEL	OTHERS	
Vehicle Manufacturer	DONGFENG	44%	0%	32%	1%	22%	0%	0%	1%	24%
	FAW	0%	97%	0%	2%	0%	0%	0%	0%	18%
	BAIC	34%	1%	15%	25%	2%	0%	9%	14%	13%
	JAC	6%	17%	46%	13%	7%	0%	0%	10%	9%
	ZOOMLION	26%	1%	2%	9%	10%	29%	0%	23%	3%
	CAMC	0%	0%	3%	55%	0%	2%	1%	39%	2%
	CIMC	12%	19%	8%	23%	3%	28%	0%	6%	1%
	OTHERS	17%	5%	13%	14%	9%	18%	2%	23%	30%
Engine OEM Market Share		22%	21%	18%	11%	9%	7%	2%	11%	100%

Gross Vehicle Weight

Specialized delivery vehicles' GVW rose from 2007—2014. Average GVW increased by 19%, from 16.8 tonnes in 2007 to 19.9 tonnes in 2014. Figure 34 shows box plots with the distribution trends. Median GVW values held around 16 tonnes except for 2010 and 2011. The range between the first and third quartiles of GVW narrowed to 9.5 tonnes in 2014 from 15.6 tonnes in 2007.

Figure 35 shows a more detailed GVW distribution for 2014. In contrast with other vehicle segments that show one or two peaks in GVW distribution, specialized delivery vehicles show three peaks, all of them very close to the GVW limits based on number of axles. This relates to the high diversity of driveline configurations among specialized delivery vehicles. As with other vehicle segments, the most common GVWs correspond to the weight limits allowed for each axle configuration.

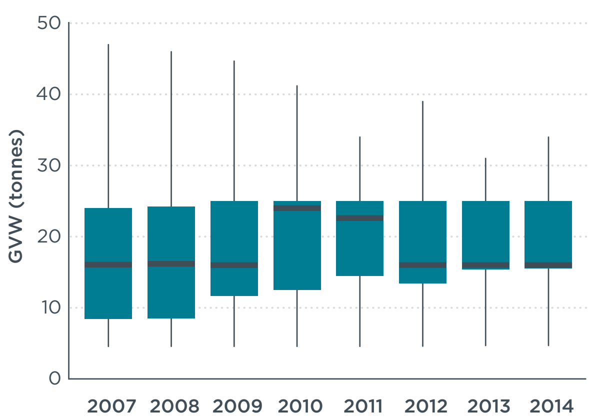

Figure 34. Historical trend of GVW: specialized delivery vehicles, 2007–2014

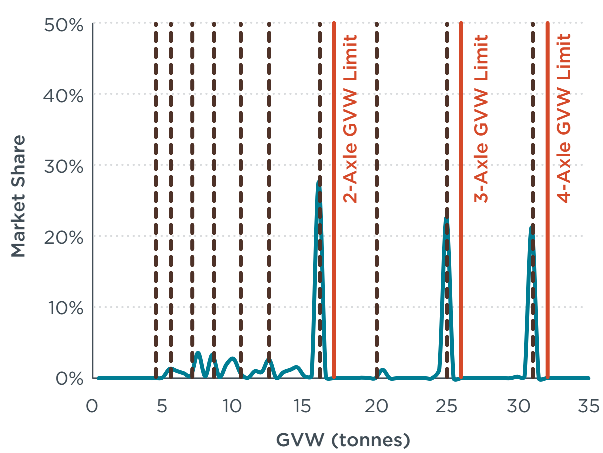

Figure 35. GVW distribution: specialized delivery vehicles, 2014

Figures 36a and 36b show the load capacity of specialized delivery vehicles by body type in 2007 and 2014. Over the 8 years, there was a noticeable increase in load capacity for all specialized delivery vehicle types, aside from tankers. The median load capacity of the two most popular body types increased significantly: stake trucks rose from 9 tonnes in 2007 to 13 tonnes in 2014, and vans almost doubled from 4.4 tonnes in 2007 to 8.6 tonnes in 2014. The span between the first and third quartiles of specialized delivery vehicles' load capacity widened by 2014 from 2007 across all types. The range increased to 2.7 tonnes for crane trucks, 4.6 tonnes for dumpers, 5.8 tonnes for special structure vehicles, 2.3 tonnes for stake trucks, 1.3 tonnes for tankers, and 1.9 tonnes for vans.

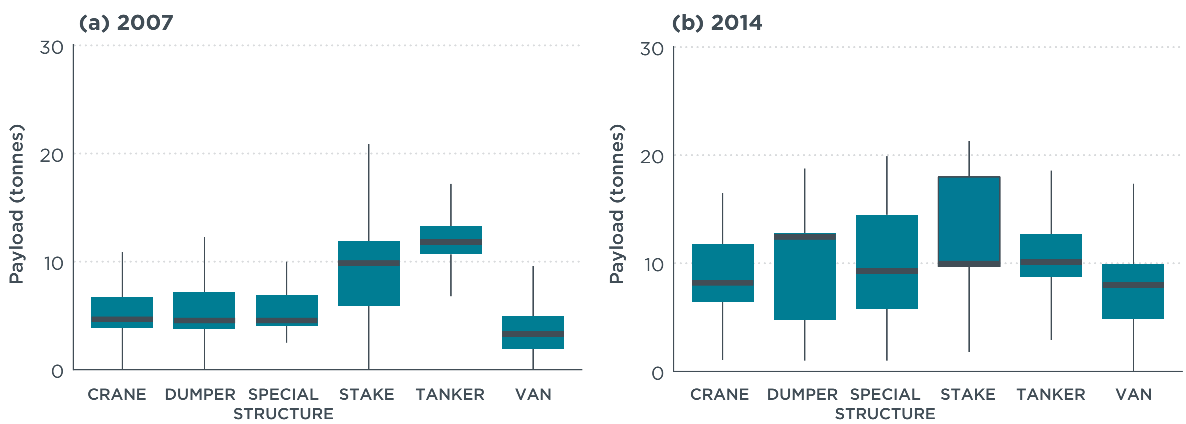

Figure 36. Loading capacity by body-type: specialized delivery vehicles, 2007 vs. 2014.

Driveline Configuration

The dominant driveline configuration for specialized delivery vehicles was 4x2, representing more than half of the market from 2007–2014 (see Figure 37). The second-most popular configuration was 8x4, accounting for 21% of the market in 2014. The 6x2 configuration decreased from 23% in 2007 to 9% in 2014. The trend toward larger traction capabilities suggests that specialized delivery vehicles were operated off-road or in difficult terrain more often than straight trucks. Figure 38 shows the load capacity distribution by number of axles. The load capacities of specialized delivery vehicles differ greatly for the same number of axles. This is consistent with the various types of body design targeted for different types of goods, where the additional equipment or infrastructure will affect curb weight and maximum payload.

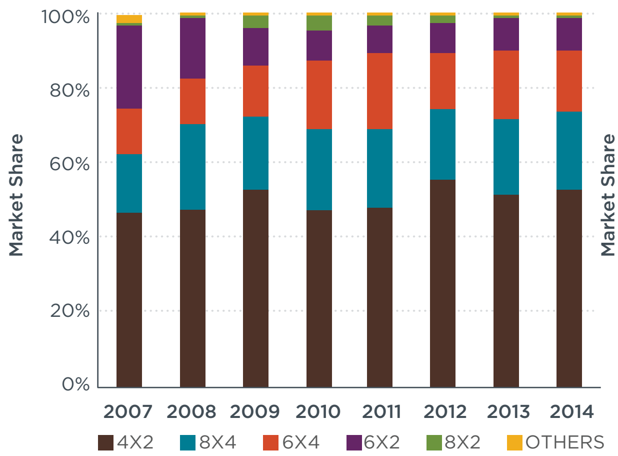

Figure 37. Historical trend of drivetrain: specialized delivery vehicles

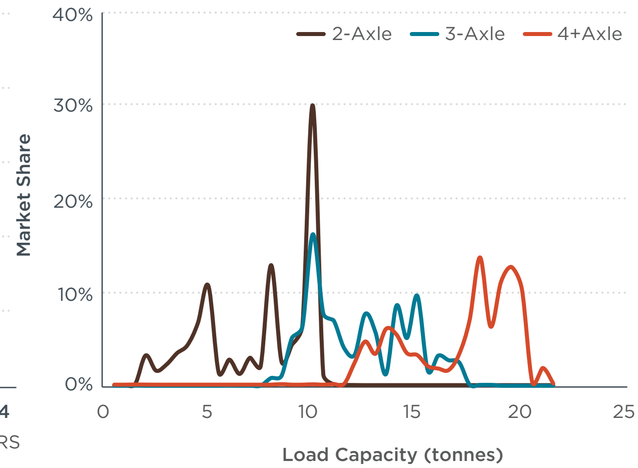

Figure 38. Load capacity distribution by axle: specialized delivery vehicles, 2014

Note: Distribution plots in Figure 38 add up to 100% for each axle configuration (shown as one color).

Engine Displacement and Power

Figure 39 shows the historical trend of engine displacement for specialized delivery vehicles. There was no significant change in average engine displacement, a rise of 2% from 6.5 L in 2007 to 6.6 L in 2014. At the same time, the share of engines with displacement of 10–12 L expanded from 2% in 2007 to 8% in 2014. Specialized delivery vehicle engine displacement is almost exclusively smaller than 12 L.

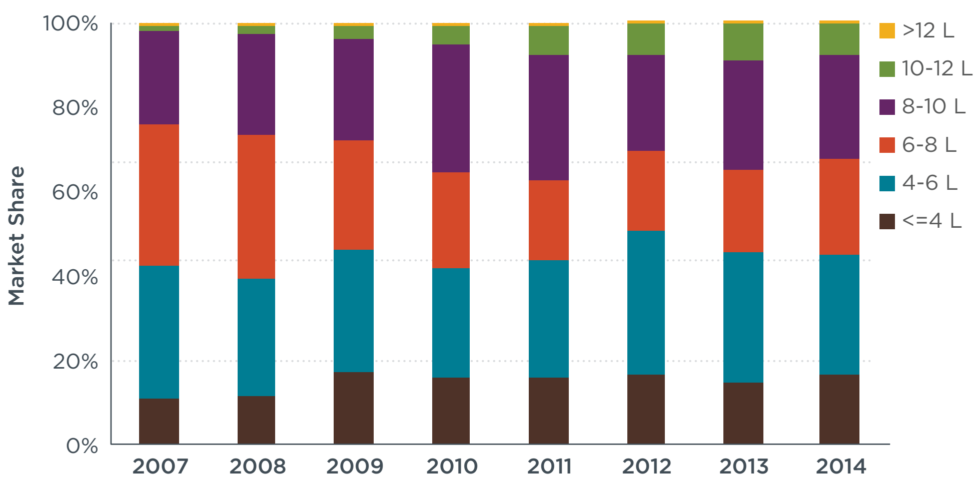

Figure 39. Historical trend of engine displacement: specialized delivery vehicles

Figure 40 shows the historical trend of engine power for specialized delivery vehicle engines. Average power increased 12% from 148 kW in 2007 to 166 kW in 2014. In 2014, 39% of specialized delivery vehicles were equipped with engines in the 100–150 kW range. The share of engines with power higher than 250 kW increased from 2% in 2007 to 11% in 2014.

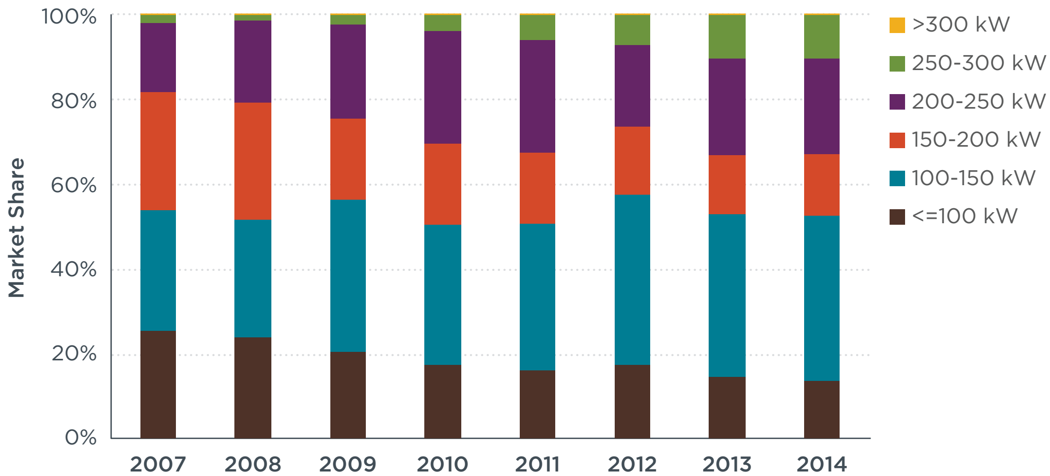

Figure 40. Historical trend of engine power: specialized delivery vehicles

3. BASELINE VEHICLE PERFORMANCE

This section builds on the market analysis to perform a fuel efficiency technology assessment for tractor-trailers and straight trucks. These two segments represent most on-road freight movement in China. Together, tractor and straight trucks consume more than 60% of total HDV fleet fuel in China.[4] Most specialized vehicles have configurations similar to those of straight trucks and are subject to the same fuel consumption regulations. The analysis uses baseline specifications to simulate baseline vehicle models and fuel efficiency. These baseline models are then modified to analyze the potential of certain technologies to reduce fuel consumption. The analysis provides a snapshot of HDV fuel efficiency in China, which provides a baseline for evaluating the potential of fuel efficiency technologies.

3.1 METHODOLOGY AND ASSUMPTIONS

Two vehicle segments—tractor-trailers and straight trucks—form the basis of the baseline vehicle analysis. Autonomie vehicle simulation software, developed by Argonne National Laboratory, was used to create a tractor-trailer model and a straight truck model to estimate baseline fuel consumption and the effect of vehicle efficiency technologies (UChicago Argonne LLC, 2016). Further details of the simulation model and its capabilities can be found in previous studies (Delgado and Lutsey, 2015; Delgado, Miller, Sharpe, & Muncrief, 2016).

The baseline vehicles are meant to represent typical configurations of 2015 model year trucks. We did not aim to exactly match specific makes and models, but rather to simulate typical configurations for tractor-trailers and straight trucks in China based on the market analysis. We recognize that there is a wide range of vehicle specifications for a given heavy-duty segment in China, and there will be vehicles in the market that are more or less technologically advanced than the model vehicles developed to represent the baseline. By identifying the most common vehicle characteristics, we aimed to simulate an average vehicle to represent the respective segment of the fleet as a first-order approximation. A key challenge is that some vehicle parameters are not readily available, such as aerodynamic drag and tire rolling resistance coefficients. To offset the missing data, we relied on consultants and industry experts who provided qualitative and quantitative information on market-specific vehicle specifications including engine efficiency, engine fueling maps, technology market penetration, transmission technologies, aerodynamics, tire rolling resistance, and other vehicle parameters.

3.2 BASELINE VEHICLE CHARACTERISTICS

Table 10 lists baseline vehicle characteristics. Our model tractor-trailer combination has a GCW of 49 tonnes. This corresponds to the most popular GCW bin of 46–49 tonnes in the current standards and represents about 60% of the tractor market of 2014. Within the bin, 60% of tractors are between 48 and 49 tonnes. Our market analysis suggests that typical tractors in this bin weigh roughly 9 tonnes, and a typical stake trailer, about 7 tonnes, adding up to a tractor-trailer combination curb weight of 16 tonnes.

The straight truck market is more diverse than the tractor truck market, with an extensive range of vehicle vocations, payloads, and specifications. Our baseline straight truck has a GVW of 16 tonnes based on the most populated GVW regulatory bin of

4 Estimated based on the HDV fuel consumption distribution: 22% (tractor) + 31% (straight truck) + [0.93 (non-dump sub-type portion of specialized delivery vehicles) * 0.86 (specialized delivery vehicles' portion of total specialized vehicles) * 12% (specialized vehicles)] = 63% (CATARC, 2013).

12.5–16 tonnes. This category represents the largest share of the 2014 straight truck market, 46%. Within the bin, 72% of the straight trucks were between 15 and 16 tonnes.

Driven primarily by maximum overall length restrictions, such as 16.5 m for a semi-trailer combination, tractor truck manufacturers in China have adopted a cab-over-engine design (AQSIQ & SAC, 2016b). A volume capacity of 88 m^3 was calculated based on maximum allowed trailer dimension of 13 m in length, 2.55 m in width, and 4 m in height (AQSIQ & SAC, 2016b). Volume capacity for a typical 16-tonne straight truck box van is around 45 m^3, according to the new model market website ChinaCar.

For tractors, 6x4 is the most common axle configuration, with 45% of the market, while 4x2 is the most common for straight trucks, with 84%. Manual transmissions are the most common for both vehicle segments. China V emissions standards are now in place (MEP, 2016). Based on engine displacement and power from the market study, engine fuel maps were developed by AVL automotive for this study. Typical aerodynamic drag and tire rolling resistance coefficients came from consultations with experts and our own engineering estimates, also listed in Table 10.

The representative models specified do not fully capture the diversity of China's HDV market. The market analysis in previous sections shows that such diversity is significant. However, in selecting a vehicle commonly used for long-haul freight transport and a vehicle commonly used for regional and urban freight, this represents a good first-order analysis.

Table 10. Baseline truck characteristics in China

	Tractor-Trailer	Straight Truck
Gross vehicle weight (tonnes)	49	16
Vehicle curb weight (tonnes)	16	6
Maximum payload (tonnes)	33	10
Volume capacity (m^3)	86	45
Axle configuration	6x4	4x2
Typical trailer type	Stake	N/A
Trailer axle number	3	N/A
Engine Displacement (liters)	10	4
Engine Power (kW)	250	118
Engine Criteria Pollutant Emission standard (NO_x emission limit)	China V* (2.0 g/kwh)	China V* (2.0 g/kwh)
Vehicle fuel consumption standard (fuel consumption limit)	China Stage 2 (47 L/100km)	China Stage 2 (28 L/100km)
Transmission type	Manual	Manual
Transmission gears	10	6
Transmission gear ratios	14.8–1	6.3–0.797
Rear axle ratio	4.11	5.00
Tire type	Radial	Radial
Tire size	12R22.5	8.25R20
Aerodynamic drag	0.75	0.77
Rolling resistance coefficient (N/kN)	6.8	7.7

** Note: Equivalent to Euro V.*

3.3 TYPICAL DRIVE CYCLES AND PAYLOADS

A regulatory duty cycle was used for evaluating fuel efficiency of the baseline vehicles, as shown in Figure 41 (AQSIQ & SAC, 2011). The C-WTVC cycle is used for fuel consumption certification of all HDVs in China and is adapted from the World Harmonized Vehicle Cycle (WHVC). Some of the original WHVC acceleration and deceleration rates are reduced to reflect China's HDV fleet, which on average has lower engine power-to-vehicle weight ratios than HDV fleets in Europe, North America, and Japan, which were used to develop the WHVC. This cycle is also used later to evaluate the technology potential for reducing fuel consumption.

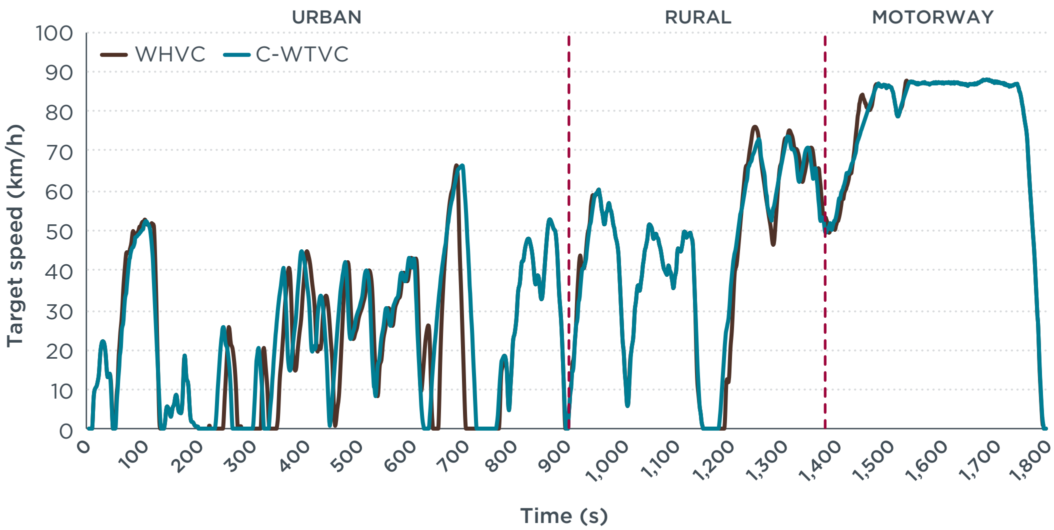

Figure 41. Time-velocity profiles of the C-WTVC and WHVC

In the HDV standards for China, fuel consumption is calculated by applying weighting factors for urban, rural, and motorway segments of the test cycle. The weighting factors are listed in Table 11 (AQSIQ & SAC, 2011). The current test protocol for the HDV fuel consumption standard requires that vehicles be tested at full payload. Therefore, the baseline tractor-trailer and straight truck models in this study are analyzed at maximum payload.

Table 11. C-WTVC Weightings

Vehicle Segment	Weightings			Average Speed (km/h)
	Urban	Rural	Motorway	
Tractor-trailer	0%	10%	90%	72.7
Straight Truck	10%	40%	50%	54.5

3.4 BASELINE VEHICLE PERFORMANCE

Fuel Efficiency Performance (type approval data)

Type approval data on the fuel efficiency performance of tractor-trailer and straight truck models for 2014–2016 were obtained from the ChinaCar website. This website contains detailed data on vehicle specifications, sales price, and reported type-approval fuel consumption values. Figure 42 shows the fuel consumption of tractor-trailer models in two selected GCW bins, covering 73 models in the 43–46 tonnes bin and 111 in the 46–49 tonnes bin. These bins were used in the analysis because they are the two most heavily populated, representing an aggregated 78% of the tractor market. China's fuel consumption standard is a per-vehicle regulation, meaning that every vehicle must comply. This contrasts with OEM sales-weighted averages used in U.S. fuel consumption standards, in which each OEM has its own target based on its sales composition, and individual vehicles might be non-compliant (U.S. EPA, 2016).

The fuel consumption results in China show a wide range, from vehicles that barely satisfy the Stage 2 limits, to vehicles that are almost already in compliance with the proposed Stage 3 limits. Fuel consumption of different models within the same weight bin were observed to differ by as much as 11% for the 43–46 tonnes category and 14% for the 46–49 tonnes bin. This degree of deviation can be attributed to differing technology levels in the engine, powertrain, and vehicle systems. Some leading high-efficiency models, such as the LZ4251T7DA Chenglong from Dongfeng and the CA4250P63K2T1HE4 Jiefang from FAW, show that the Stage 3 limits are technologically feasible with already available technologies.

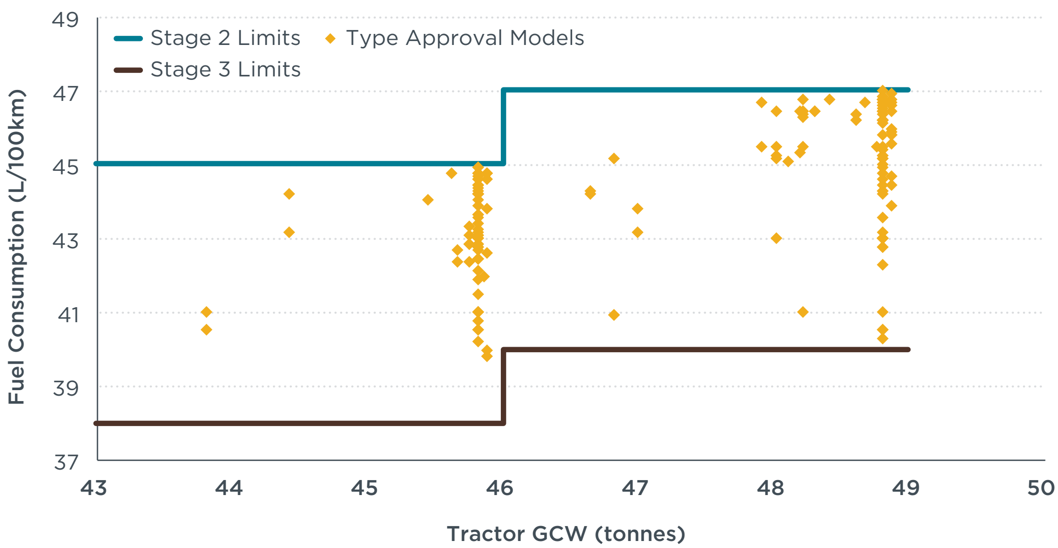

Figure 42. Fuel consumption of tractor-trailer models in selected bins

Figure 43 shows the fuel consumption of straight truck models in two representative GVW bins, including 65 models in the 10.5–12.5 tonnes bin and 233 models in the 12.5–16 tonnes bin. These categories cover about 40% of the market. As with tractor-trailers, fuel efficiency of different models varies greatly. Fuel consumption within the same weight bin can vary by as much as 22% for the 10.5–12.5 tonnes class and by 14% for the 12.5–16 tonnes bin. Similarly to the tractor-trailer case, some leading high-efficiency models including the cargo truck HFC1161PZ5K1E1AF from JAC and the cargo truck CA1140P62K1L3A1E4 from FAW show that the Stage 3 limits can be achieved and even surpassed with off-the-shelf technologies.

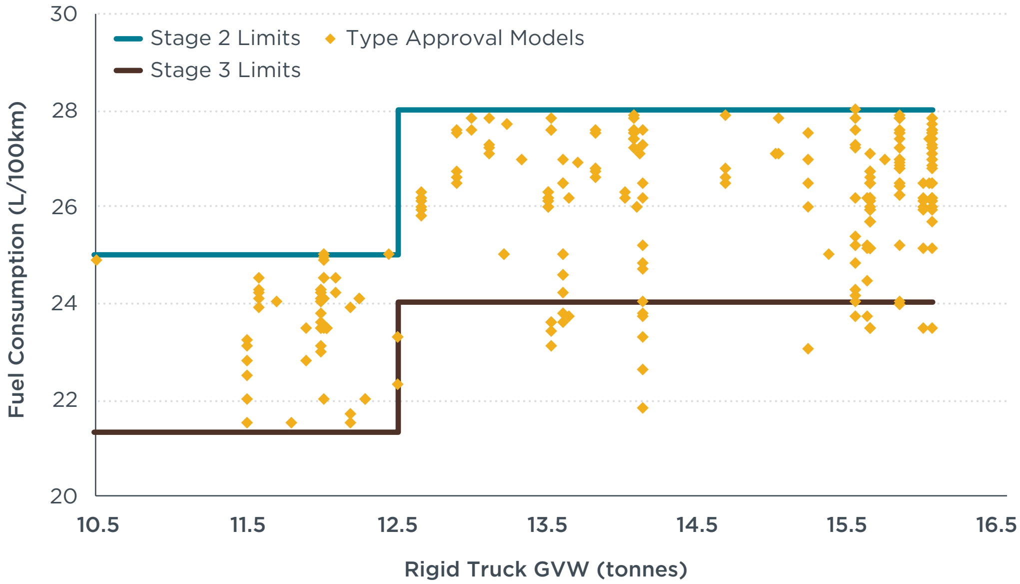

Figure 43. Fuel consumption of straight truck models in selected bins

Fuel Efficiency Performance Simulation

Table 12 summarizes fuel consumption results from simulations of the baseline vehicles over their representative cycles and payloads. Both vehicles comply with Stage 2 standards, with fuel consumption levels 2%–3% below Stage 2 limits. These values provide the basis for estimating technology potential.

Table 12. Baseline results over market-specific duty cycles and payloads

Vehicle Segment	GCW/GVW (tonnes)	Payload (tonnes)	Simulated fuel consumption (L/100km)	Stage 2 Fuel Consumption Limits (L/100km)
Tractor-trailer	49	34	46.1	47
Straight truck	16	10	27.1	28

Energy Audit

Figure 44 shows energy audits for the baseline tractor-trailer at full payload over the urban, rural, and motorway segments of the C-WTVC cycle and for the complete C-WTVC, without weighting. The findings show how energy losses in different vehicle technology components vary with the duty cycle. For example, braking losses become more important with the stop-and-go of the urban segment and aerodynamic losses become more important at the higher speeds of the motorway segment. Tire rolling resistance represents more than 12% of losses for the different cycles. At roughly 60%, engine losses are the largest energy consumer for all cycles, suggesting that even small gains in engine efficiency could result in significant reductions in fuel consumption. Losses through inefficiencies in the driveline and for power accessories are relatively smaller. It is important to note that these audits do not include fuel consumption at extended idle, such as hoteling loads for driver comfort while sleeping in the tractor cab, which can be substantial. However, anecdotal evidence suggests that hotel idling is not prevalent in China.

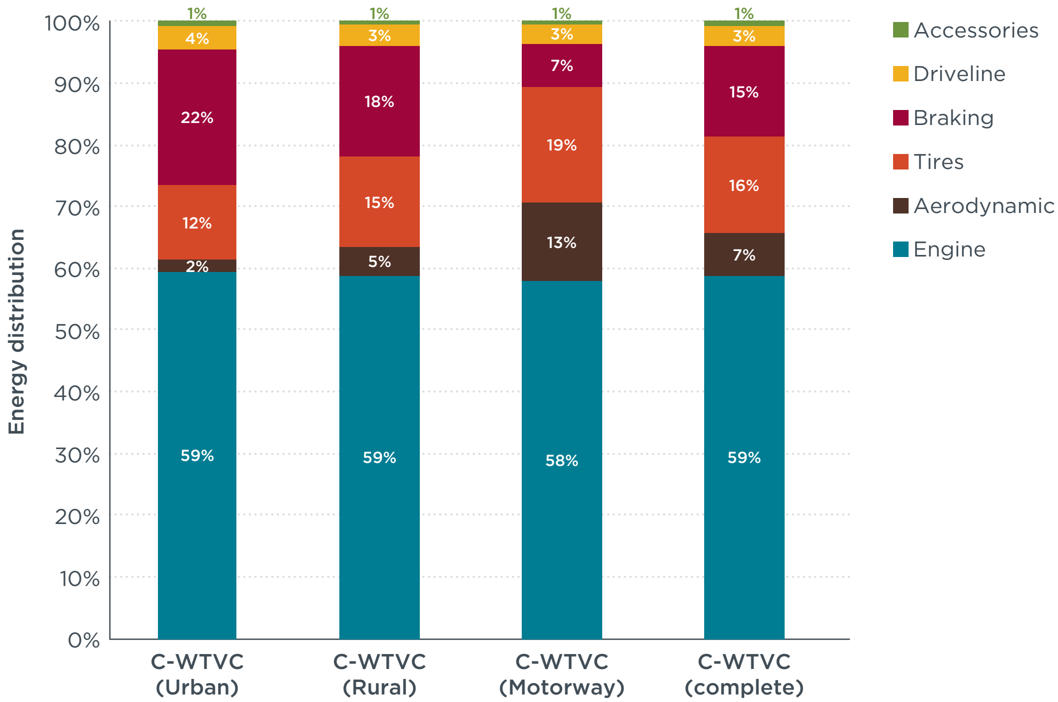

Figure 44. Tractor-trailer energy audit

4. TECHNOLOGY POTENTIAL

When the proposed China Stage 3 fuel consumption standard was open for public comments, a supplemental policy description file was released stating that the average fuel consumption of HDVs in China was 10%–15% higher than in the U.S. and Japan, with HDV efficiency regulations already in place. The document also said the proposed standards were designed to close the gap by 2020 (AQSIQ & SAC, 2016c). It is difficult to make regional comparisons of fuel consumption because trucks are designed for market-specific use, which may include differences in topography, speed limits, maximum weight and dimensions, and road infrastructure, among others. It is therefore important to consider the impact of different duty cycles and typical payloads used in the different standards. It is not clear whether the 10%–15% estimate took such considerations into account.

This section includes an "apples-to-apples" comparison using the same duty cycle and payloads between China and U.S. standards. It is of interest to explore whether the current Chinese standard is properly designed to achieve the objective of obtaining real-world fuel consumption on a par with that of other major markets as well as what technological potential exists for further reductions in fuel consumption beyond the proposed Stage 3 levels. We reviewed the literature regarding technology developments in China and evaluated the potential for lowering HDV fuel consumption.

4.1 LITERATURE REVIEW OF HDV EFFICIENCY TECHNOLOGIES IN CHINA

A review of studies on technologies related to engines, lightweighting, aerodynamics, tires, and transmission and other more advanced technologies provides the basis for constructing scenarios on fuel efficiency potentials.

Engines

There are several trends in HDV engine technology and opportunities for efficiency gains in China. Chinese manufacturers are developing larger engines (Jackson, Addis, Jun, GuoTao, & Sawant, 2008; Lan, Jin, & Di, 2011). However, engines are still underpowered when compared with those in the U.S. and EU markets. Market penetration of engine technologies such as advanced turbochargers, turbo-compounding, on-demand accessories, friction reduction, and high efficiency selective catalytic reduction (SCR) systems is still very low (Rodriguez, Muncrief, Delgado, & Baldino, 2017). Waste heat recovery (WHR) can reduce fuel consumption by as much as 5.1% (Wang, Zhang, Zhang, Peng, & Shu, 2014). Other research has been conducted on maximizing the fuel-saving benefits of WHR systems (Shu, Liu, Tian, Wei, & Xu, 2013; Shu, Liu, Tian, Wei, & Yu, 2014). A study showed that an organic Rankine cycle can improve power output by 6% for a heavy-duty diesel engine without consuming additional fuel (Wei, Fang, Ma, & Danish, 2011).

Lightweighting

Lightweighting technology can be a feasible and effective strategy for improving HDV fuel efficiency. HDVs in China on average are 10% heavier than comparable vehicles in other markets, and key components such as vehicle frames and suspension springs are heavier by 30%–40% (SAE China, 2014).

For tractor-trailers, a measure of lightweighting is the traction ratio, or the ratio of a tractor's maximum towing capability to its GVW, without considering the trailer's GVW. For the same maximum towing capability, which mostly corresponds to the same trailer payload capacity, a higher traction ratio indicates a lower tractor GVW, and thus a lower tractor-trailer GCW, leading to better fuel efficiency. It was found that half of the tractor market in China had traction ratios of 4.5 to 5.0, and only 20% of domestic tractors achieved a traction ratio higher than 5.0 (Wang & Zhang, 2015).

For rigid trucks, a measure of lightweighting is the payload ratio, or the ratio of maximum payload to curb weight. Wang & Zhang (2015) found that 43% of straight trucks in China had payload ratios over 1.6, but more than a quarter had ratios below 1.0. About 96% of dump trucks have payload ratios between 0.95 and 1.05. Payload utilization is lower for dump trucks than straight trucks because of higher curb mass. The researchers estimate that lightweighting technology could reduce fuel consumption by as much as 8%.

Aerodynamics

Improving aerodynamics can increase fuel efficiency by lowering the significant share of energy losses related to aerodynamic drag, especially at highway speeds. Figure 44 shows that the share of energy losses from aerodynamic drag can vary from 2%–13%. Reducing aerodynamic drag has accordingly attracted the attention of manufactures and research organizations in China.

Research from Dongfeng indicates that modifying the front profile can reduce aerodynamic drag of a high-roof tractor truck by as much as 7% (Jiang, Wu, Tang, 2011). Other studies indicate that a roof fairing, a structure on the tractor cab roof designed to channel air up over the trailer, can reduce aerodynamic drag by 9%–14% (Gong, Gu, Li, Song, & Wang, 2010; Lu, Zhang, Liu, Le Loc'h, & Friz, 2010). Although trailer side fairings, commonly referred to as "skirts," are a common technology in the U.S. and Canada, they are still in the development phase in China.

There are other technologies to reduce aerodynamic drag. Rear add-on devices for trailers can reduce aerodynamic drag by 5%–8%, as evaluated by numerical simulations and experimental measurements (Li, 2011; Zhang, Wang, & Tang, 2009). An aerodynamic device in the front of the cargo compartment (a hash symbol-shaped fence) was found to reduce aerodynamic drag by 21.3%, a result validated through 1:10 wind tunnel testing (Qi, Liu, & Du, 2011). Optimizing the head shape of a dump truck can reduce aerodynamic drag by 13.7% (Wei, Wang, & Feng, 2008). Combining technologies can reduce aerodynamic drag even more. For example, adding front and rear aerodynamic devices can reduce drag by 24.8% (Yang & Ma, 2013).

Tires

Low rolling resistance tires are expected to have significant fuel saving benefits for HDVs in China, as rolling resistance losses are proportional to weight. Currently, there is no mandatory tire labeling system in China. A voluntary green tire-labeling program, China Green Car Tires Level Certification, was started in April 2016 (CATARC, 2016). Even though research has found that low rolling resistance tires can result in significant fuel savings, studies show that the adoption rate in China is low (M.J. Bradley & Associates, 2012). Low purchase price often motivates trucking fleets to use less durable tires with high rolling resistance, such as bias tires, which represented more than half of the market in 2012 (M.J. Bradley & Associates, 2012). The situation may have changed, but data is not currently available. As compared with other technologies for saving fuel, reducing tire rolling resistance is highly cost-effective and offers an attractive area for advancement in China (Xin & Pinzon, 2014).

4.2 METHODOLOGY

The potential for lowering fuel consumption by integrating efficiency technologies is estimated for each vehicle segment using a combination of simulation modeling, engineering analysis, and technology effectiveness calculations from available literature. The analysis examines the impact of known and applicable technologies that are predicted to be commercially available in the U.S. by 2030 or sooner. We used Autonomie vehicle simulation software, which helped define the baseline vehicles.

This enabled us to model the impact of efficiency improvements on the key loss areas depicted in Figure 44: accessories, driveline, braking, tires, aerodynamics, and engine. The vehicle simulation software considers any potential interactions between technologies. It is then possible to calculate the potential for reducing fuel consumption from employing a specific technology package on a baseline vehicle. It should be noted that some technologies could not be modeled directly. For those cases, we adjusted the final fuel consumption estimates during post-processing. This strategy is like the one used by the U.S. Environmental Protection Agency and National Highway Traffic and Safety Administration in developing Phase 1 and 2 HDV greenhouse gas emissions and fuel efficiency regulations (U.S. EPA, 2011; U.S. EPA, 2016).

To determine the 2030 technology potential for the baseline China vehicles, we selected two technology steps. The first, named U.S. Phase 2, represents the technology level that U.S. trucks will have in 2027, the final stage of the U.S. Phase 2 HDV GHG/efficiency regulation. The second step represents a more advanced vehicle that would include technologies that are expected to be commercially available in the 2025–2030 timeframe.

We chose the technology pathway detailed in the U.S. Phase 2 standard as the first benchmark. The U.S. HDV standard is the only efficiency regulation in the world with a detailed description and analysis of technology and its applicability to the HDV fleet. The Phase 2 regulation shows one projected pathway that is used to determine the stringency of reductions in fuel consumption. Stringency is calculated by aggregating feasible technologies weighted by expected adoption rates. However, vehicle manufacturers can choose their own compliance pathways based on their own technology mix. We applied the technologies from the comparable vehicle segments in the U.S. Phase 2 rule to the two representative vehicle types in this analysis. As such, we modeled the impact of the baseline tractor-trailer in this study adopting similar levels of technology from the model year 2027 U.S. Phase 2 Class 8 high-roof sleeper cab tractor, matched with a model year 2027 Phase 2-compliant trailer. The baseline straight truck adopts the technology from a medium heavy-duty, or U.S. Class 6/7, multipurpose vocational vehicle.[5] The basic configuration and market-specific traits of the two baseline models were not changed.

The second step, designated post-2030, represents longer-term technologies that have been demonstrated, or are already or nearly commercially available. For tractor-trailers, post-2030 technology is set to the level of what has been demonstrated in the U.S.

5 Although a 16-tonne truck would belong in the Class 8 category in the U.S., we chose to integrate U.S. Class 6/7 technology packages because the specifications and operation characteristics are closer to our baseline vehicle.

SuperTruck program and best available technologies from the EPA/NHTSA final rule (Delgado, 2016; U.S. DOE, 2014). For straight trucks, a hybrid drivetrain technology is adopted. The post-2030 technology packages aim to represent maximum feasible technology by 2030 but not necessarily the maximum that could be accomplished with improvements in all technology areas. For example, straight truck aerodynamics is not considered in this analysis but could represent substantial fuel savings if the operational profile of the vehicle involves higher-speed driving. We also did not consider zero-emission technologies such as battery-electric, catenary cables (e-highway), or fuel cells. We did not assess the cost, payback, and cost-effectiveness of individual technologies and technology packages.

4.3 POST STAGE 3 TECHNOLOGY POTENTIAL ANALYSIS

Beyond Stage 3, our analysis shows additional opportunities to further reduce fuel consumption using known technologies.

Tables 13 and 14 list the assumptions made to estimate technology potential for tractor-trailers and straight trucks. Of the two sets of data in each table, the top portion corresponds to vehicle parameters used in simulation, while the bottom presents technology effectiveness values used to account for some technologies that are not captured during simulation. China-specific regulatory cycles were used to estimate reductions in fuel consumption from technologies captured by the simulation.

Table 13. Technology potential assumptions for tractor-trailers

	Technology	U.S. Phase 2 equivalent	Post-2030
Vehicle parameters	Engine efficiency (peak BTE)	~47%	~50%
	Tractor aerodynamics (CdA)[a]	5.3 m^2	5.1 m^2
	Trailer aerodynamics (delta CdA)	1.1 m^2	1.6 m^2
	Tire rolling resistance (RRC)[b]	5.6N/kN (steer) 5.9N/kN (drive) 4.8N/kN (trailer)	4.3N/kN (steer) 4.5N/kN (drive) 4.3N/kN (trailer)
	Transmission type	AMT	AMT/DCT[c]
	Axle configuration	6x2	6x2
	Rear axle ratio	3.2	2.3
	Weight reduction	—	Up to 2,800 pounds
Technology effectiveness	Automated transmission benefit	1.8%	2.0%
	Axle configuration benefit	1.5%	2.5%
	Axle lubricant	0.2%	0.5%
	Predictive cruise control	0.8%	2.0%
	Accessories improvement	0.3%	1.0%
	A/C improvement	0.2%	0.5%
	Automatic inflation systems (ATIS)	0.4%	1.0%
	ATIS (trailer)	1.4%	1.5%
	Idle reduction	3.0%	5% APU / 7% other

Notes: [a]CdA is aerodynamic drag area. [b]RRC is rolling resistance coefficient. [c]DCT is dual-clutch transmission.

Table 14. Technology potential assumptions for straight trucks

	Technology	Phase 2 U.S. equivalent	Post-2030
Vehicle parameters	Engine efficiency (peak BTE)	~44%	~44%
	Tire rolling resistance	6.4N/kN (steer) 7.0N/kN (drive)	6.2N/kN (steer) 6.5N/kN (drive)
	Transmission	AMT	Hybrid
	Axle ratio	4.33	4.33
	Weight reduction	10 lbs	400 lbs
	Truck aerodynamics	none	none
Technology effectiveness	Two more gears (over 5-speed)	0.1%	1.7%
	DCT or AMT (over AT)	0.2%	3.4%
	Strong hybrid	4.1%	22.9%
	Deep driveline integration	4.4%	6.2%
	Axle lubricant	0.4%	0.5%
	Stop-start	2.7%	3.8%

The results for reductions in fuel consumption under the two scenarios are shown in Figure 45. Our analysis finds that if Chinese tractor-trailers were to adopt technology levels equivalent to those of U.S. Phase 2, fuel consumption over the Chinese regulatory cycles would drop by 31.3%. Post-2030 tractor-trailer technology would reduce fuel consumption by 55.1%. Chinese straight trucks would reduce their fuel consumption by 29.5% if they adopt technology levels equivalent to U.S. Phase 2 and by 43.3% if they adopt post-2030 technologies.

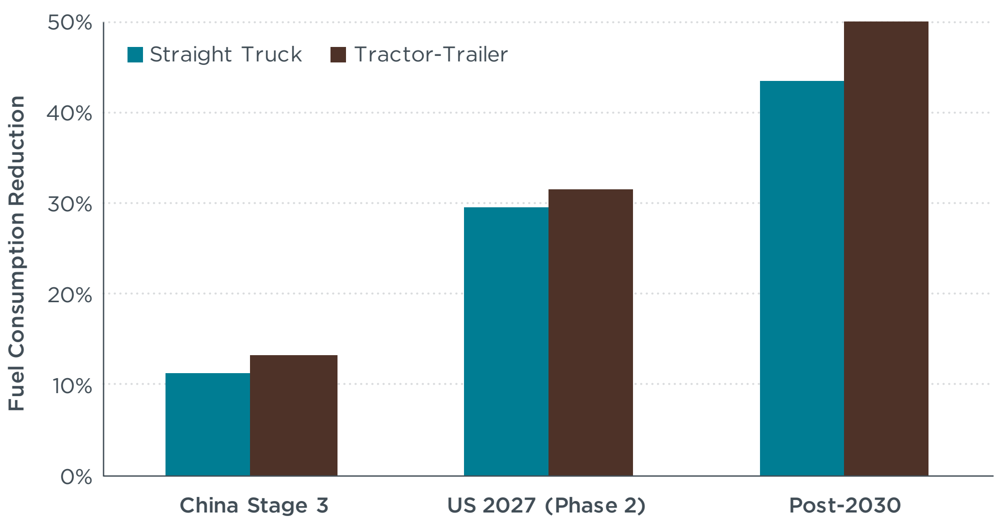

Figure 45. Fuel efficiency potential

Figures 46 and 47 show the potential roll-out of technology improvements, assuming a constant yearly rate of improvement, starting from China Stage 2 baselines. After implementation of China Stage 3, there still exists significant potential to further reduce fuel consumption by tractor-trailers and straight trucks. The average annual reduction rate of fuel consumption for Stage 3 is 2.8% for tractor-trailers and 2.4% for straight trucks. If Chinese HDVs keep improving at similar rates beyond 2020, their efficiency will be on par with the U.S. Phase 2 fleet by 2030. If no further improvements are made after implementation of Stage 3, in 2027 the predicted fuel consumption gap between trucks in China and the U.S. will be 20.8% for tractor-trailers and 20.4% for straight trucks. Full implementation of Post-2030 technologies would bring fuel consumption reductions above Stage 3 of 35.0% for rigid trucks and 44.5% for tractor-trailers.

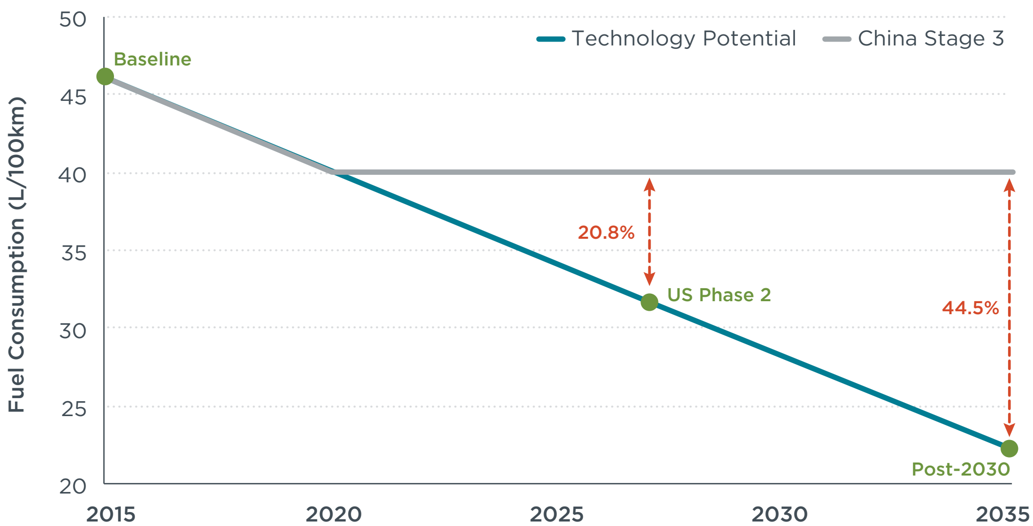

Figure 46. Comparison of fuel consumption between Stage 3 and predicted potential: tractor-trailers

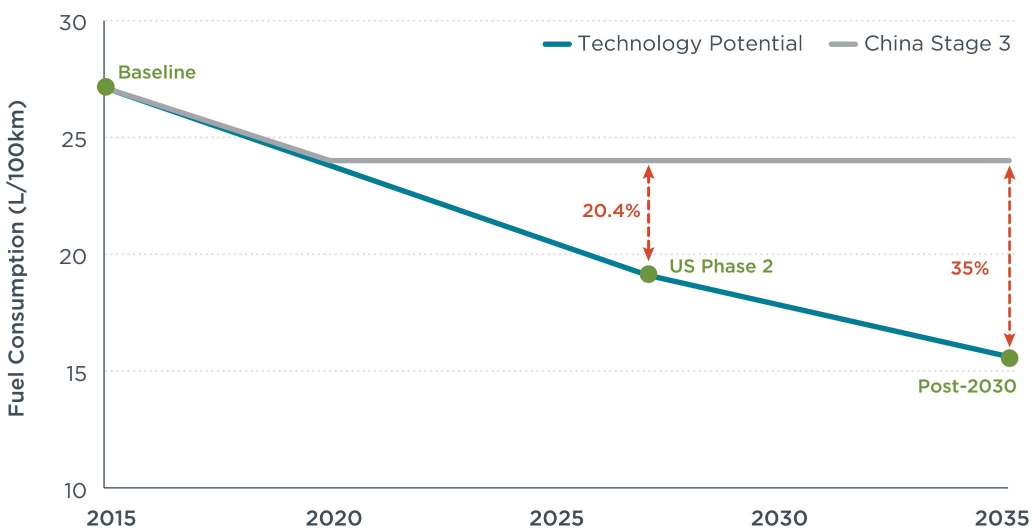

Figure 47. Comparison of fuel consumption between Stage 3 and predicted potential: straight trucks

5. SUMMARY

This paper analyzed the main characteristics of the Chinese HDV market, evaluated the fuel-saving potential of advanced technologies, pointed out current regulatory issues, and made regulatory recommendations. The key findings are:

- **China's HDV market is growing at a rapid pace.** HDV registrations in 2014 were 40% higher than in 2007, an average annual increase of 5.7%. This robust growth intensifies fuel demand and the need for fuel efficiency regulations.
- **China's HDV market has a relatively large number of manufacturers and is much less consolidated than the U.S. and EU markets.** There are more than 460 HDV manufacturers in China. The tractor truck market consists of around 30 manufacturers, and the rigid truck segment, 70. In the specialized delivery truck category, there are around 300 manufacturers. The top 10 vehicle makers accounted for 62%–67% of the HDV market from 2007–2014. In the U.S., the top five manufacturers account for 70% of the HDV market, and in the EU, 91%.
- **HDV engines in China are mostly supplied by domestic OEMs, and the engine market is more consolidated than the vehicle market.** Of domestic HDV engines, 88% are from domestic suppliers. Only 7% of tractors, 16% of straight trucks, 1% of dump trucks, and 21% of specialized delivery vehicles use engines from joint ventures between domestic and foreign engine makers. The aggregate market share of the seven largest engine makers, including joint ventures, is 99% for tractors, 95% for straight trucks, 97% for dump trucks, and 86% for specialized delivery vehicles.
- **China is not using efficient logistics.** Logistics costs in China as a percentage of GDP are 18%, double the 9% for the U.S. (Xiong, 2010). The share of the most efficient vehicle segment for long haul trips, tractor-trailers, has been lower than 40% among HDVs with vehicle weight larger than 15 tonnes since 2009. The stake trailer body type, the most popular, represented 40% of the market in 2014 while the box type, the most fuel-efficient, was less than 7%. Drop-and-hook capabilities of trailers are not fully realized, although there are nascent green freight program efforts and other pilot programs and transportation industry's efforts to implement efficient logistics. These will create significant benefits if implemented on a larger scale.
- **Chinese trucks are increasing in size.** Between 2007 and 2014, the average weight of tractor-trailers increased by 10%, straight trucks by 32%, dump trucks by 45%, and specialized delivery vehicles by 19%.
- **Engines are increasing in power and displacement.** Between 2007 and 2014, tractors' engine power increased by 15%, straight trucks' by 6%, dump trucks' by 27%, and specialized delivery vehicles' by 12%. In the same period, tractors' engine displacement increased by 11%, dump trucks' by 15%, and specialized delivery vehicles' by 2%. On the other hand, straight trucks' engines decreased in displacement by 4%, enhancing their power/displacement ratio.
- **A large range of type-approval efficiency performance is observed within the regulatory categories analyzed.** Although all registered HDVs are compliant with the current fuel consumption standard (Stage 2), their fuel efficiency performance varies significantly. Within the same weight bins, HDV type-approved fuel consumption can vary by as much 14% for tractor-trailers and 22% for straight trucks. This indicates wide differences in technology deployment among OEMs.

- **The fuel consumption limits in the proposed Stage 3 standards are a good step toward closing the efficiency gap with more advanced markets but more-stringent, longer-term standards are required to ensure world-class efficiency levels.** Thanks to Stage 3 standards, China will reduce the fuel efficiency gap with advanced markets in the 2015–2020 period. However, post-2020 efficiency standards in the U.S. will reverse that trend. More-stringent, longer-term standards are required to ensure that the efficiency gap declines over time. Long-term standards will provide vehicle manufacturers with regulatory certainty to develop fuel-saving technologies in a cost-effective way.
- **Advanced technologies show great potential to further improve fuel efficiency of Chinese HDVs.** Based on the simulation results from the two baseline models—tractor-trailer and straight truck—about a 20% reduction in fuel consumption compared with Stage 3 limits is feasible by adopting the technologies included in the U.S. Phase 2 standard. Post-2030 technologies could reduce fuel consumption by 35% to 45% compared with the Stage 3 limits.

6. POLICY RECOMMENDATIONS

Based on our analyses of the China market and the potential of technology advances, we make these policy recommendations:

Scope of Standard

About 15% of HDVs remain unregulated in China, including alternative-fuel HDVs and specialized vocational vehicles. The unregulated segment is expected to grow in response to regulatory and financial incentives (MOF, MIIT, & State Administration of Taxation of the People's Republic of China, 2014). HDVs of all segments and all fuel types should be regulated to avoid unintended market distortions and to maintain fuel neutrality.

For example, even though natural gas engines may reduce tailpipe GHG, nitrogen oxides, and particulate emissions compared with conventional fuel engines, they tend to be 5%–15% less thermally efficient than a comparable diesel engine (U.S. EPA, 2016). In addition, methane leakage throughout the transmission system contributes significantly to climate change (Camuzeaux et al., 2015; Clark et al., 2017; Delgado and Muncrief, 2015). Thus, excluding alternative-fuel vehicles may cause the market to tilt toward alternative-fuel HDVs that may not be fuel-efficient but do have lower prices. This would run counter to the goal of reducing fuel consumption and CO_2 emissions.

The standard should be based on environmental performance without special protection for alternative-fuel vehicles or specialized vocational vehicles. Any exclusion might create unfair incentives and unintended consequences.

In addition, trailers are not yet covered by China's fuel consumption standards. Fuel-saving technologies for trailers such as aerodynamic devices, low rolling resistance tires, and automatic tire inflation systems represent a significant opportunity. Compared with a baseline of no efficiency technologies, using advanced aerodynamics alone could reduce CO_2 emissions by as much as 13% for box trailers (U.S. EPA, 2016). Requirements for trailer efficiency would help promote applicable and promising fuel-saving technologies.

To achieve the goal of reducing HDV fuel consumption, we recommend expanding the scope of the fuel consumption standard by incorporating:

a. Fuel consumption limits for specialized vocational vehicles. If the specialized nature of these vehicles impedes adoption of certain vehicle-level technologies such as aerodynamic devices, an engine efficiency standard would help guarantee reductions in fuel consumption for this category.

b. Fuel consumption limits for alternative-fuel vehicles to maintain fuel neutrality.

c. Trailer efficiency limits, or establishment of a separate standard for trailers to further improve fuel efficiency of tractor-trailers.

Long-Haul Freight Efficiency

The market analysis highlighted opportunities to optimize long-haul freight efficiency beyond what technology offers. The share of tractor-trailers larger than 15 tonnes is less than 40%. Tractor-trailers have been proven to be the most efficient among all HDV segments for saving fuel on long-haul freight transportation. They also offer the benefits of drop-and-hook to reduce the number of empty miles driven. The ratio of registered trailers to tractor was around 1:1 in the 2007–2014 data. Previous studies have shown that a ratio of 3:1 will enable more fuel-efficient freight transportation by reducing loading and unloading time (Sharpe, Clark, & Lowell, 2013).

Although box trailers have the greatest potential for fuel efficiency, they accounted for less than 7% of the market in 2014. The most popular body type was stake trailers, with 40% in 2014. The aerodynamic devices that can make box trailers more fuel efficient will not fit a stake trailer.

Consequently, economic and regulatory incentives should promote the use of drop-and-hook tractor-trailers in long-haul freight transportation, improving logistics management, and the use of more-aerodynamic box trailers.

Step Function of Stringency Targets

Fuel consumption limits and test cycle weightings are based on GVW/GCW using a step function. The step function may reduce effectiveness of fuel consumption standards by creating "edge effects" that allow manufacturers to slightly alter GVW to fit into a favorable weight bin for meeting standards. Previous studies have shown that edge effects might apply to light-duty vehicle (LDV) markets in China and Japan, where LDV fuel consumption regulations also follow a step function (Hao, Wang, Liu, & Zhao, 2016; Oliver, 2005).

The edge effect may also occur in the HDV market. We offer two potential scenarios:

» First, the different weightings for the urban, rural, and motorway segments of the WTVC-China cycle can be problematic for adjacent weight bins. For example, the weightings for straight trucks in the GVW 10.5–12.5 tonnes bin are 60% rural, 30% motorway, and 10% urban. For the GVW 12.5–16 tonnes bin, the weightings are 40% rural, 50% motorway, and 10% urban. Fuel consumption on the rural segment is generally higher than on the motorway segment because of the more frequent transient operation. The maker of a truck whose GVW is close to 12.5 tonnes may decide to certify the truck in the heavier bin to take advantage of a less stringent standard.

» Second, having relatively wide weight bins could also be problematic. For example, the tractor-trailer baseline selected for this analysis is in the 46–49 tonnes GCW bin. The 3-tonne difference would cause a 3.4% difference in fuel consumption, so the compliance pathway for a 46-tonne tractor would be easier than for a 49-tonne vehicle. Since the Stage 3 limit for the category is 13.2% fuel consumption reduction, nearly a quarter of the compliance—3.4%/13.2%—can be accomplished by understating GCW.

Using a smooth function rather than a step function for setting HDV fuel consumption limits might be a good alternative for avoiding these issues. Regulators might re-evaluate the segmentation of weight bins and drive cycle weightings to ensure the effectiveness of fuel consumption standards and minimize the potential for gaming.

Future Stages of Fuel Efficiency Standards

Longer-term and more stringent limits are required to achieve an HDV fleet with world-class technology. If China were to maintain the Stage 3 limits after 2020, the gap in fuel efficiency between China and advanced markets would increase considerably. For example, in 2027 when U.S. Phase 2 is completely implemented, the fuel consumption of U.S. HDVs will be 20.8% lower for tractor-trailers and 20.4% lower for straight trucks than Chinese vehicles. China's Stage 3 standard was proposed in 2016, giving manufacturers 3–5 years to meet the limits required in 2019 for new type approvals and 2021 for all new vehicles. In comparison, the US Phase 2 standard was proposed in 2015, giving manufacturers 12 years to meet the limits required in 2027. Without sufficient lead time, vehicle and component manufacturers may lack the regulatory certainty to develop and commercialize those technologies that have sizeable fuel-saving potential but require long-term investments.

We recommend setting longer term fuel consumption standards that incorporate stringency based on known technology potential. The next stage of HDV fuel efficiency standards ideally would require about 30% fleet averaged fuel consumption reduction from 2020 to 2030 (about 45% reduction from Stage 2 compliant vehicles). Ideally, manufacturers would have approximately 10 years of lead time to meet these standards. Long-term targets will encourage investment in technology and provide manufacturers ample time to manage compliance in a cost-effective way.

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