WHITE PAPER

JUNE 2015

COSTS AND BENEFITS OF MOTOR VEHICLE EMISSION CONTROL PROGRAMS IN CHINA

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ACKNOWLEDGEMENTS

This work was supported by the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) and the William and Flora Hewlett Foundation. The authors thank the ICCT staff who contributed toward the development of this report at multiple stages, including Rachel Muncrief, Ray Minjares, Hui He, Zifei Yang, Cristiano Façanha, Sarah Chambliss, Josh Miller and Francisco Posada. The authors also thank Michael Walsh for his critical reviews.

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EXECUTIVE SUMMARY

China has made tremendous progress in emission control for on-road vehicles (light-duty vehicles, buses, and heavy-duty trucks) in recent decades. The vehicle population in China grew nearly sevenfold, from 16 million to 108 million, between 2000 and 2012, and this rapid pace will continue for the foreseeable future. Although the burgeoning vehicle market brings enormous environmental pressures, China has responded forcefully to mitigate the effects of adding these vehicles to its roads and highways. In less than 15 years, vehicle emission control standards in China have advanced to China 4/IV (equivalent to Euro 4/IV in the European Union), and the fuel quality standards have been tightened to 50 parts per million (ppm) maximum sulfur content.[1] Despite these accomplishments, though, China's air quality remains poor throughout the country. More must be done in all sectors to lower pollutant emissions., This report focuses on means of controlling vehicle tailpipe emissions in the transportation sector.

The International Council on Clean Transportation has reviewed China's existing efforts to rein in air pollution from vehicles and has conducted a cost-benefit analysis of the introduction of stringent new vehicle emissions and fuel quality standards. The analysis estimates future emissions, health and climate impacts, and costs according to different policy pathways, including an aggressive timetable for standards adoption (known as "World Class"), as shown in Table ES-1. Key regions—the so-called Jing-Jin-Ji (agglomeration surrounding the capital, Beijing, the city of Tianjin, and Hebei province), the Yangtze River delta, and the Pearl River delta—are expected to lead this process.

Table ES-1. Scenarios: Vehicle emission standard implementation year

Scenario	Beijing		Shanghai		Guangzhou, Shenzhen		Three critical regions		Nationwide	
	China 5/V	China 6/VI	China 5/V	China 6/VI	China 5/V	China 6/VI	China 5/V	China 6/VI	China 5/V	China 6/VI
Current	2013	N/A	2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Baseline	2013	2016	2014	N/A	2015	N/A	2018	N/A	2018	N/A
Improved	2013	2016	2014	2018	2015	2018	2015	2018	2018	2021
World Class	2013	2016	2014	2016	2015	2016	2015	2016	2016	2018

The results show that the implementation of China 6/VI emission standards and ultra-low-sulfur fuel standards in China would yield emissions reductions from the motor vehicle fleet in both the near and the long term. These emissions reductions would lead to corresponding improvements in public health from reduced exposure to pollution, as well as reductions in climate pollutant emissions. Neither China 4/IV nor the somewhat more stringent China 5/V standards (which are in effect only in Beijing and Shanghai at this time) would suffice to prevent an increase of emissions and the incidence of premature mortality caused by the dramatic rise in the motor vehicle population. Only with the introduction of the stringent China 6/VI standards nationwide (Improved and World Class scenario) would emissions from motor vehicles continue to decline through

1 The light-duty vehicle diesel standard remains at China 3 but will be upgraded to China 4 in 2015. The share of diesel-powered light-duty vehicles in the fleet is very low in any case. With regard to fuel quality, 50 ppm gasoline is fully phased in, and 50 ppm diesel will be ready in 2015.

2030 (see Figure ES-1 using black carbon emission trends as an example). In addition, adopting China 6/VI as early as the 10 ppm sulfur fuel is available (World Class scenario) will yield additional benefits in emission reduction. Beyond the tightening of standards, instituting a vehicle replacement (or "scrappage") program for vehicles unable to meet the China 6/VI emission rules could speed up emission reductions in the near term.

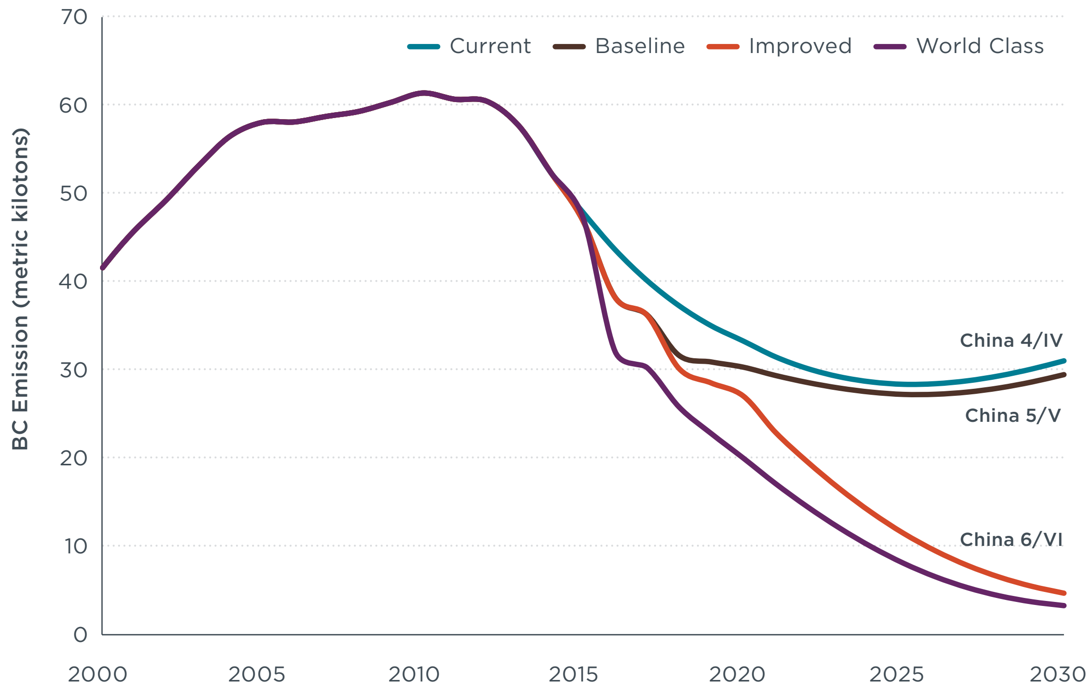


Figure ES-1. China motor vehicle black carbon (BC) emissions, 2000–2030

Moreover, ICCT's results demonstrate that the benefits could be maximized if China 6/VI were implemented in sync with the announced timeline for the introduction of 10 ppm[2] sulfur (or "ultra-low-sulfur") fuel. By adopting China 6/VI early, in 2018 across the country, additional emission reduction benefits would be realized, and these would continue well beyond 2030. Tens of thousands of early deaths could be avoided through early adoption, even under the most conservative estimates. Further, the China 6/VI standards have been shown to be extremely cost-effective, consistent with results tallied in other regions around the world implementing advanced tailpipe emission standards. By 2045, a conservative estimate of the annual benefits of the China 6/VI standards indicates that they would outweigh the corresponding costs by a factor of 5.5 to 1 (see Figure ES-2).

2 Ppm stands for parts per million sulfur in the fuel.

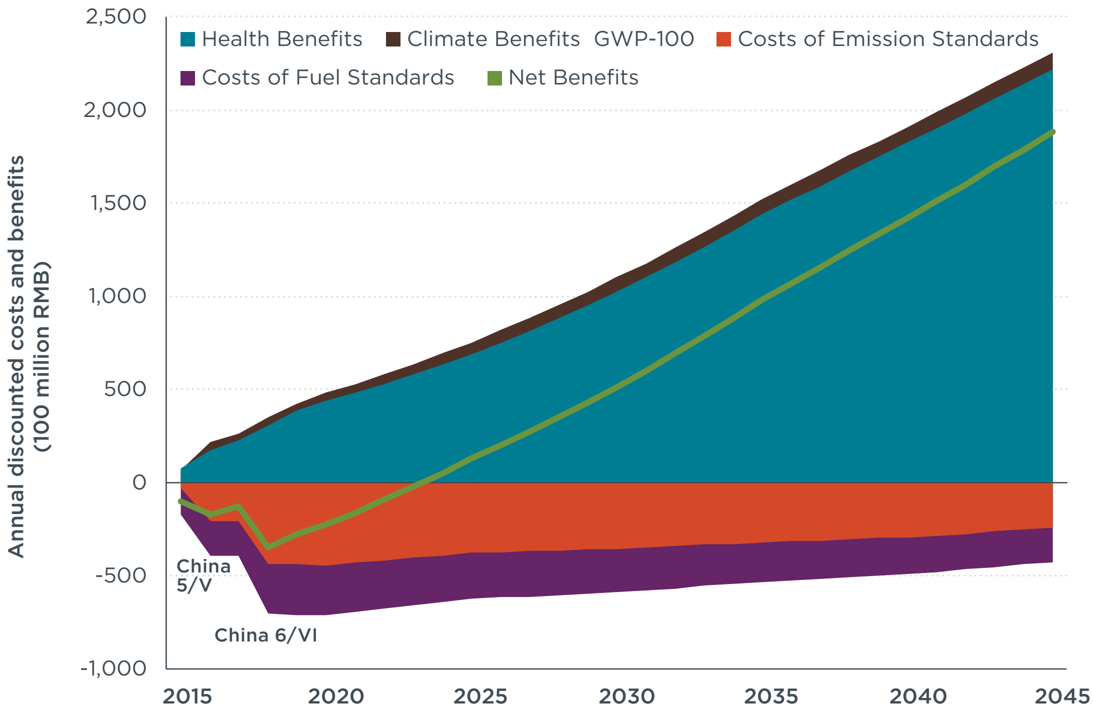


Figure ES-2. Annual discounted benefits and costs, 2015–45

Therefore, the ICCT strongly recommends that China implement the China 6/VI vehicle emission standards universally in parallel with the adoption of ultra-low-sulfur fuel. The country needs to keep to its announced ultra-low-sulfur fuel timeline, as this is a determinative step toward more stringent vehicle emission standards. The most exacting standards—China 6/VI—are the only practicable option if China is to realize long-term emission reductions from on-road motor vehicles. Further, it is recommended that China 6/VI be in place as early as possible, so that the most forward-looking policies can start to take effect as soon as the technologies supporting them are available. Taking full advantage of the ultra-low-sulfur fuel timeline, China 6/VI vehicle emission standards could be implemented nationwide whenever 10 ppm fuel is ready for widespread distribution.

In parallel with the national efforts, individual regions, especially the three critical ones mentioned above, ought to move more quickly on their own account. The most critical regions are expected to be more proactive with respect to their own local policymaking and enforcement, phasing in China 6/VI by 2016. Early adoption in the critical regions can help push the rest of the country toward China 6/VI earlier than had been slated. In the final analysis, the national China 6/VI plan, though ambitious, is not enough to counter the rapid emissions growth expected in the coming years without an assist from localities and regions setting their own pace.

INTRODUCTION

China's remarkable economic growth in recent times has been accompanied by a dramatic rise in its motor vehicle population. From 2000 to 2012, the number of cars, trucks, and buses grew nearly sevenfold, from 16 million to 108 million, far exceeding even the wildest predictions.[3] Along the way, China surpassed the United States to become the world's largest automobile market in 2009. With a continued rapid rise in sales, the country could be home to the world's largest fleet of on-road vehicles as early as 2020.

The unexpectedly rapid proliferation of vehicles in China has created enormous environmental pressures, especially urban air pollution, greenhouse gas (GHG) emissions, and congestion. China's Ministry of Environmental Protection (MEP) has estimated that vehicles contribute a quarter to a third of particulate matter (PM) air pollution and at least a quarter of urban nitrogen oxide (NO_X) pollution throughout the country (MEP, 2013). Drivers are the biggest consumers of imported petroleum products in China, and their cars, vans, and trucks are a key source of the nation's increasing GHG emissions. Beijing's notorious congestion contributed to the city being ranked as one of the worst for commuting in 2010 and 2011 (IBM, 2011).

China has responded aggressively with efforts to mitigate the impact of these millions of vehicles crowding the roadways. At the national level, it has gone forward with stepwise implementation of increasingly stringent tailpipe emission regulations and fuel consumption standards for nearly all classes of vehicles. In 2013, China established a roadmap for the nationwide upgrading of fuel quality to the strictest (deemed "world-class") levels. Provinces and cities have moved even more energetically, in some cases restricting vehicle activity and even placing limits on the total vehicle population. Government institutions at every level—including the State Council, China's highest government body—are increasingly prioritizing the environmental management of vehicles.

Despite much progress, though, more must be done. China's air quality remains poor throughout the land. Petroleum imports and GHG emissions continue to rise. The country could conceivably be home to more than half a billion vehicles in 2050. How it manages the environmental impacts of these billion vehicles will have profound implications not just for China itself but for the entire world.

3 For example, Michael Wang and colleagues (2006) predicted that China would have just 53 million highway vehicles in 2010 under a "high-growth" scenario; the actual vehicle population in 2010 was 77 million.

PROJECT OVERVIEW

This analysis reviews the history of emission control policies and evaluates the total emissions, costs, and benefits (both for public health and the climate) of current and likely future motor vehicle emission control programs in China over the period 2000–2030. A variety of national and subnational forward-looking policy scenarios are modeled and compared. The objective of the analysis is to investigate the cost-effectiveness of world-class emission control programs in limiting the environmental impacts of China's proliferating vehicle fleet.

SCOPE: MODES, POLLUTANTS, COSTS, AND BENEFITS

This report focuses exclusively on cars, trucks, and buses. Motorcycles as well as nonroad mobile pollution sources such as rural low-speed vehicles, construction and agricultural equipment, marine vessels, and locomotives, are not included here.

Only vehicles equipped with internal combustion engines—that is, those fueled by gasoline, diesel, or natural gas—are considered. China has in recent years actively sought to promote electric vehicles to reduce petroleum consumption and local air pollutant emissions and to boost industrial competitiveness. However, existing initiatives have failed to achieve stated numerical targets for electric vehicles. By mid-2013, the nation had fewer than 50,000 electric vehicles, most of which were used as taxis or for public transit (Jiang, 2013). Even if China were to meet the government's extremely ambitious electric-powered fleet goal of 5 million by 2020, these vehicles would constitute just 2 percent of the overall vehicle population. The inclusion of electric vehicles is noted as an area for future modeling expansion, though they are not included here.

The emissions inventory model developed for this analysis is a customized version of the International Council on Clean Transportation (ICCT) peer-reviewed Global Transportation Roadmap Model. The model estimates emissions of numerous conventional pollutant species, including particulate matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$), NO_X, carbon monoxide (CO), hydrocarbons (HC) (either total hydrocarbons or nonmethane hydrocarbons), and others. The model also yields results for emissions of climate pollutant species, including carbon dioxide (CO_2), methane (CH_4), organic carbon (carbon locked into organic compounds, OC), and black (or elemental) carbon (BC). The emission factors (EFs) adopted in this study are generated based on the latest COPERT (Computer Program to Calculate Emissions from Road Transport) model, a European-devised technical procedure for estimating vehicle fleet emission inventories. Detailed discussion on the uncertainty accompanying the EFs can be found in Appendix D.

Health results are calculated based on a methodology ICCT developed for estimating the effects of primary $PM_{2.5}$ from motor vehicles on human health. The methodology, which is described in detail in the ICCT publication *The Impact of Vehicle and Fuel Standards on Premature Mortality and Emissions* (Chambliss et al., 2013), converts emissions to urban exposure by means of the intake fraction approach (a means of determining the percentage of emissions that are actually inhaled). Based on urban exposure, health impacts may be calculated using standard dose-response curves.

Benefit and cost analysis is performed by weighing the public health and climate benefits against the costs associated with upgrading engine/vehicle technology and fuel quality. Societal benefits are quantified according to the economic value of reductions in premature mortality attributable to improved urban air quality, as well as the value of the damages that are avoided as a result of mitigating global climate change. Costs modeled include the additional technology investments needed to meet more stringent standards as well as production outlays required to refine higher-quality fuel. The benefits and costs included in this analysis are shown in Table 1 below. More detailed descriptions of the models and methodologies used may be found in Appendix A.

Table 1. Benefits and costs included in the analysis

Benefits	**Climate**	Short-lived climate pollutant reductions
	Health	Public health improvement (reduction in premature mortality)
Cost	**Fuel**	Costs of fuel quality refining upgrades
	Vehicle	Costs of advanced emission control technologies

SCOPE: REGIONS

China's government has cited advances at the municipal, provincial, and regional levels as a high priority in the coming years. Most recently, in September 2013, China's State Council (cabinet) released a major air quality improvement plan that establishes concrete environmental targets for three critical regions (State Council, 2013b). These are the greater Beijing "Jing-Jin-Ji" region (which includes Beijing, Tianjin, and Hebei province), the Yangtze River delta (which includes Shanghai, as well as neighboring Zhejiang and Jiangsu provinces), and the Pearl River delta (which includes nine adjacent cities in Guangdong province, notably Guangzhou and Shenzhen). The analysis and modeling presented here are designed to take into account anticipated vanguard policy actions in these regions.

Nationwide modeling results are the sum of independent modeling estimates for the following seven regions:

Table 2. Modeled regions in China

Modeled Region	Grouping
Beijing	Beijing-Tianjin-Hebei "Jing-Jin-Jin" combined greater region
Tianjin-Hebei	
Shanghai	Yangtze River delta combined greater region
Jiangsu-Zhejiang	
Pearl River delta region[1]	Guangdong province
Rest of Guangdong province	
Rest of China	

1. The Pearl River delta lies within Guangdong province. This densely populated area is the economic center of Guangdong. It is composed of nine municipalities: Guangzhou, Shenzhen, Foshan, Dongguan, Zhongshan, Zhuhai, Huizhou, Jiangmen, and Zhaoqing. Among these, Guangzhou and Shenzhen have typically led the way on vehicle emission control policies, including the adoption of emission standards on an accelerated schedule.

The three critical regions (Jing-Jin-Ji, Yangtze River delta, and Pearl River delta) are highlighted in Figure 1. Although the rest of Guangdong province is not designated as one of the critical regions, it is still highlighted in the model (Table 2 and Figure 1). This is because Guangdong shows a strong interest in addressing vehicle emission issues ahead of the nation at large. Its recent, province-wide early adoption plan for the China

5/V emission standards is evidence of this determination (ICCT, 2015). Thus, led by its urban core—the Pearl River delta, Guangdong is expected to make strides toward tighter emission standards.

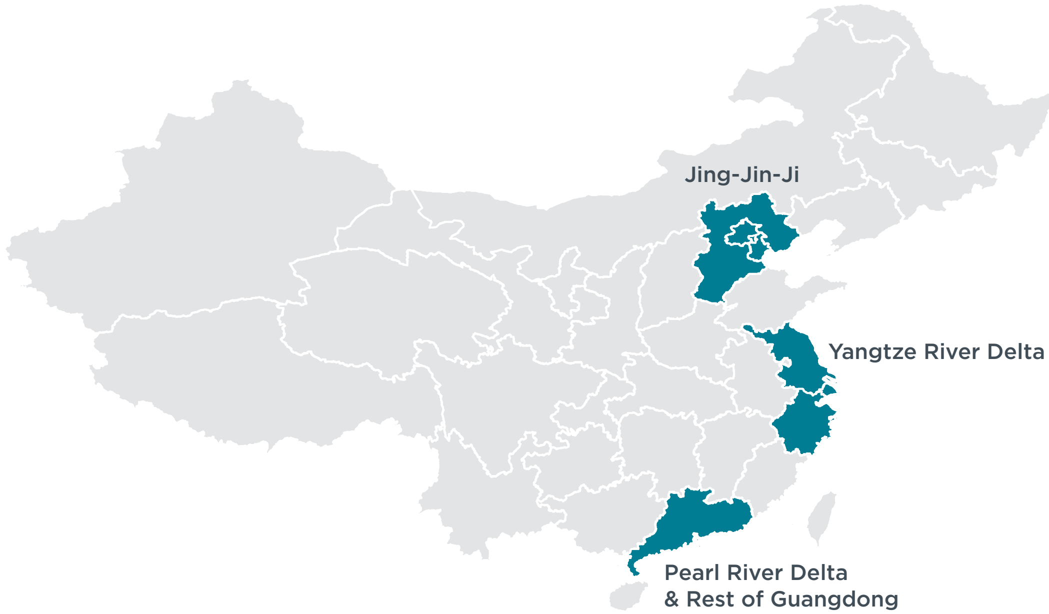


Figure 1. Map of modeled regions

SCOPE: POLICIES

The objective of the modeling is to generate and compare quantitative results of selected motor vehicle emission control policies for both light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs). Specifically, the analysis considers the impacts of stringent new vehicle emission standards, fuel quality improvements, and scrappage/replacement programs at the national and subnational levels. The model is also capable of evaluating the implications of new vehicle fuel consumption standards, though fuel consumption scenarios are not included at present.

China has numerous other motor vehicle emission control programs whose effects are not reflected quantitatively in the modeling results. These include inspection and maintenance (I/M) as well as other in-use vehicle policies beyond vehicle replacement initiatives, which are the only in-use control program taken into account in the modeling, emissions labeling, vehicle electrification pilot schemes, and more. ICCT's 2010 assessment (introduced in the next section) included a full qualitative assessment of all aspects of China's motor vehicle emission control programs. Further qualitative and, where feasible, quantitative analysis of these additional policies will be explored in follow-up work.

COMPARISON WITH ICCT'S 2010 RETROSPECTIVE

In 2010, at the request of China's MEP, the ICCT conducted an assessment of China's existing motor vehicle emission control programs implemented over the period 2000–2010 (Fung et al., 2010). The research concluded that China's existing programs delivered enormous emissions reductions compared with a hypothetical scenario in which emissions remained uncontrolled, preventing hundreds of thousands of cases of premature death and disease over the first decade of this century. The 2010 project included a qualitative review of China's full range of motor vehicle emission control programs, including comparisons with international best practices for environmental management of vehicular pollution. The analysis also looked at future emissions projections and the consequences for public health under various policy scenarios, highlighting the need for early implementation of world-class emission control programs.

This new report seeks to expand on the analysis presented in 2010. For the current analysis, input data have been completely updated, control scenarios have been revised, and a new modeling framework (including a completely redesigned health impact model)[4] has been developed and employed. Furthermore, the updated analysis includes higher-resolution modeling of subnational regions in China, modeling of additional pollutants including short-lived climate-forcing pollutants, and full estimation of control costs in all scenarios.

VALIDATION OF RESULTS

Like ICCT's 2010 exploration, this research represents an independent but validated analysis of China's motor vehicle emission control programs. Independent means that the researchers built their own models using peer-reviewed data for many parameters such as emission factors, correction factors, and vehicle activity (vehicle kilometers traveled, or VKT) degradation curves. Validated means that, throughout the modeling process, the authors communicated closely with project partners in China to identify missing data, seek feedback on early model runs, verify scenarios, etc. The goal was to ensure that the resulting conclusions would be credible—and therefore influential—within China. An especially valuable partner was the Vehicle Emission Control Center (VECC), China's national vehicle emission policy and emissions modeling research center, housed within the MEP, which provided critical data inputs on regional VKT and more. The research team worked closely with VECC-MEP over the course of late 2013 and early 2014 to review results and calibrate the model.

4 The updated health model is consistent with the one used in ICCT's most recent global health report (Chambliss et al., 2013). The methodology is in line with that of the Global Burden of Disease Study from the World Health Organization (http://www.healthdata.org/gbd). The major improvements include revising the approach for estimating the intake fraction to take into account more Chinese cities and updating the data for specific incident rates for different age cohorts.

REVIEW OF CHINA'S CURRENT MOTOR VEHICLE EMISSION CONTROL PROGRAMS

This section reviews the history of China's motor vehicle emission control programs, focusing on new vehicle emission regulations, fuel quality standards, fuel consumption standards, and vehicle scrappage/replacement schemes. An overview of the relevant regulatory authorities and their particular responsibilities can be found in Appendix B. Additional information, including more comprehensive comparative analysis with international best practices, is presented in ICCT's 2010 retrospective study (Fung et al., 2010).

HISTORY OF TAILPIPE EMISSION STANDARDS AND FUEL QUALITY STANDARDS IN CHINA

Table 3 provides a summary of the timeline for nationwide vehicle tailpipe emission and fuel quality standards in China, as well as for those critical urban regions that are moving ahead on their own. Tailpipe emission standards and fuel quality standards are listed separately by their implementation date. The table looks back as far as 2000, when China's first national motor vehicle emission control program, China 1 (equivalent to the European Union's Euro 1),[5] began. Since then, tailpipe emission regulations for nearly all categories of vehicles have been issued and periodically tightened following EU precedents. To ensure the full effectiveness of stringent emission policies, fuel quality standards in China have been periodically upgraded over the past two decades.

Table 3. The history of vehicle tailpipe emission and fuel quality standards in China

Tailpipe Emission Standards[1]	Year	Fuel Quality Standards
Jan.: *Beijing[2] (1999)—China 1/I* Jul.: *Shanghai (1999) —China 1/I*	Pre-2000	
Jul.: **National—China 1**	2000	
Sep.: **National—China I diesel**	2001	
	2002	Jan.: **National—2,000 ppm[3]**
Jan.: *Beijing—China 2/II* Mar.: *Shanghai—China 2/II diesel* Jul.: **National—China I gasoline**	2003	Oct.: *Beijing—500 ppm gasoline* Oct.: **National—500 ppm diesel**
Sep.: **National—China II**	2004	
Jul.: **National—China 2** Dec.: *Beijing—China 3/III*	2005	Jul.: *Beijing—350 ppm gasoline/ 150 ppm diesel*
Sep.: *Guangzhou—China 3/III*	2006	Sep.: *Guangzhou—350 ppm gasoline/ 150 ppm diesel* Dec.: **National—500 ppm gasoline**
	2007	
Mar.: *Beijing—China 4* Jul.: **National—China 3/III diesel** Nov.: *Beijing—China IV*	2008	Jan.: *Shanghai—350 ppm diesel* Jan.: *Beijing—50 ppm* Jul.: *Shanghai—150 ppm gasoline*
Nov.: *Shanghai—China 4/IV*	2009	Nov.: *Shanghai—50 ppm*

5 Arabic numerals are used to refer to light-duty vehicle emission standards, while Roman numerals are used to refer to heavy-duty vehicle emission standards.

Tailpipe Emission Standards[1]	Year	Fuel Quality Standards
Jun.: *Guangzhou—China 4/IV* Jul.: **National—China III gasoline**	2010	Jan.: **National—150 ppm gasoline** Jun.: *Guangzhou—50 ppm*
Jul.: **National—China 4 gasoline**	2011	Jul.: **National—350 ppm diesel**
	2012	Aug.: *Beijing—10 ppm*
Feb.: *Beijing—China 5/V* Jul.: **National—China IV** Sep.: *Shanghai—China 5/V*	2013	
	2014	Jan.: **National—50 ppm gasoline** May: *Shanghai—10 ppm* Jul.: *Guangzhou—10 ppm*
National (2015) —China 4 diesel *Guangzhou (2015) —China 5/V* **National (2018) —China 5/V**	Post-2014	**National (2015) —50 ppm diesel** **National (2018) —10 ppm**

Notes:
1) Standards apply to both gasoline- and diesel-powered vehicles unless noted. National steps are shown in bold, while early adoptions in discrete regions are shown in italics.
2) For regions with HDV early adoption (Beijing, Shanghai, and Guangzhou), the policy only applies to the public fleet.
3) "Ppm" stands for parts per million sulfur in the fuel.

China's fuel quality standards have historically lagged the corresponding rules for tailpipe emissions, creating a mismatch that has caused delays in the implementation of emission control measures. One of the most notorious examples of problems caused by this mismatch was the repeated delays in implementing the China IV diesel HDV tailpipe emissions standard. Made public in 2005, the China IV and China V heavy-duty diesel vehicle emission standards were initially scheduled for implementation nationwide for all vehicle sales and registrations on January 1, 2011, and January 1, 2013, respectively. However, concerns over the nationwide availability of the low-sulfur fuel needed for the advanced after-treatment systems vital to meeting the tougher regulations to function properly forced the MEP to delay the implementation of the China IV standard twice. China IV finally came into effect nationwide on July 1, 2013. The China V standard has been delayed indefinitely, although it is expected that it will be implemented on January 1, 2018.

The most important fuel quality parameter affecting the introduction of stringent tailpipe emission rules, as mentioned above, is fuel sulfur level. In early 2013, in response to severe air pollution episodes across northern China, the State Council issued a directive calling for the nationwide introduction of ultra-low-sulfur fuels (10 parts per million, or ppm) by the end of 2017 (State Council, 2013a). This directive was translated into formal regulatory action over the course of 2013 (ICCT, 2013a).

In China, cities or provinces are permitted to implement a standard in advance of the nationwide implementation date, with the State Council's approval. In most cases, the national standard must have already been issued publicly in order for it to be implemented early in a particular region. An exception to this rule is the Beijing 5 light-duty vehicle standard, which was developed by the Beijing municipal Environmental Protection Bureau (EPB) and approved by the State Council independent of the national China 5 light-duty standard.[6]

6 After the China 5 regulation (GB18352.2-2013) was released on September 17, 2013, Beijing moved to comply with the national standard and phased out Beijing 5.

As with new vehicle emission standards, cities have moved more rapidly than the national government to improve fuel quality. Beijing has consistently been a leader; in 2012, Beijing became the first area in mainland China to supply 10 ppm sulfur gasoline and diesel. Further subnational action is expected over the coming years. In September 2013, the State Council called for the introduction of 10 ppm fuels in the three critical regions cited in the project overview section above by the end of 2015.

China follows the European Union precedent for tailpipe emission standards but has occasionally made some important revisions. Recently, it issued several significant supplemental testing regulations to amend the China IV and V heavy-duty diesel vehicle standards (equivalent to Euro IV and V). In early 2014, the MEP issued a new nationwide requirement that China IV and V urban heavy-duty diesel engines be tested over the World Harmonized Transient Cycle (WHTC) (MEP, 2014c). This regulation will go into effect in 2015 for China IV engines and will be in operation for China V immediately after that standard comes into force nationwide, at a date yet to be determined. While the WHTC was not required in Europe until the implementation of Euro VI (in January 2013), Chinese policymakers are eager to adopt it in advance so as to prevent excess NO_x emissions from heavy-duty diesel vehicles. In particular, the policy is targeting large vehicles (weighing more than 3,500 kg) used in urban environments with low load (the amount of work the engine must perform) or low speed, such as public buses, postal trucks, and sanitation vehicles (ICCT, 2014b). This sets an important precedent for other countries and local jurisdictions that are following the European standards.

This national initiative follows a similar approach taken by the Beijing EPB in 2013, although Beijing went one step further and adopted an in-use Portable Emission Measurement System (PEMS) testing requirement to provide additional assurance that real-world emissions do not significantly exceed certification limits (ICCT, 2013b).

Figure 2 shows ICCT estimates for on-road vehicle populations in China since 2000 according to tailpipe emission standard. These estimates are the results of combining vehicle fleet and sales data with tailpipe standard implementation dates and assumed scrappage rates. The figure shows national-level aggregate data only, though these data account for the different implementation schedules for light-duty and heavy-duty vehicles, as well as the varying local enforcement dates as described previously. By the end of 2013, there were more than 120 million on-road highway vehicles in the country. Although China has rapidly implemented increasingly stringent tailpipe emissions standards for new vehicles, in 2013, over 30 percent of the fleet still consisted of China 2/II and older vehicles.

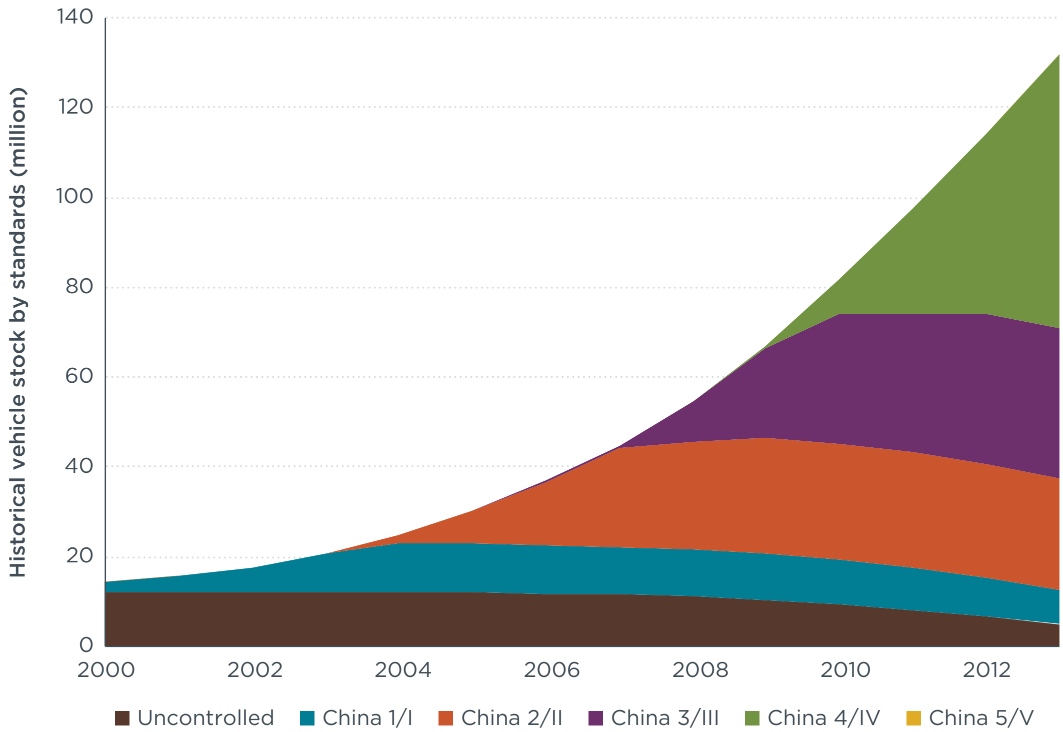


Figure 2. Vehicle stock by tailpipe emission standard in China, 2000–2013

Modern emission control systems are extremely effective at reducing tailpipe emissions to near-zero levels. As shown in Figure 3, vehicles meeting the world-class Euro 6/VI tailpipe emission standards emit 99 percent less $PM_{2.5}$ than uncontrolled vehicles. As vehicle populations around the world surge—especially in developing countries—reducing tailpipe emissions to a minimum is essential for controlling overall emissions and protecting public health (Chambliss et al., 2013).

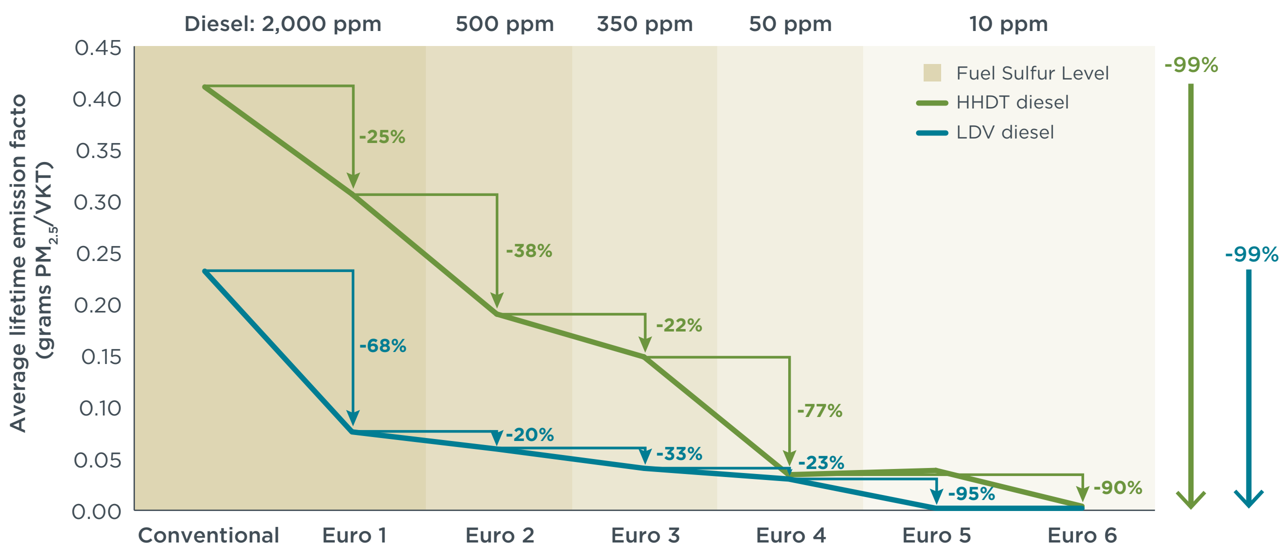


Figure 3. Comparison of $PM_{2.5}$ emission factors

Over the period 2000–2010, the Chinese government implemented new, more stringent tailpipe emission standards every three to five years. However, in recent years this pace has slowed, in particular as China has struggled to implement the China IV heavy-duty diesel vehicle standard and the China 5/V standards for both light- and heavy-duty vehicles. The lack of availability of the lower-sulfur fuel needed to put these regulations into effect is one of the primary reasons for the delays. Figure 4 shows the approximate number of years between implementation of successive nationwide tailpipe emission regulations in China. For light-duty vehicles, note that the time gap between the changeover from China 2 to China 3 and that from China 3 to China 4 was just three years, but it will be another seven years before the China 5 standard goes into effect. For heavy-duty trucks and buses, note that it took one year longer in each case to go from instituting China II to China III and then to China IV. The China V implementation date has not yet been determined.

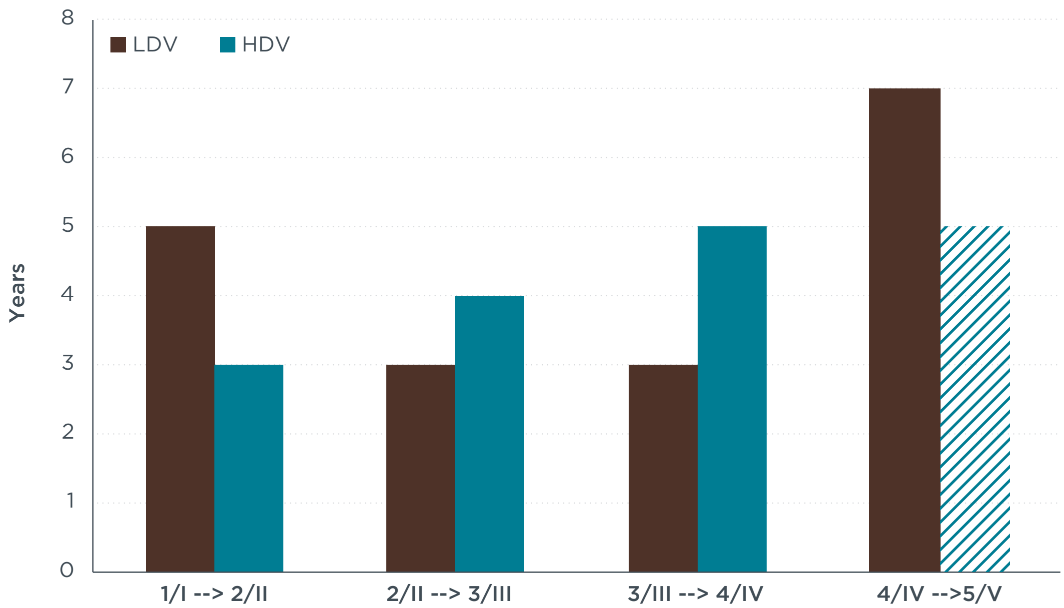


Figure 4. Number of years between implementation of China's national tailpipe emission standards

Figure 5 charts the time lag in the implementation of equivalent emission standards in China versus the European Union. China has generally been seven to eight years behind the EU, although it implemented the China 4 light-duty gasoline vehicle standard just five years after Europe.

Also revealed in the figure is the extraordinary progress Beijing has made. The capital has historically led the national government in the implementation of new vehicle emission standards, most recently becoming the first region in China to implement the China 5/V standards. In recent years, Beijing has implemented European-equivalent standards just one year behind the EU for LDVs.[7]

7 Early adoption by Beijing's HDVs as shown in Figure 5 applies only to the public HDV fleet (buses, sanitation vehicles, postal trucks, and other civic vehicles). Privately owned or operated HDVs still follow the national timeline. The reason for this is the mismatch between advanced vehicles/engines and the availability of the proper low-sulfur fuel for them. Commercial HDVs usually travel longer distances and thus are more likely to be refueled outside Beijing's city limits, where fuel quality is much poorer. Thus, application of the strictest standards for HDVs across the board will have to wait until compatible fuel can be dependably supplied in those surrounding areas.

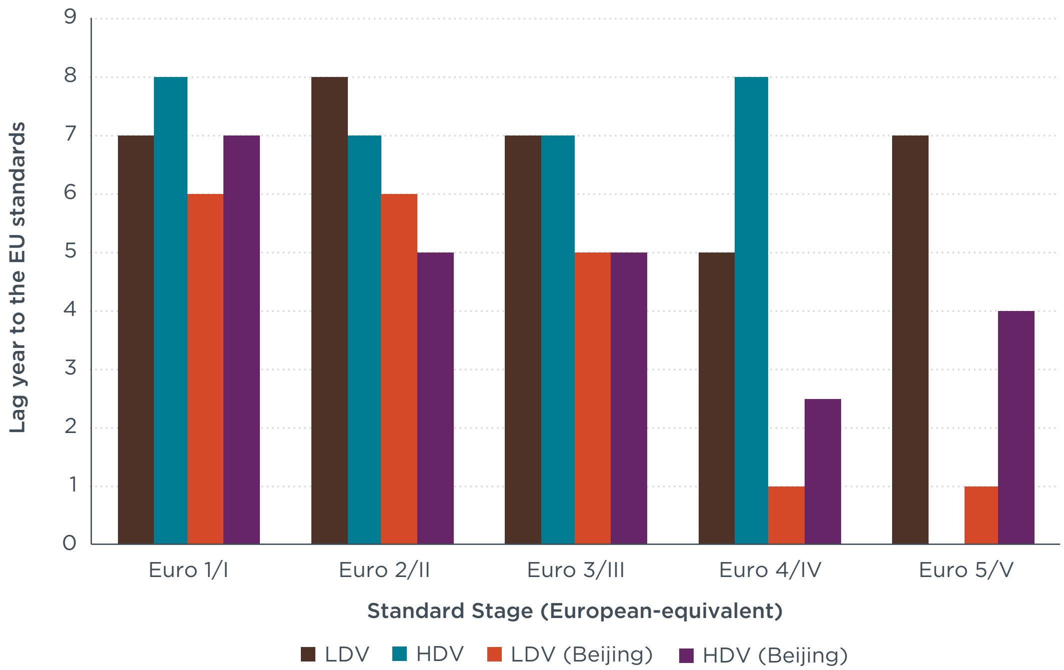


Figure 5. Tailpipe standard implementation in China—time lag with Europe

The upcoming China 6/VI standards should bring the emissions performance of China's new vehicles into alignment with global best practices. China first signaled its intention to develop and implement China 6/VI standards in 2013. Beijing has set a goal to implement its own local Beijing 6/VI regime as early as 2016. The national government has committed to publishing the China 6/VI standards by the end of 2017 but has not yet indicated when those standards would be implemented.

Because China continues to suffer serious air pollution, reducing urban transportation emissions has become one of the top priorities for air quality improvement. The China 6/VI tailpipe emission standards will compel strict emission limits. Most important, in order to meet the requirements, heavy-duty diesel vehicles will need to install diesel particulate filters (DPF), which virtually eliminate emissions of PM and BC. Using heavy-duty diesel vehicles as an example, the NO_x ceiling will be reduced by 80 percent versus China V; the emission limit value will decrease from 2.0 grams per kilowatt-hour (g/kWh) to 0.4 g/kWh. Similarly, the PM limit will be lowered by 50 percent, to 0.01 g/kWh from 0.02 kWh at present. More significantly, mandatory installation of DPFs in order to meet the PM and particulate number (PN) limits could successfully capture more than 99 percent of particulate matter, including BC.

Furthermore, it is expected that the China VI test cycle will include cold-start testing and a wide range of urban driving conditions. The test cycles for heavy-duty engines—cold- and hot-start tests under the WHTC and hot starts under the World Harmonized Stationary Cycle (WHSC)—will better capture the real-world conditions that drivers encounter on China's roads. Together with the requirement to adopt a portable emissions measuring system (PEMS) for off-cycle (in-use) testing at type approval, China 6/VI should be able to lower vehicular emissions under various driving conditions. PEMS will also be involved in the field measurements specified by China 6/VI for in-service conformity testing.

Another essential tool in the service of complying with China 6/VI is on-board diagnostics (OBD). A well-designed OBD system can effectively diagnose and detect deterioration or malfunctioning of after-treatment devices, notably selective catalytic reduction (SCR) and DPFs. This can largely prevent emissions increases stemming from after-treatment failure.

COMPLIANCE AND ENFORCEMENT PROGRAMS IN CHINA

Compliance programs for vehicle emission control are detailed in China's Air Pollution Prevention and Control Law (MEP, 2000). The law covers the emission limits, prohibitions on vehicles failing to meet the in-use standards, and provisions for regulatory agencies to stop entities from producing, selling, or importing vehicles that do not conform to standards. However, it does not clearly specify which agencies are responsible for enforcing these provisions. The law is currently under process of revision and is expected to deal with the urgent air quality issues in China through a stricter and more comprehensive approach.

The State Council's Action Plan on Prevention and Control of Air Pollution, released in 2013, stresses the role of compliance programs for new vehicles. Five departments, including the MEP, the Ministry of Industry and Information Technology (MIIT), the Ministry of Public Security (MPS), the State Administration for Industry and Commerce (SAIC), and the General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ), will work together to carry out joint operations to ensure vehicle emissions are reduced as intended (MEP, MIIT, MPS, SAIC, and AQSIQ [henceforth "MEP et al."], 2014). The new plan gives the MEP new enforcement authority over testing, production, sales, registration, and other aspects of compliance for new vehicles and engines, especially medium- and heavy-duty engines. The other agencies are required to give the MEP their full support. The Action Plan endows these departments with more enforcement authority, including fines and even criminal penalties. The release of the Action Plan clarifies the responsibilities and provides collaboration guidance for all these ministries.[8]

Vehicle enforcement and compliance programs in China include three main areas: 1) new vehicle type approval; 2) conformity of production (COP) testing (demonstrating that production-line models conform to type-approval specifications); and 3) inspection and maintenance (I/M) programs. The national environmental protection authority, the MEP, focuses its compliance efforts on new vehicle type approval and COP testing, supported by the Vehicle Emission Control Center of MEP (VECC-MEP), which conducts these programs. Local I/M programs are carried out by the provincial and municipal EPBs.

Manufacturers must submit vehicle prototypes to accredited testing laboratories for type-approval testing prior to production. Twenty-four labs nationwide, certified by the MEP, conduct the testing. Vehicle type-approval environmental reports are submitted to VECC-MEP for review.

VECC-MEP is responsible for random COP tests. Each year, vehicles are selected directly off the assembly line or purchased on the market for the testing. Final results are

8 The China IV HDDV standard has been delayed twice in part because of the unclear division of responsibility between MEP and MIIT. The catalog with the required vehicle standards was inconsistent between versions issued by the MEP and MIIT, and truck manufactures were able to exploit this loophole to delay implementation for more than two years. For new vehicle registration, the MPS reviews vehicle requirements only through the MIIT catalog, in which critical components of emission control are missing. The release of the Action Plan clarifies the roles of each ministry, thus helping prevent a similar situation from developing in the future.

summarized for MEP review. Nonconforming enterprises are told to bring the production line in question into compliance before a stated deadline; in the meantime, their type-approval application is temporarily suspended. In addition, manufacturers are required to submit quarterly COP assurance reports to VECC-MEP, based on testing of at least three randomly selected vehicles from each engine family or group. With the China 4/IV emission standards in place, the MEP now orders vehicle manufacturers to submit in-use compliance testing plans and annual reports.[9] But no national level-testing program is being conducted to verify the reports, owing to a lack of resources.[10] For HDVs, the COP standards are under development.

Provincial- and municipal-level EPBs manage the inspection and maintenance tests based on general guidance from the MEP (MEP, 2005). Local EPBs are allowed to set stricter limits according to need. For regulatory simplicity, many local governments combine their I/M program with the issuance of inspection stickers: vehicles that pass the test are issued a color-coded windshield sticker that identifies the model's emission standards.. Yellow-label vehicles are defined as gasoline vehicles not meeting the China 1/I standard (in other words, they have uncontrolled emissions) and diesel vehicles not meeting the China 3/III standard (uncontrolled, China 1/I, and China 2/II). Green-label vehicles meet or exceed China 1/I (gasoline powered) or China 3/III (diesel fueled). Both LDVs and HDVs can be registered only if they have an emission sticker.

Although there have been efforts to make the compliance and enforcement regime in China more effective, significant improvements in a number of areas are needed. For example, there is no requirement for mandatory in-use testing by vehicle manufacturers to prove that their emissions control systems are working in real-world conditions and are durable over the lifetime of the vehicle. In addition, the COP tests, particularly for HDVs, exist only on paper in many cases, rather than being based on actual testing. In fact, recent tests of heavy-duty engines indicated that most of the production vehicles do not comply with the required emission standards (CENEWS, 2014). There are a number of reasons for the lack of robust compliance and enforcement practices in China. These range from lack of resources to unclear lines of responsibility in the environment-related ministries. The absence of strong compliance and enforcement can significantly offset or even completely negate the potential benefits of a limit setting emissions standard. Hence, resolving the compliance issues has become one of the top priorities for the MEP in the coming years. Learning from best practices in both the EU and the United States will be essential. Although the shortcomings of regulatory compliance could have a significant impact on emissions standards, there are not enough data available at the current time to allow for the inclusion of this concern in the modeling presented in this paper.

IN-USE CONTROL PROGRAMS IN CHINA

China's primary in-use vehicle emission control programs include inspection and maintenance, scrappage, and the establishment of low-emission zones (LEZs). The

9 The testing plan explains how the testing has been performed and serves as the guidance for actual tests. The test results will be considered in the annual reports.

10 At the local level, the city of Beijing conducts its own in-use testing program for LDVs. In March 2009, the Beijing EPB launched a randomized in-use testing program for all China 3 and 4 LDVs with less than 100,000 km. The following year, 60 vehicles were tested. The in-use testing identified various problems with many on-road vehicles. Detailed results were not made public, however, and it is unclear what follow-up actions the Beijing EPB took against manufacturers making noncompliant vehicles. Further, Beijing has issued regulations requiring manufacturers to conduct in-use testing of any engine or vehicle model that sells more than 500 units per year in the city.

use of remote sensing, spot checks, and the retrofitting of older vehicles complement these strategies.

An I/M program, a routine practice to manage in-use vehicle emissions, demands that vehicles go through certified safety and emissions tests periodically. If a vehicle fails to meet a performance threshold, it must undergo repair or maintenance before it is permitted to return to the road. Depending on vehicle type and age, vehicles are mostly required to test from twice a year to once every two years.[11] Since September 1, 2014, private passenger cars are exempted from I/M testing every other year for the first six years ([G]AQSIQ, 2014). The I/M program is often coordinated with environmental labeling to indicate that vehicles have passed the I/M test. Vehicles without labels are not allowed on the road. The MEP also plans to link all testing centers to a centralized database for easier monitoring of such facilities and identification of vehicle problems that are occurring across multiple regions (Wagner and Rutherford, 2013).

For older vehicles, China is currently implementing one of the world's most ambitious voluntary scrappage programs (Posada et al., 2015). The primary vehicles targeted for early retirement are China 0 (uncontrolled) gasoline vehicles (those manufactured before 2000) and China 0, 1/I, and 2/II diesel vehicles (pre-2008 models). These vehicles, which are known in China as "yellow-label vehicles" (YLVs) because of the stickers affixed to their windshields, emit a disproportionate share of total emissions. According to the annual report on China's vehicular emissions released by VECC-MEP, YLVs are responsible for more than 58 percent of NO_x emissions and 78 percent of PM emissions in 2012 (MEP, 2014b). Accordingly, eliminating them is a high priority for the Chinese government as it strives for rapid urban air quality improvements.

China's first national scrappage subsidy program was jointly initiated by eight ministries, including the Ministry of Commerce (MOC), the Ministry of Finance (MOF), and the MEP, in mid-2009. The yearlong program offered subsides ranging from 3,000 to 6,000 renminbi (RMB) ($490 to $980) per scrapped vehicle (MOF et al., 2009). Subsidies varied by vehicle type and targeted both LDVs and HDVs. However, initial consumer response was lukewarm. At the end of 2009, the government revised the subsidies upward to 6,000 to 18,000 RMB ($980 to $2,940) and extended the program until the middle of 2010 (MOF and MOC, 2010). It was then further extended until the end of 2010 (MOC, 2010). Although no national-level scrappage subsidy program has been run since then, the government has repeatedly mentioned wide-scale scrappage of yellow-label vehicles as an important near-term goal. The State Council released a detailed plan for scrappage of YLVs as the first of ten major new air pollution control measures (State Council, 2013a; State Council, 2013b), aiming to scrap all YLVs nationwide by 2017. The three most salient regions—Jing-Jin-Ji, the Yangtze River delta, and the Pearl River delta—are expected to retire five million YLVs by 2015. The YLV scrappage plan from the State Council encourages the provision of subsidies at the provincial level (MEP et al., 2014).

In fact, certain regions have developed their own scrappage subsidy programs that go beyond the national subsidies. The State Council's Action Plan specifically encouraged local governments to strengthen their policy support for early scrappage of YLVs (State Council, 2013b). To date, Beijing has been the most successful Chinese city in encouraging the voluntary early retirement of older vehicles. From 2006 to 2010, its

11 YLVs are required to test four times a year; passenger cars are exempted from testing for the first six years.

municipal government offered two rounds of subsidies—with the average per vehicle subsidy reaching 7,347 RMB ($1,225)[12] in 2010—to eliminate YLVs from the city. In the five years since, Beijing has stopped giving such subsidies for YLVs since the goal had largely been achieved. The city has continued offering subsidies, though, to eliminate older (over 6-year old), green-label vehicles (i.e., China 1, 2, and 3 gasoline-fueled vehicles and China 3/III diesel-powered vehicles) from the fleet. This has been a great success, as the initial goal (400,000 vehicles) was reached by the end of 2012. Subsequently, the goal was revised upward to 700,000 (Beijing Municipal Government, 2011; Beijing EPB, 2012). In August 2013, the capital announced a new plan to scrap a further one million older vehicles by 2017 (Beijing Municipal Government, 2013).

In parallel with the efforts to remove YLVs from the road, many regions and cities also restrict their operation by having instituted low-emission zones (LEZs). LEZs are defined differently from jurisdiction to jurisdiction. Measures include blanket bans on specified classes of vehicles, restrictions on vehicles not meeting certain requirements, or temporal bans on vehicles during particular times of the day or week (Wagner and Rutherford, 2013). Starting from 2003, YLVs were not allowed to drive within the bounds of the Second Ring Road in Beijing, and the ban was extended to the Sixth Ring Road in April 2014. YLVs will eventually be barred from the entire Beijing metropolitan area. Both Shanghai and Guangzhou follow a similar approach in limiting the ambit of YLVs, especially in the central city areas. As one of the primary measures to restrict the use of YLVs, LEZs have been required in all of the most critically significant cities since October 2014 to speed up the scrappage program in China (MEP et al., 2014).

In addition to limiting YLVs, LEZs also serve to control the operation of certain other types of vehicles. In Beijing, all heavy-duty trucks are banned inside the area circumscribed by the Fifth Ring Road between 6 a.m. and 11 p.m., and all LDVs are banned for selected days determined by the last digit of their license plate (Beijing Municipal Commission of Transport, 2014). In the center of Guangzhou, motorcycles have not been allowed since 2007. All those measures are in place in the service of regional air quality targets.

To ensure that on-road vehicles are actually emitting at or below certified emission levels, roadside testing is an effective approach to supplement I/M programs (Borken-Kleefeld, 2013). Remote sensing is conducted in various cities to carry out roadside inspections. Though remote sensing is not precise enough to test discrete emission factors for individual vehicles, by scanning exhaust emissions, it can readily identify the high emitters amid traffic. Moreover, it is useful for analyzing fleetwide trends over time and for evaluating the effectiveness of I/M programs (Wagner and Rutherford, 2013; Borken-Kleefeld, 2013).Roadside remote sensing vehicles and equipment are widely used in Beijing. The equipment is able to monitor and detect on-road vehicle emissions continuously, day and night. The owners of those vehicles identified as high emitters will receive financial penalties and be ordered to fix the outstanding issues. These vehicles are not allowed to renew registration unless they pass the emission tests.

Besides remote sensing, spot checks and public spotter programs are used to test on-road vehicles with high emission potential or those that visibly emit black smoke. Under the spot-checking program, local authorities create checkpoints by the roadside

12 The Beijing EPB reported total spending of 85,749,600 RMB (around $13 million) in 2010 on the elimination of 11,670 vehicles (Beijing EPB, 2011).

or in parking lots and conduct emission tests. This is recommended to help identify YLVs that violate municipal restrictions on operation (MEP et al., 2014). Under public spotter program, local authorities encourage citizens to report voluntarily the license plate numbers of smoky vehicles. Financial incentives are provided region by region. All these are policies to complement the I/M program.

Beyond scrappage and LEZs, a retrofitting program is being conducted in various areas to extend vehicles' useful life with lower emissions. This typically is more cost-effective than retirement and replacement if the vehicle is not too old or in bad condition. Unlike the scrappage program, however, retrofitting initiatives are typically small in scale (Wagner and Rutherford, 2013). The technical requirements for after-treatment, involving the use of diesel oxidation catalysts (DOCs), selective catalytic reduction (SCR), and diesel particulate filters (DPFs), were first formulated in 2009 (MEP, 2008). Beijing has tried a few pilot projects to retrofit the in-use fleet, including retrofitting three-way catalytic converters, clean-fuel taxis, and bus DPFs (Yang, Wang, and Shao, 2015). Other small programs have been launched in various cities. But the need for low-sulfur (less than 50 ppm) diesel fuel in order for the retrofitting equipment (e.g., advanced filters) to function properly often imposes a high hurdle.

MODELING RESULTS

CHINA'S MOTOR VEHICLE POPULATION PROJECTIONS

Figure 6 shows the ICCT's modeling projection for the total numbers of China's on-road vehicles (cars, trucks, and buses) from 2000 to 2030. The data for 2000–2012, during which period the number of vehicles grew from 16 million to 108 million, are consistent with historical data published by China's National Bureau of Statistics (CATARC, 2014).[13] Driven largely by the continued explosive growth in private passenger cars, the model predicts in excess of 400 million vehicles in China by 2030. These results incorporate the rapid market growth of the past decade, and are broadly consistent with MIIT's projection: a stock of 260 million motor vehicles by 2020 (Xinhua, 2010).

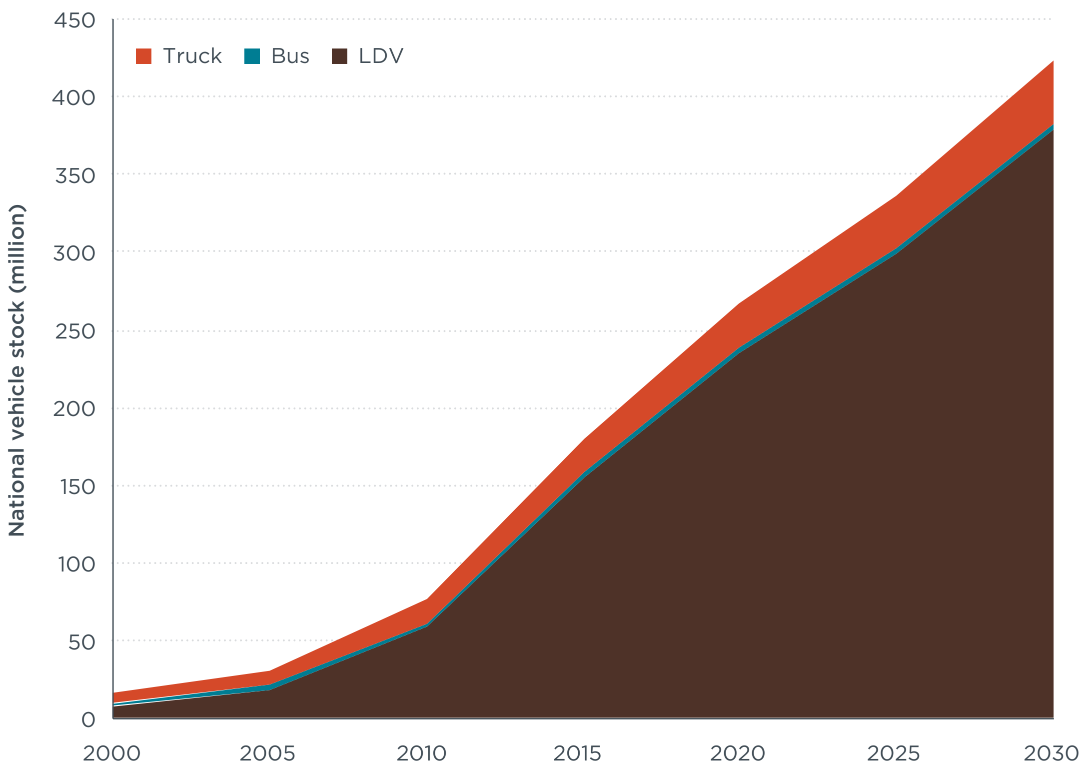


Figure 6. Vehicle population in China, 2000–2030

Figure 7 shows the projected motor vehicle population in three critical regions (Jing-Jin-Ji, the Yangtze River delta, and the Pearl River delta) as well as the rest of the country. More than 50 percent of all vehicles nationwide are in these three localities, indicating that early, aggressive action there will have a significant impact on the overall vehicle market.

13 At the end of 2012, China also had 104 million motorcycles and 11.5 million low-speed vehicles, mostly mopeds but also on-road agricultural equipment (MEP, 2014b), which are not reflected in this figure.

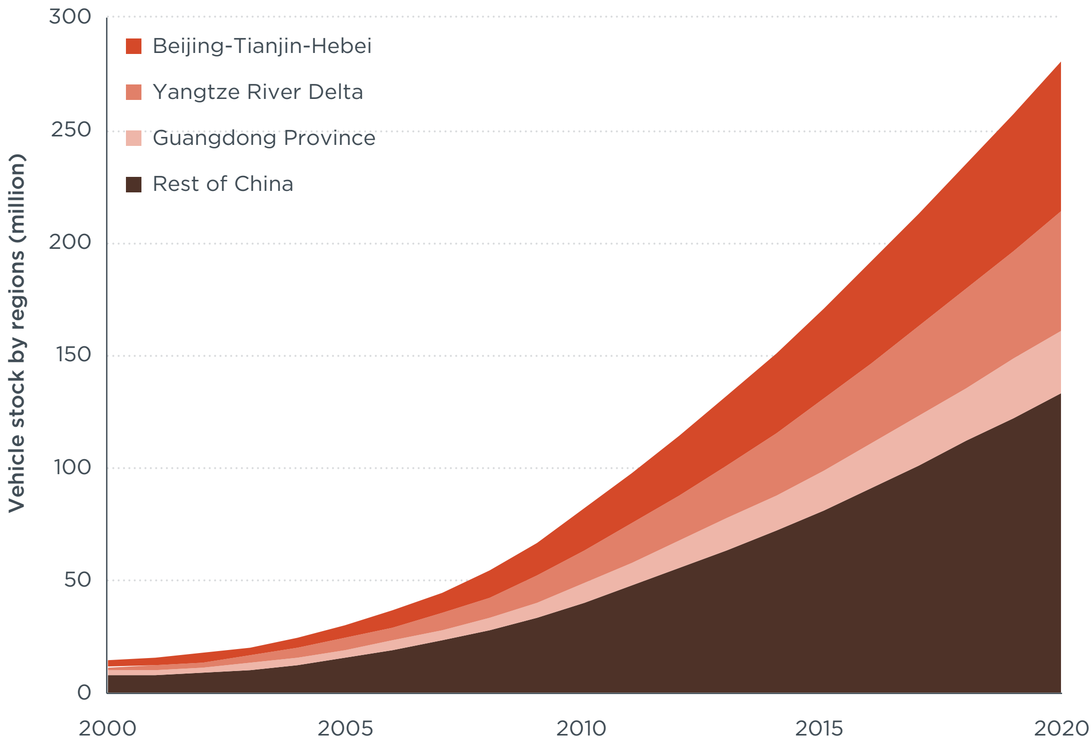


Figure 7. Vehicle population by region in China

Note: For Guangdong province, more than 80 percent of the vehicle population is based in the Pearl River delta.

All of the policy scenarios in this analysis assume identical vehicle population growth trends. The purpose is to explore the impact of the expedited introduction of cleaner vehicles and fuels, as opposed to mode shift (encouraging switching from one form of transport to another), limiting vehicle population growth, or broader transportation demand management scenarios.

POLICY SCENARIOS

Policy implementation scenarios were developed in consultation with Chinese partners and experts. The chosen scenarios were based on current experience in China as well as likely future action. Four primary scenarios were modeled: Current, Baseline, Improved, and World Class, as introduced in the Table 4.

Table 4. Overview of the four main modeled scenarios

Scenario	Description
Current	No additional progress beyond the standards already in place in mid-2014
Baseline	Future standards that have already been announced go into effect, but otherwise, no additional progress
Improved	International best-practice standards are implemented following a conservative timeline
World Class	International best-practice standards are implemented following an accelerated timeline

Detailed information on assumed vehicle tailpipe emission standard implementation dates for each scenario is presented in Table 5. As mentioned in the project overview section above, scenarios are customized for selected regions where earlier proactive measures are expected. No official China 6/VI standards have been released yet, but it is assumed here that China will still follow in the European Union's footsteps. All China 6/VI standards mentioned in the analysis may be treated as Euro 6/VI–equivalent.

Table 5. Scenarios: Vehicle emission standard implementation year

Scenario	Beijing		Shanghai		Guangzhou, Shenzhen		Three critical regions		Nationwide	
	China 5/V	China 6/VI	China 5/V	China 6/VI	China 5/V	China 6/VI	China 5/V	China 6/VI	China 5/V	China 6/VI
Current	2013	N/A	2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Baseline	2013	2016	2014	N/A	2015	N/A	2018	N/A	2018	N/A
Improved	2013	2016	2014	2018	2015	2018	2015	2018	2018	2021
World Class	2013	2016	2014	2016	2015	2016	2015	2016	2016	2018

As mentioned earlier, the China 6/VI standards would be aligned with the world's most advanced tailpipe emission restrictions and would result in dramatic reductions of pollutant emissions from both light- and heavy-duty vehicles. To date, only Beijing has signaled a specific date for the implementation of China 6/VI standards (in 2016). The national government has formally begun the routine development and drafting process for China 6/VI and has committed to issuing the standards by the end of 2017. However, it has not yet indicated when the standards would be implemented.

In the Baseline scenario, China is expected to move to China 5/V nationwide around 2018, when 10 ppm sulfur fuel will be supplied universally. In the Improved scenario, China 6/VI is to be implemented another three years down the road, in 2021. However, the ICCT strongly recommends that China speed up the transition to China 6/VI. Taking full advantage of pioneering efforts at the local level, it urges broad-based adoption of China 5/V by 2016 and China 6/VI by 2018 (World-Class scenario). The proposed three-year speedup of China 6/VI implementation envisioned in the World-Class scenario could lead to enormous benefits for China.

Table 6 presents more detailed information on schedules for fuel quality improvement. Unlike the case for tailpipe emissions, the Chinese government has issued a clear nationwide time frame for making available fuel that is world-class in quality, removing a key barrier to the introduction of best-practice technologies to control vehicle emissions.

Table 6. Scenarios: Fuel quality improvement

Scenario	Beijing	Shanghai	Guangzhou, Shenzhen	Three critical regions	Nationwide
Current	10 ppm	10 ppm	50 ppm	350 ppm (diesel); 50 ppm (gasoline)	350 ppm (diesel); 150 ppm (gasoline)
Baseline	Same as Current	Same as Current	2015: 10 ppm	2015: 50 ppm (diesel) 2018: 10 ppm	2014: 50 ppm (gasoline) 2015: 50 ppm (diesel) 2018: 10 ppm
Improved	Same as Current	Same as Current	Same as Baseline	2015: 10 ppm	Same as Baseline
World Class	Same as Current	Same as Current	Same as Baseline	Same as Improved	Same as Baseline

In addition to modeling differing tailpipe emissions and fuel quality standard implementation dates, the ICCT also modeled various scrappage programs in each scenario. The modeling is based on goals established by the State Council to scrap all high-emitting yellow-label vehicles in the three aforementioned prominent regions by 2016 and nationwide by 2018 (State Council, 2013b). There were an estimated 14.5 million YLVs in China at the end of 2012 (MEP, 2014a). The scenarios also reflect more rapid progress in this regard in selected cities. The scrappage scenarios are described in Table 7. Going beyond the national YLV scrappage plan, Beijing is expected to remove all China 3/III vehicles from the fleet by 2017.

This analysis assumed full replacement of scrapped vehicles for both LDVs and HDVs. This is to say, all the YLVs scrapped in China will be exchanged for those equipped with latest tailpipe emission control technology in force for new vehicles in any particular region and year, though this is not mandated in China currently. Also, the patterns of use are assumed to remain the same for the newer vehicles as previously.

Table 7. Scenarios: Scrappage

Scenario	Beijing	Shanghai	Guangzhou, Shenzhen	Three critical regions	Nationwide
Current	All YLVs scrapped from 2010	N/A	N/A	N/A	N/A
Baseline	All China 3/III scrapped by 2017	All YLVs scrapped by 2016	All YLVs scrapped by 2015	50 percent of YLVs scrapped by 2016; all by 2018	50 percent of YLVs scrapped by 2016; all by 2018
Improved	Same as Baseline	Same as Baseline	Same as Baseline	All YLVs scrapped by 2016	All YLVs scrapped by 2016
World Class	Same as Baseline	Same as Baseline	Same as Baseline	Same as Improved	Same as Improved

As noted above, other policy scenarios, including those involving fuel consumption, compliance, other in-use vehicle emission control programs, or broader transport demand management programs, are beyond the scope of the analysis, which focuses primarily on various approaches to controlling pollutant emissions through technology and fuel quality upgrades.

RESULTS: NATIONWIDE EMISSIONS

The following figures show aggregate nationwide emissions of three main pollutants of concern—$PM_{2.5}$, BC, and NO_x—under the four scenarios. Although the analysis includes results for multiple pollutants (as summarized in Appendix A), here the results for just these three are presented because they are the major drivers of both atmospheric/climate pollution and public health problems.

Particulate matter is known to be the major contributor to China's heavily polluted air. $PM_{2.5}$, the fine particles, are inhaled and can penetrate deep into lungs, causing or aggravating various diseases, including lung cancer, cardiopulmonary disease, and acute respiratory infection. BC strongly absorbs solar radiation across all visible wavelengths and converts that energy to heat. As a component of $PM_{2.5}$, BC also threatens public health through exposure (ICCT, 2009). NO_X emissions contribute to smog and secondary PM in urban areas, which increase the premature mortality in a manner similar to $PM_{2.5}$.

All the graphs presented show that emissions from the relentless rise of the motor vehicle fleet in China will overwhelm the per vehicle emission reductions achieved through the China 4/IV and 5/V standards (Current and Baseline scenarios, respectively). Only under the Improved and World-Class scenarios, both of which incorporate China 6/VI, do emissions fall consistently through 2030. These results strongly support the implementation of China 6/VI–equivalent standards in China for maximum emission reductions and corresponding climate and health benefits.

Fine particulate matter ($PM_{2.5}$) results

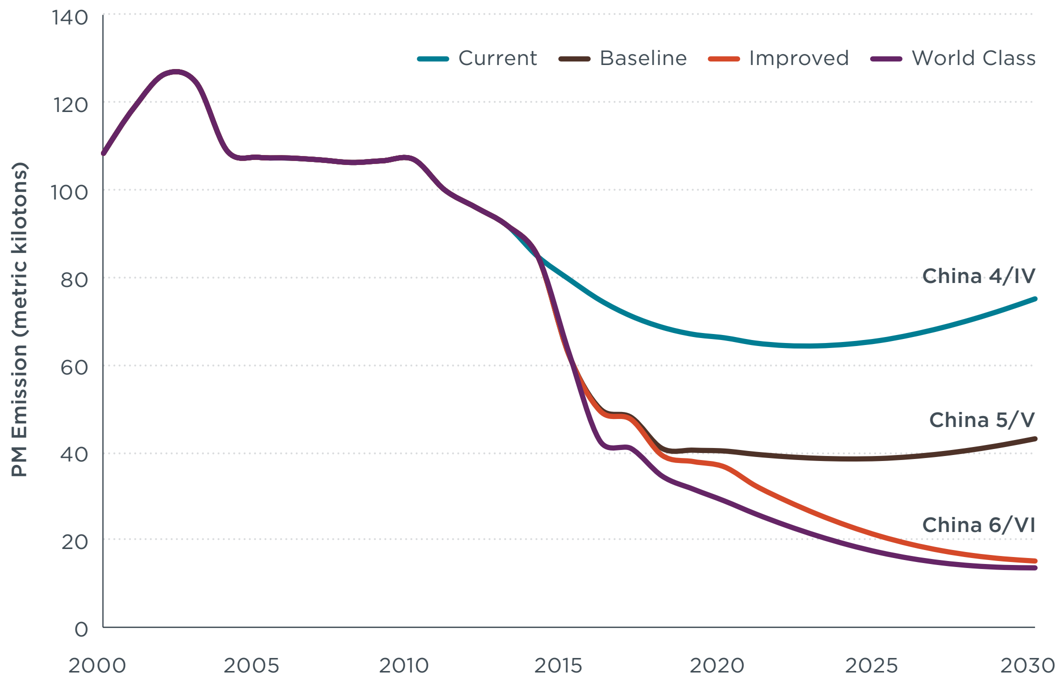


Figure 8. China motor vehicle PM emissions, 2000–2030

The fine PM emission results demonstrate that China has made consistent progress in reducing emissions from motor vehicles since 2003. The lowering of nationwide diesel sulfur levels from 2,000 to 500 ppm in 2003 quickly resulted in an impressive reduction in PM. Subsequently, the introduction of the China III and IV heavy-duty diesel emission standards and the continued tightening of permissible diesel sulfur levels from 2008 to 2013 yielded additional reductions. However, with current policies alone, emission cuts will slow down after 2015. Because of the continued growth of the vehicle population, PM emissions are projected to begin increasing again shortly after 2020 if no further action is taken.

In the Baseline scenario, the introduction of 50 ppm and 10 ppm sulfur diesel fuel results in marked reductions in PM emissions well beyond the Current scenario. Sulfates, the other major component of PM emissions besides black carbon (BC) and organic carbon (OC), are determined largely by the sulfur content in the fuel. The introduction of low- and ultra-low-sulfur fuel removes a large proportion of the sulfates, leading to a substantial decrease in PM emissions. However, because the China V PM limit for heavy-duty diesel vehicles is identical to that for China IV, the Baseline scenario does not yield significant additional reductions aside from the benefits associated with lower-sulfur fuel. In the Baseline scenario, emissions reductions continue through around 2018, following which emissions stabilize for about another decade. However, emissions begin to increase after 2025, again because of continued fleet growth.

The Improved and World-Class scenarios both achieve consistent reductions in motor vehicle PM emissions through 2030. The China VI standards are especially important for PM control because they lead heavy-duty vehicle manufacturers to install diesel particulate filters (DPFs), which virtually eliminate emissions of solid particles from diesel vehicles.

Black carbon results

BC is light-absorbing carbonaceous material emitted as solid particulate matter created through the incomplete combustion of carbon-based fuels (Minjares and Hon, 2012). It is ranked as the second-most important emission in today's atmosphere in terms of its climate-forcing properties (Bond et al., 2013). In contrast to CO_2—the number-one global warming emission source—BC persists only a little bit longer than a week in the atmosphere. Although it is a short-lived pollutant, it has stronger effects on climate change in short term (World Bank, 2014): the instant radiative impact from one kilogram of BC is up to one million times stronger than for the same mass of CO_2 (Bond and Sun, 2005).

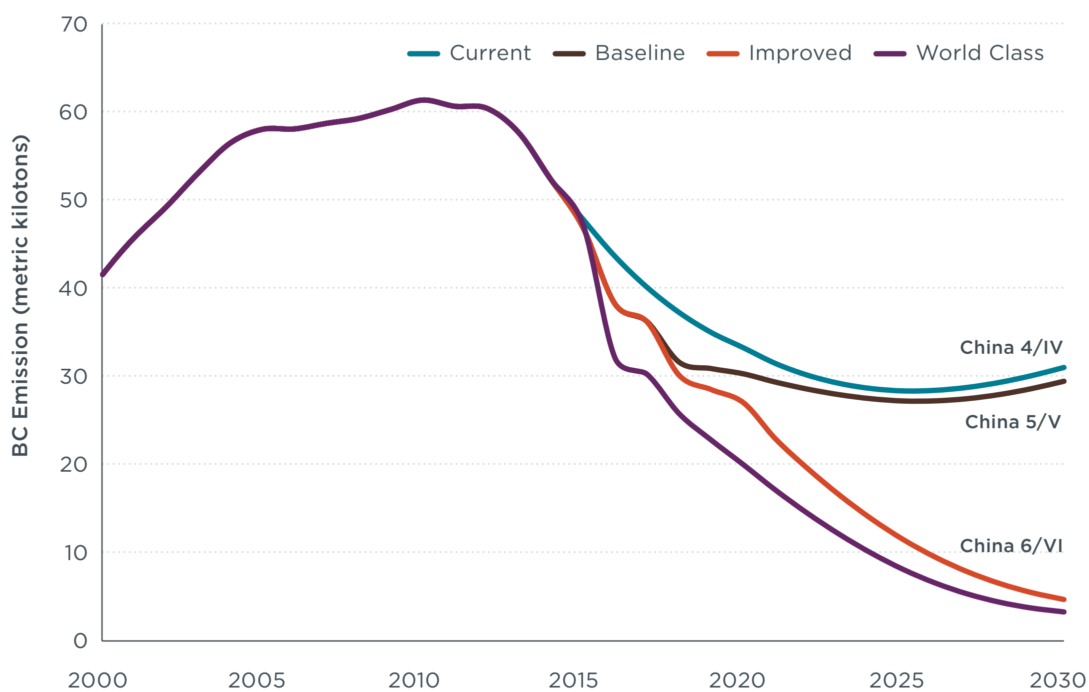


Figure 9. China motor vehicle BC emissions, 2000–2030

Figure 9 highlights the long-term importance of the World-Class China 6/VI standards. In the Current and Baseline scenarios, in which China only implements the China 4/IV and 5/V standards, emissions rise again after 2025 as a result of the inexorable rise of the motor vehicle population. In contrast, the long-term trends for the Improved and World-Class scenarios head in the opposite direction: rapid and steady reductions through 2030. By 2030, the China 6/VI standards will result in black carbon emission reductions of more than 90 percent compared with 2010. The lessening of BC emissions would translate into less planetary warming.

The black carbon trends shown in Figure 9 are similar to the total PM trends, although with some important differences. In particular, the black carbon emission trends are unrelated to any fuel sulfur level changes. For this reason, the difference between the Current and Baseline scenarios is not pronounced, reflecting the fact that the China IV and V PM limits are identical. The drop between 2015 and 2020 comes mostly from regional efforts: moving to China 6/VI (Beijing), adopting 10 ppm fuel (Guangdong), and putting into practice YLV scrappage (Shanghai and Guangdong).

Since the PM and BC reduction benefits from China 5/V are limited, especially for HDVs (whose diesel engines are major contributors to on-road emissions), it is strongly advisable to put China 6/VI into effect, with the world-class emission control technology (e.g., DPF) that it demands, as soon as possible. Leapfrogging from China IV to China VI could maximize the emission reduction benefits, and the concomitant air quality improvement, especially in the near team. Besides, the experience of the European Union suggests that compliance and enforcement are easier to manage through Euro 6/VI with improved on-board diagnostics (OBD), durability, and test procedure requirements, which can ensure better emission control in the real world.

In fact, reducing PM through lower sulfate emissions but not BC could actually be worse for the goal of climate change mitigation. Black carbon increases the surface temperature by absorbing energy from the sun and radiating it back as heat, while sulfates have proved to have cooling effects that partially offset the global warming tendencies of BC. Thus, China 6/VI ought to be implemented alongside the scheduled introduction nationwide of ultra-low-sulfur fuel in 2018—in other words, the World-Class scenario—so that both sulfates and BC can be brought under control.

NO_x results

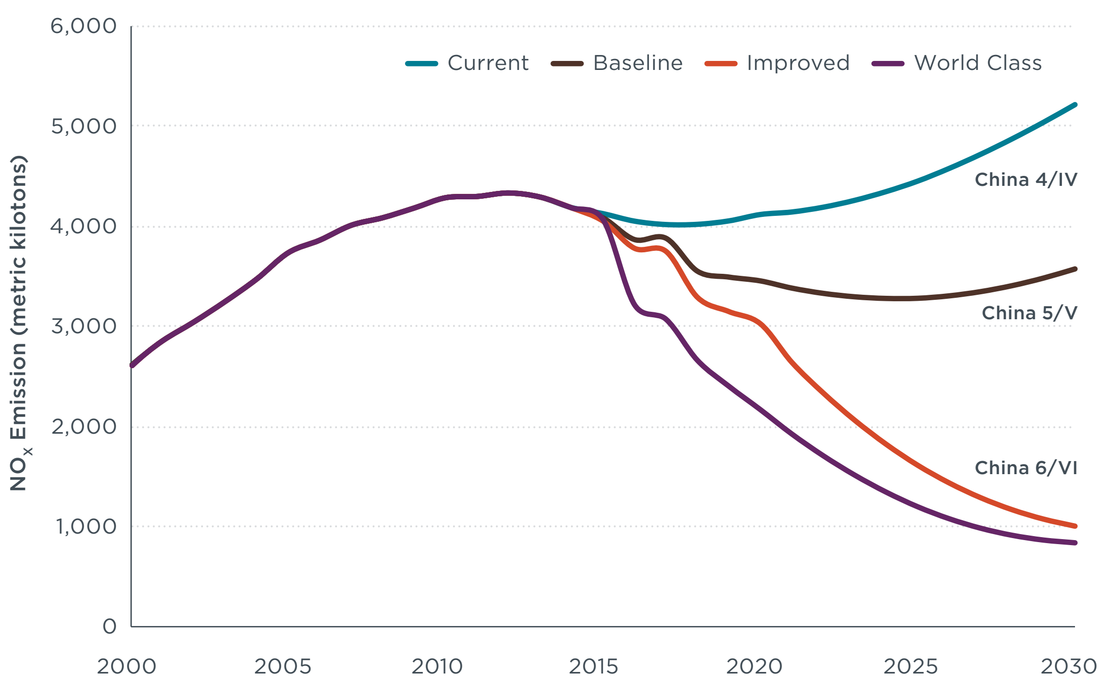


Figure 10. China motor vehicle NO_x emissions, 2000–2030

The NO_x results also make an unequivocal case for China 6/VI. The results illustrate that NO_x emissions in China increased steadily until China 3/III standards were implemented in 2008, after which emissions growth began to slow. In the Current scenario, in which nationwide emissions standards do not progress past the China 4/IV levels, emissions begin to increase once more as early as 2018. As in the case of PM, the China 5/V standards, incorporated in the Baseline scenario, are somewhat effective at stabilizing emissions, though these begin to grow again after 2025. Only the China 6/VI standards are sufficient to bring about long-term emission reductions.

A closer look at Improved versus World-Class Scenarios

As the previous figures clearly demonstrate, both the Improved and World-Class scenarios result in long-term emissions reductions through China 6/VI tailpipe regulations. However, it is important to stress that the timing of the introduction of China 6/VI and 10 ppm fuels can have a major impact on annual emissions for many years. Figure 11 points out the emission reduction from early adoption in the period 2018–30, showing the discrepancy between the Improved scenario, in which China 6/VI is implemented nationwide in 2021, and the World-Class scenario, in which it happens in 2018. The major difference in those two scenarios comes from this three-year implementation delay, which leads to additional thousands of metric tons of PM and BC emissions and millions of tons of NO_x emissions annually.

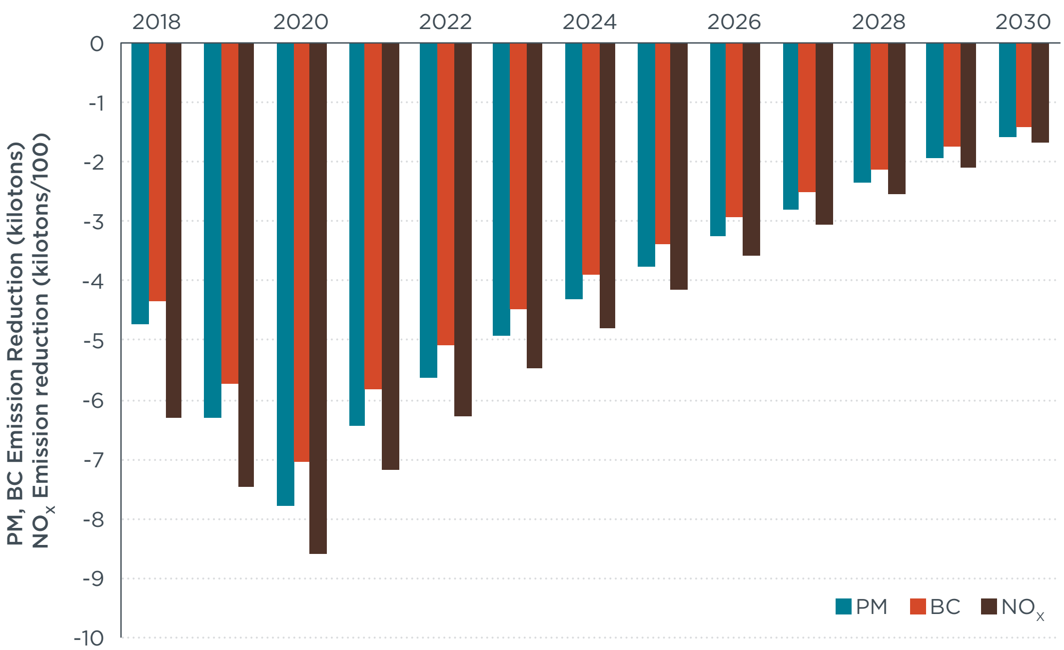


Figure 11. Emission impacts from early adoption of China 6/VI (World Class) versus Improved scenario, 2018–30

Note that a substantial gap in emissions persists for many years following the introduction of the standards. Table 8 quantifies the annual emission cuts achieved through a three-year acceleration in implementation—the World-Class scenario (China 6/VI in 2018) as compared with the Improved scenario (China 6/VI in 2021). These could represent nearly one-third again of the emission reductions from the Improved scenario, and the effects would last at least 15 years. The majority of the PM reduction comes from BC, which will help temper the warming climate trend. Since those fine and ultrafine PM emissions are the major drivers of pollution, the reductions from early adoption could lead to better air quality nationwide earlier.

Table 8. Annual emissions reductions for World-Class vs. Improved scenario

	PM reduction		BC reduction		NO_x reduction	
Year	**Metric tons**	**%**	**Metric tons**	**%**	**Metric tons**	**%**
2018	-4,742	- 12	-4,357	- 14	-629,347	- 19
2020	-7,782	- 21	-7,035	- 26	-858,278	- 28
2025	-3,748	- 18	-3,388	- 29	-414,639	- 26

Another way to consider the impact of a three-year gap is to look at the vehicle market. From 2018 to 2021, approximately 70 million motor vehicles will be sold in China; these vehicles will remain on the roads for a decade or more. A 2018 implementation date for China 6/VI (World-Class scenario) would ensure that the emissions performance of these tens of millions of vehicles is comparable to international best practices, yielding critical air quality improvements and emissions reductions over the following decade.

It would be advantageous for the nation as a whole if the three prominent regions—Jing-Jin-Ji, the Yangtze River delta, and the Pearl River delta—were to remain in the vanguard of environmental policymaking. The leading role of these three areas in pushing the rest of the country (as well as car- and truck-makers) to move toward more stringent standards has been beneficial. As revealed in Figure 7, almost half of the vehicle market in the next decade will come from these three economic powerhouses. Thus, the combined regional efforts to transition to China 6/VI as early as 2016, as in the World-Class scenario, would result in tremendous emission savings. An added benefit of the early adoption of China 6/VI in these three regions is that it would put additional pressure on the oil companies responsible for producing the requisite ultra-low-sulfur fuel to keep to the prescribed timeline.

A closer look at scrappage versus no-scrappage scenarios

The effectiveness of scrappage programs was examined by comparing scrappage and no-scrappage scenarios. Because the benefits of scrappage are smaller in magnitude than those of the fuel and technology advances discussed previously, in the figures that follow they are displayed separately from the other policy initiatives.

Scrappage programs are most effective when coordinated with tightened emission standards. Figure 12 and Figure 13 forecast clear impacts from the scrappage of YLVs. Both PM and NO_x emissions are likely to drop instantly if nationwide scrappage is instituted starting around 2016, with reductions of up to 25 and 15 percent, respectively, compared with a World-Class scenario in which scrappage is absent. The benefits can be realized only under the assumption that China 6/VI standards are adopted early in 2018 nationwide. Otherwise, the vehicles replacing older models would still emit excessively. In other words, to achieve full benefit from the world's most aggressive scrappage program, China needs to ensure that the most advanced vehicle emission standards will be in place on time.

However, it is also obvious from the charts that the benefits of scrappage dissipate over time. The trend lines of World-Class scenarios with and without scrappage converge around five years out from the proposed institution of a retirement-and-replacement program. This is a helpful reminder that scrappage is strictly a near-term emission control measure. More lasting strategies for air pollutant reduction lean heavily on the tighter vehicle emission and fuel quality standards discussed earlier.

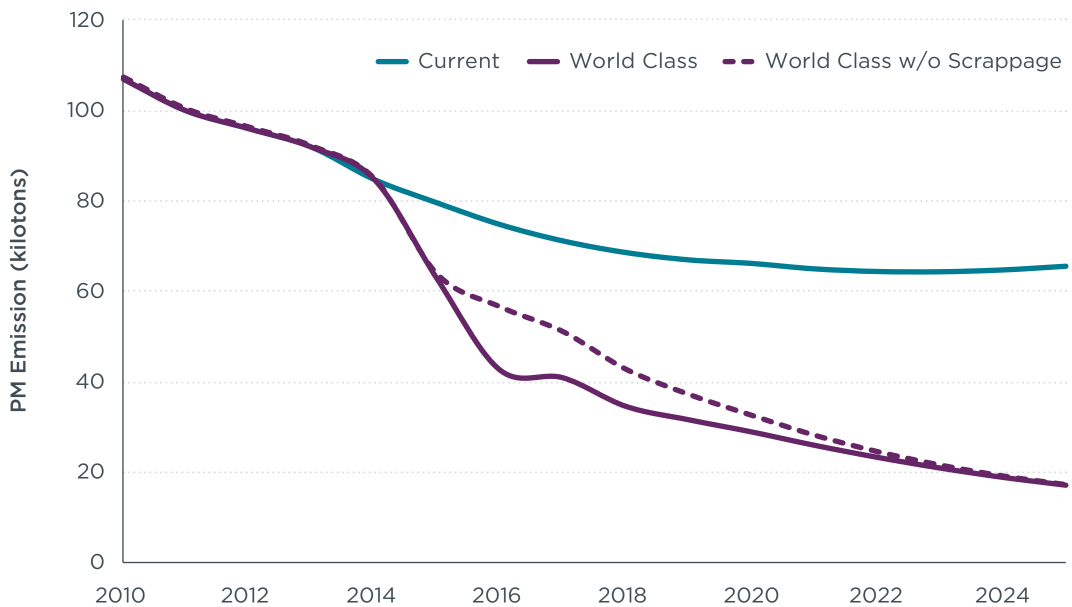


Figure 12. Scrappage impact on $PM_{2.5}$ under World-Class scenario, 2010–25

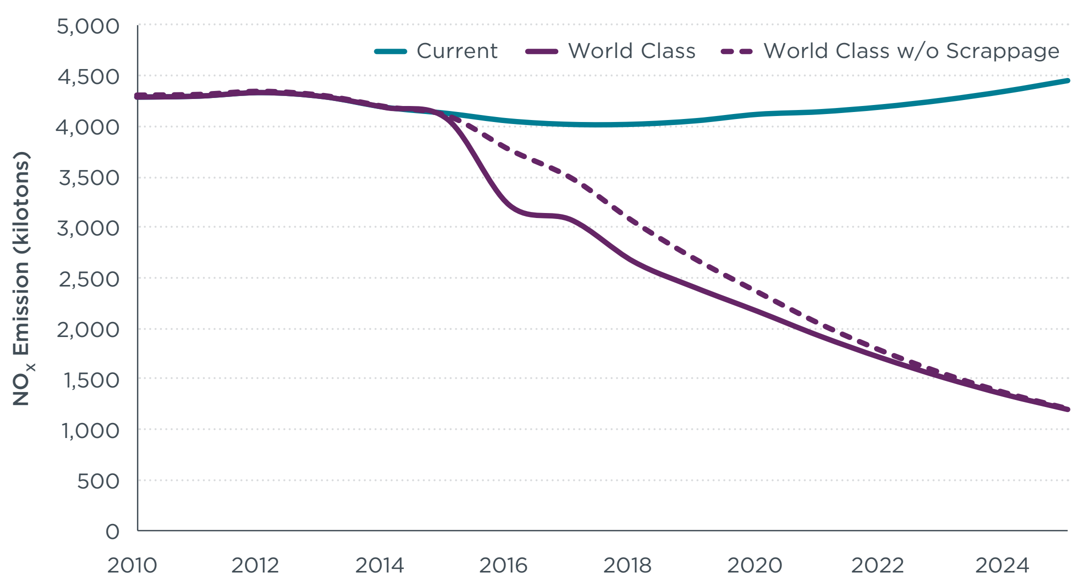


Figure 13. Scrappage impact on NO_x under World-Class scenario, 2010–25

A closer look at LDVs versus HDVs

Though LDVs dominate the fleet in China (Figure 6), HDVs (both buses and trucks) consistently contribute at least 85 percent of total on-road vehicle PM, BC, and NO_x emissions, and they will continue to do so if no more exacting regulations are introduced (Current scenario). With China 6/VI, the HDV share of total on-road NO_x emissions would fall below 77 percent, and the HDV share for PM and BC emissions would drop below 60 percent. Figure 14 illustrates how China 6/VI could slash BC emissions relative to the present situation. The size of the pie slices represents emission levels in 2010 and 2030. As discussed in Figure 9, although China 4/IV can reduce BC emissions over the next decade or so, China 6/VI is the only effective approach to achieve long-term reductions. Both the projected share of BC emissions contributed by HDVs and their absolute value can be largely prevented from rising with the successful implementation of China VI. The share of heavy-duty truck BC emissions would be cut from three-quarters to less than half.

Both the emission level and the share of LDV BC emissions increase in the Current scenario because of the explosive growth of the vehicle population. Only China 6 can maintain LDV BC emissions at a steady level even with the surging market. Owing to the scale of the chart, emission reductions for LDVs from putting China 6 into effect cannot be fully appreciated in viewing Figure 14.

All the benefits can be achieved only assuming that China VI can go into effect alongside the 10 ppm fuel sulfur requirement—by the end of 2017.

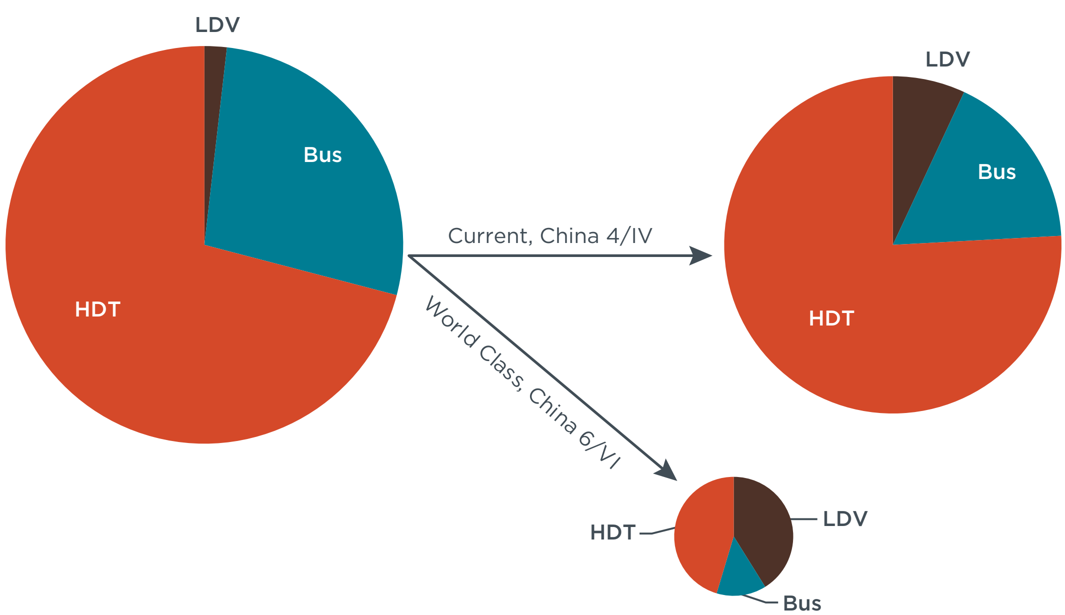


Figure 14. BC emission trends and share by mode, 2010–30

HEALTH IMPACTS

This analysis estimates premature mortality from lung cancer, cardiopulmonary disease, and acute respiratory infection as a consequence of breathing in primary $PM_{2.5}$ emissions in urban areas. Morbidities and impacts from emissions of other pollutants or secondary PM are not considered. Accordingly, the public health results presented here should be regarded as highly conservative calculations.

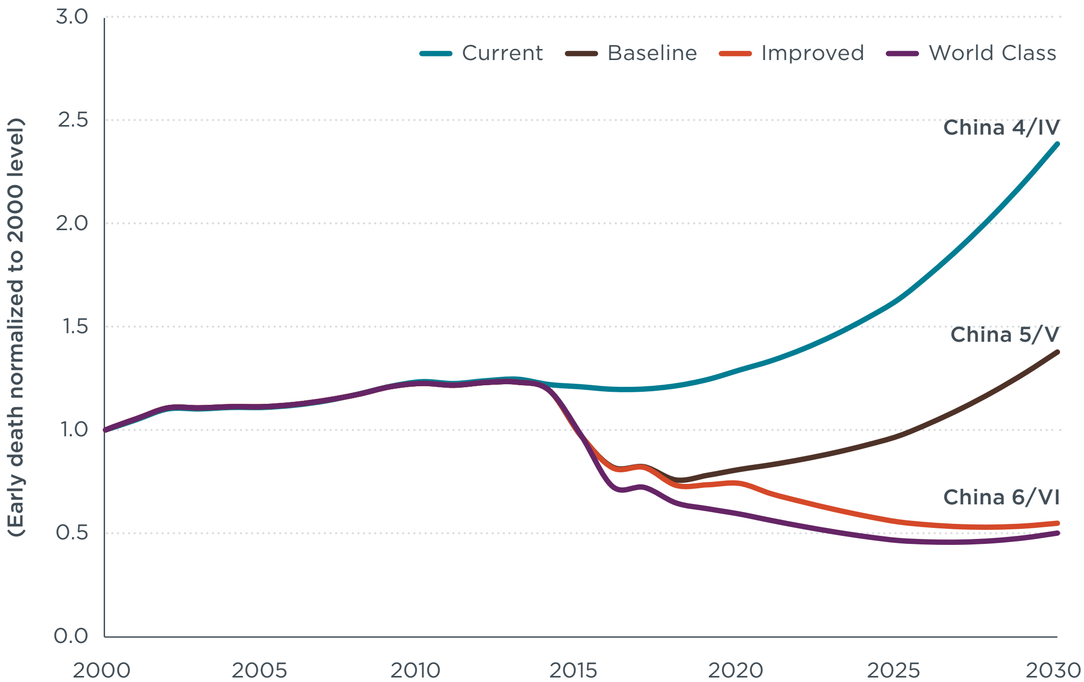


Figure 15. Annual premature mortality cases in China, 2000–2030

At present, primary $PM_{2.5}$ emissions from cars, trucks, and buses in China cause a gradual increase in the incidence of premature mortality every year. Figure 15 shows modeling results for the annual incidence of premature mortality from vehicular emissions in China, 2000–2030, under the four scenarios. The results are normalized to the 2000 level. Without further policy action (Current scenario), this number is projected almost to double by 2030. Much of this increase is driven by the expected urban population growth in China.

Under the Baseline scenario, annual premature mortalities decrease through 2018 but then begin to rise again as emission reductions disappear and the urban population continues to grow. In parallel with the results seen earlier in this report for emissions, only the Improved and World-Class policy scenarios result in large, long-term human health improvements, with the incidence of premature mortality declining by 55 and 60 percent, respectively, in 2030.

The critical importance of the early introduction of China 6/VI is highlighted by the 2020 premature mortality results. Table 9 shows the incidence of premature mortality in 2020 and 2030 for each scenario and the percentage reductions compared with 2010. With early adoption, a further 15 percent of premature deaths could be avoided. This estimate has to be viewed as conservative since only primary $PM_{2.5}$ emissions in urban areas are considered.

Table 9. Premature mortality in 2020 and 2030, by scenario

Scenario	Premature mortality reduction in 2020 vs. 2010	Premature mortality reduction in 2030 vs. 2010
Current	-5%	-93%
Baseline	34%	-12
Improved	39%	55%
World Class	52%	59%

CLIMATE IMPACTS

Vehicle emissions affect not only public health but also the environment in a variety of ways. Climate impacts of the introduction of advanced fuel quality and vehicle emission standards can be evaluated by examining the net warming or cooling caused by tailpipe emissions of CO_2 emissions and non-CO_2 climate pollutants, including black carbon and organic carbon. Climate benefits here include only the valuation of the reduction in emissions of non-CO_2 pollutants such as black carbon. This is because fuel efficiency improvements, which lead to CO_2 reductions, are not taken into account in the scenarios described above.

The climate benefits of moving to the World-Class scenario are illustrated in Figure 16, comparing with the Current scenario. Both global warming potential (GWP) and global temperature potential (GTP) values are applied here to estimate the standard greenhouse gas emissions inventory. The total CO_2-equivalent benefits can exceed 80 million metric tons in 2030 when using GWP-20 values (a twenty-year time horizon for global warming potential). The benefits are still better than 2 million metric tons in 2030 when using GTP-100 values (a hundred-year time frame). Most of the benefits come from lessened HDV emissions. Considering the significant variations that are generated by employing different GWP and GTP values, climate benefits according to GWP-100 are used in the central estimates.

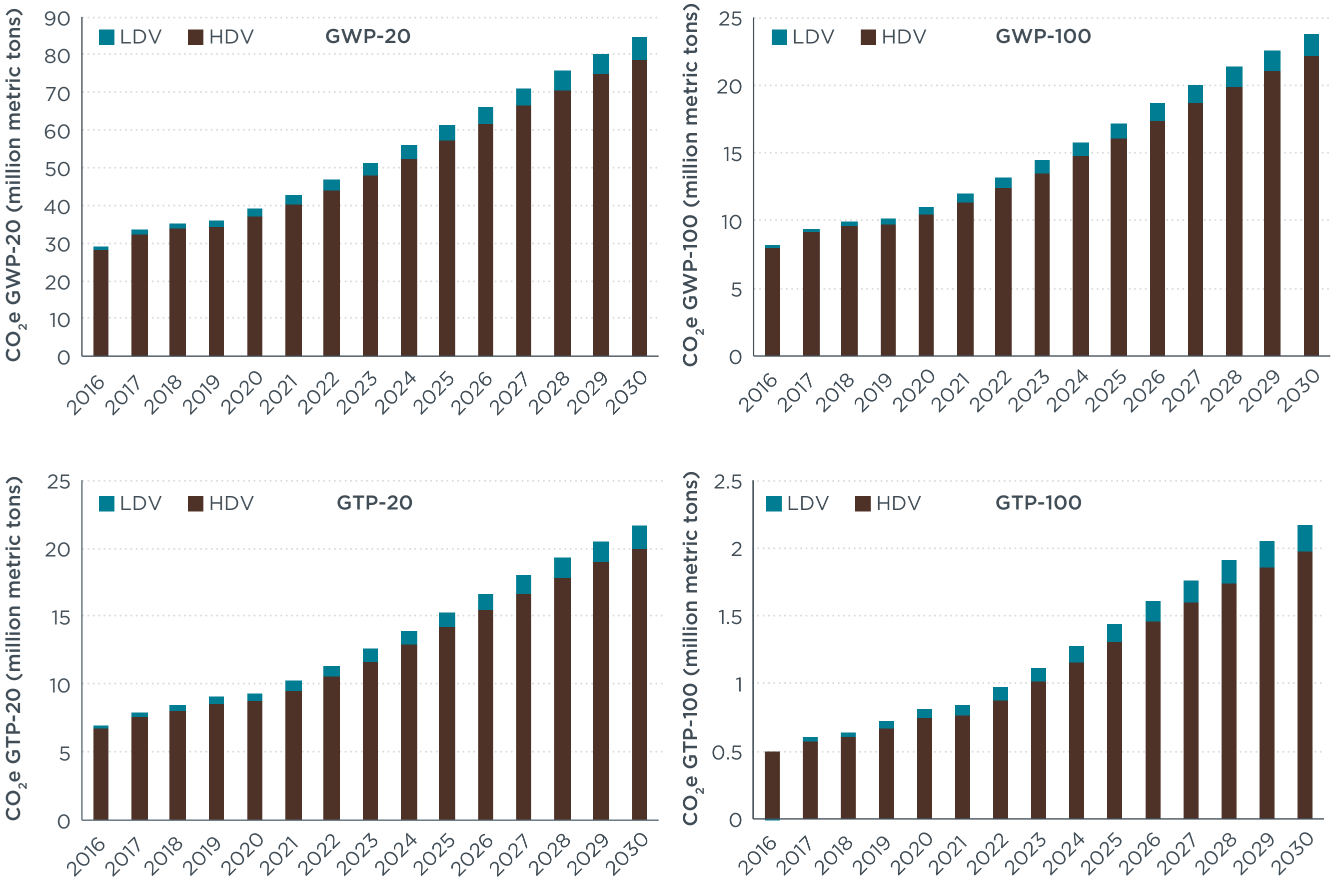


Figure 16. Climate benefits, World Class vs. Current scenario, 2016–30

The value of climate impacts is measured as the product of emissions of CO_2 equivalents in each year and the corresponding social cost of carbon, which is used to estimate the economic benefits of climate mitigation.[14]

COSTS

The costs of each scenario are estimated for both fuel production and advanced vehicle emission control technologies. Administrative costs involved in running various programs and implementing standards are not included in this study.

Fuel costs

The costs of upgrading China's refineries to produce ultra-low-sulfur fuels were estimated in a 2012 study commissioned by the ICCT and undertaken by Hart and MathPro (ICCT, 2012). The results of the study suggest that the increased costs to produce 10 ppm sulfur gasoline and diesel in China are just 0.04 and 0.11 RMB per liter, respectively, with a total investment requirement of 38 billion RMB. This is on a par with international experience elsewhere and equivalent to 0.5–1.5 percent of the pump price. The accounting includes both upfront refinery outlays (e.g., capital equipment upgrades) and increased operating costs.

14 The "social cost of carbon" is a useful term to measure the benefits from CO_2-equivalent reductions. According to the U.S. Environmental Protection Agency, the social cost of carbon is "a comprehensive estimate of climate change damages and includes, but is not limited to, changes in net agricultural productivity, human health, and property damages from increased flood risk." Further information can be found at http://www.epa.gov/climatechange/EPAactivities/economics/scc.html.

In October 2013, the National Development and Reform Commission (NDRC) approved a price increase of 0.33 RMB per liter for gasoline and 0.45 RMB for diesel to pay for desulfurization in order to reach the 10 ppm goal (ICCT, 2012). This amounts to a 5–6 percent increase in the current pump price. The price hike is sufficient to cover all the additional refinery costs.

Vehicular/engine costs

Beyond fuel costs, the ICCT has modeled the costs associated with the introduction of advanced vehicle control technologies required to meet the more stringent emission standards (Posada Sanchez, Bandivadekar, and German, 2012). Table 10 summarizes the presumed vehicle and engine costs. Those numbers are adjusted based on engine size and labor and other expenses that are specific to China. The incremental costs are summed to estimate the additional costs for manufacturers when they are compelled to make changes relating to more stringent standards.

The incremental costs borne in transitioning to Euro VI seem high, especially for heavy trucks and buses, but the benefits of Euro VI are more significant still. As shown in Figure 3, 99 percent of PM can be removed from tailpipe emissions, and this can help China achieve long-term emission reductions in spite of its burgeoning vehicle market. The analysis here also indicates that most of improvements come from heavy-duty vehicles (Figure 14). For passenger cars, the cost increase inherent in upgrading to Euro 6 from Euro 4 is nominal.

Table 10. Cumulative additional vehicle emission control technology cost over uncontrolled level

	Large Buses	Private Cars	Light Trucks	Heavy Trucks
Fuel	**Diesel**	**Gasoline**	**Diesel**	**Diesel**
Euro 1/I*	$158	$142	$150	$174
Euro 2/II*	$210	$204	$200	$232
Euro 3/III*	$683	$326	$650	$752
Euro 4/IV*	$2,727	$351	$2,414	$4,991
Euro 5/V*	$2,958	$361	$2,632	$5,394
Euro 6/VI*	$4,700	$361	$4,190	$9,075

*Costs are summarized as European standards equivalent.

COMBINED ANALYSIS: BENEFIT-COST RATIOS

Reducing vehicle pollutant emissions yields corresponding improvements in ambient air quality, which has broad positive effects on the environment and public health. The health and climate benefits stemming from the introduction of advanced vehicle emission and fuel quality standards are quantified in terms of the economic value of lessened health burdens and climate damages. Estimated social benefits are attributable to reductions in premature mortality from improved urban air quality and the tempering of global climate change (net warming caused by tailpipe emissions of non-CO_2 climate pollutants, estimated under the assumption of a 100-year time horizon for global warming potential). The economic benefits of reductions in premature mortality are calculated based on a value of statistical life (VSL) approach.[15] The economic benefits from climate mitigation are calculated based on the social cost of carbon. Climate benefits here include only valuation of the reduction in emissions of short-lived climate pollutants such as black carbon, organic carbon, and methane and do not take into account CO_2 reductions from fuel efficiency gains. A 5 percent annual discount rate is assumed.[16]

Combining these quantified benefits with the cost constraints described in the previous section, the study can now calculate long-term benefit-cost ratios for stringent vehicle standards as well as fuel quality standards. It will specifically examine the cost-effectiveness in 2040 of the early introduction of the China 6/VI standards.

Cost-benefit analysis is an important framework for evaluating any public policy. Costs are what the government must spend to implement a new regulation and what society pays to comply. Benefits include potential economic, environmental, public health, safety, or other advantages of a new regulation.

Most studies around the world that weigh the costs of controlling vehicle emissions and lowering fuel sulfur levels against the value of improved public health and climate benefits have found that the benefits far surpass the costs of the relevant regulation. This implies that motor vehicle emission control is an extremely cost-effective strategy to reduce air pollution, improve public health, and avert climate change damages.

Table 11 summarizes some international precedents in benefit-cost analysis of motor vehicle emission control:

Table 11. International precedents in benefit-cost analysis of motor vehicle emission control

Region	Policy	Costs	Benefits	Ratio (Benefits: Costs)	Source
USA	Tier 2 motor vehicle emission standards	$5.3 billion	$25.2 billion	5:1	U.S. EPA, 1999
USA	Tier 3 motor vehicle emission standards	$1.5 billion	$6.7–$19 billion	4:1 to 13:1	U.S. EPA, 2014b
India	Ultra-low-sulfur fuel supply and World-Class emission standards	$14.2 billion	$107 billion	8:1	Bansal and Bandivadekar, 2013

The adoption of China 6/VI yields tremendous benefits over the long term. Figure 17 shows the discounted benefits and costs arising over time from actualizing the World-Class scenario. The benefits keep increasing once the tighter standards are adopted. Most of the benefits come from productivity gains and medical care savings through curtailing the incidence of premature mortality as a result of $PM_{2.5}$ reduction in urban areas. The climate benefits amount to approximately 9 billion RMB (1.5 billion U.S. dollar) (discounted) annually. The costs tend to decrease over the time as well because of the discount rate applied. The net benefits become positive in less than 10 years and grow

15 The value of statistical life (VSL) is an economic concept. It is used to estimate "how much people are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused by environmental pollution" (U.S. EPA, 2014a). It is used mostly in scientific research and the related literature. Most important, it is a generalized figure, not a value assigned to preventing death for any particular person. This study adopts the suggested VSL value from the EPA, with an adjustment for China based on gross national income.

16 The discount rate represents the present value of an anticipated future benefit.

significantly after that point. The annual benefits and costs over the period 2015–45[17] are shown in Figure 17. The benefits far exceed the costs, outweighing them by more than 5.5 to 1 in 2045, reaching as much as 7 to 1 in 2050.[18] Owing to the limitations of the methodology used to figure health impacts, the benefits estimate should be considered conservative. This explains why the benefits value seems small when compared with the other studies on the same subject.

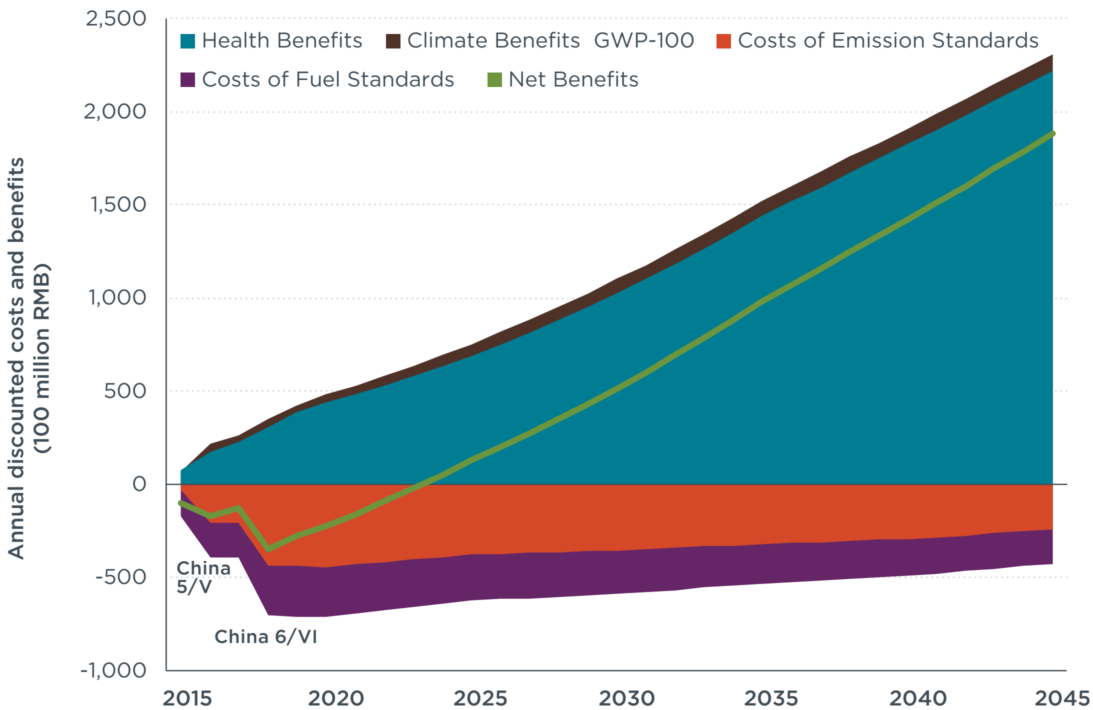


Figure 17. Annual discounted costs and benefits, 2015–45

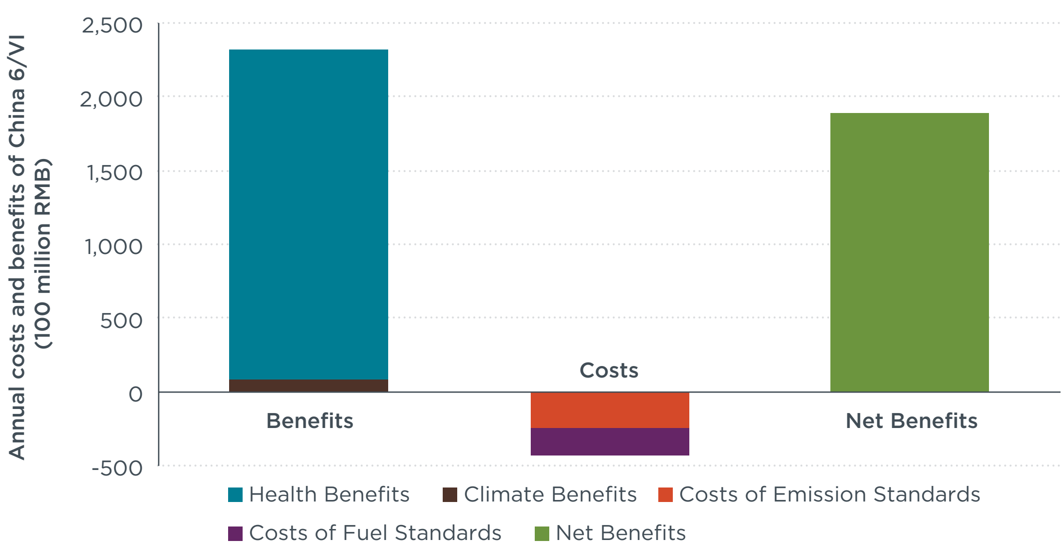


Figure 18. Annual costs and benefits of China 6/V in 2045

17 The time frame for estimating costs and benefits is 27 years, assuming an implementation year of 2018. This accounts for up-front investments in capital infrastructure and full turnover of the vehicle fleet.

18 The cumulative ratio of benefits and costs is around 2.5 to 1 in 2045.

CONCLUSIONS AND RECOMMENDATIONS

Adopting the China 6/VI vehicle tailpipe emission standards across the country in tandem with the nationwide rollout of 10 ppm sulfur fuel is a cost-effective approach to reducing the air pollution problem in China. By combining these stringent new vehicle and fuel quality standards with an ambitious scrappage program—which can play a powerful near-term role in reducing on-road emissions, the country will avoid further atmospheric deterioration. Improving air quality benefits public health by reducing the risks of cardiopulmonary disease, stroke, cancer, and other illnesses and conditions. Because the overall cost of these health issues—valued in terms of premature mortality, medical treatment expenses, lost productivity, and more—is significant, improving air quality delivers enormous economic benefits to society above and beyond the gains for public well-being. Early implementation of China 6/VI can guarantee that cost-effective benefits are rapidly achieved. The following are a few recommendations drawn from the analysis.

Recommendation 1: Prioritize implementation of the scheduled ultra-low-sulfur fuel timelines for the entire nation and for regions of particular importance.
Ultra-low-sulfur fuel availability is a prerequisite for further steps toward World-Class vehicle emission standards. Achieving the objective of 10 ppm sulfur fuel nationwide by the end of 2017, a milestone for China, would eliminate any potential delay in imposing China 6/VI arising from a mismatch between fuel and vehicle/engine emission standards. Moreover, the existing fleet would also contribute to lower PM emissions through the use of low-sulfur fuel. Thus, it is important to make sure that the timeline is actually met.

Recommendation 2: Groundbreaking regional action is important but not sufficient; implement nationwide standards as early as possible.
The nationwide vehicle emission standards timetable should be accelerated. Local jurisdictions, led by the city of Beijing, have already implemented China 5/V and are considering the adoption of China 6/VI standards. Regional leadership in espousing the latest vehicle technologies available, by helping to bring the rest of the country along in its wake, is important in controlling vehicle emissions in China, as detailed in Appendix C. However, this is far from enough to solve the problem. The national government needs to take the reins, promoting and enforcing the most advanced vehicle and engine standards, together with the universal introduction of ultra-low-sulfur fuel, in order to maximize progress. The analysis in this paper shows the tremendous benefits for both the environment and public health that can be secured by adopting China 6/VI earlier (the World-Class scenario) rather than later.

Recommendation 3: Aggressive scrappage is essential for immediate emission reductions, but the impacts are short term only.
Early retirement of high-emitting yellow-label vehicles is effective in bringing down emissions quickly. The current YLV scrappage program guarantees that older and more polluting vehicles are taken out of the fleet expeditiously. However, the results clearly indicate that scrappage only delivers emission reductions for a short period, until the program runs its course. Moreover, without standards for cleaner vehicles in force, the benefits from scrappage would be limited, as the vehicles replacing the high emitters would still be still equipped with suboptimal technologies. In order to maximize the benefits from the world's biggest scrappage program, China should take this opportunity to push for the tightest vehicle standards nationwide.

Recommendation 4: China 6/VI is the only choice for controlling long-term emissions growth.

For long-term emission reduction, the most stringent standards—in other words, China 6/VI—are essential for China, given the country's rapid vehicle market growth and relentless urbanization. The introduction of China 6/VI would greatly ameliorate air quality overall, and particularly in congested regions. Public health would be dramatically improved since the rate of people dying early and the risk of illnesses related to breathing polluted air would be brought down. Those effects would be felt soon after the introduction of China 6/VI. Furthermore, the implementation of China 6/VI standards promises to be highly cost-effective, with the benefits estimated to outweigh the costs by greater than a 5.5–to-1 ratio in 2045 under the World-Class scenario (China 6/VI implemented nationwide in 2018).

Recommendation 5: Early adoption is recommended since benefits are greater the sooner action is taken.

The ICCT strongly recommends implementing the China 6/VI standards as early as possible. Results from the analysis demonstrate convincingly that only China 6/VI can spare the country from a future of long-term emissions growth and the consequential environmental and public health hazards. Benefits from enacting the most forward-looking policies would start to appear immediately upon adoption, and the payback period for recouping the costs of implementation would be short as well. Adopting China 6/VI starting in 2018 would take full advantage of the introduction of ultra-low-sulfur fuel, which will be ready nationwide by the end of 2017. The results here demonstrate a three-year acceleration of the anticipated adoption schedule (2018 versus 2021) would yield impressive additional gains for both environmental and public health that would endure for at least 15 years.

The recently announced timeline for 10 ppm sulfur fuel nationwide could even accelerate the implementation of China 6/VI beyond the World-Class scenario. According to China's State Council, China V 10 ppm gasoline and diesel fuel are expected to be phased in as early as January 1, 2017 (State Council, 2015). This is one year earlier than the original timeline (December 31, 2017), which opens a window of opportunity for moving to China 6/VI in tandem with the revised fuel schedule. The near- and long-term benefits with respect to air pollution, climate, and public health will be greater the sooner China 6/VI is implemented, exceeding projected estimates under the World-Class scenario.

APPENDIX A: MODELS AND METHODOLOGY

The air pollutants surveyed in this analysis, including fine particulate matter ($PM_{2.5}$), nitrogen oxides (NO_x), and black carbon (BC), were calculated using ICCT's China model. This is a customized version of the ICCT Global Transportation Roadmap model (ICCT, 2014a). It uses socioeconomic forecasts in which population, gross domestic product (GDP), and fuel prices are central to estimating future transportation activity and mode shares. (Façanha, Blumberg, and Miller, 2012). By relying on exogenous input parameters related to vehicle technology, efficiency, new vehicle emission standards, and fuels, the model projects corresponding well-to-wheel (WTW) emissions out to 2050. WTW emissions encompass the fuel life cycle, comprising the refining, processing, distribution, and combustion of fuels. The China model does not assess life cycle emissions from vehicle manufacturing, distribution, or end-of-life processes (i.e., disposal or recycling), nor does it examine the transportation infrastructure life cycle.

This analysis reports tank-to-wheel emissions of $PM_{2.5}$, NO_x, and BC from the model, wherein selected greenhouse gases—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) —and local air pollutants—NO_X (consisting of nitric oxide [NO] and nitrogen dioxide [NO_2]), $PM_{2.5}$, nonmethane hydrocarbons (HC), carbon monoxide (CO), BC, and sulfur dioxide (SO_2)—were taken into consideration. Emission factors were derived from COPERT, an emissions model developed for official road transport emissions inventory preparation in European Environment Agency member countries and widely adopted by research and academic institutions (EMISIA S.A., 2014). $PM_{2.5}$ emission factors were further adjusted to account for the effect of diesel sulfur content using a mass-balance (conservation of mass) approach, assuming a 2 percent conversion of fuel sulfur to sulfates. The calculation of vehicle emissions for this analysis did not include evaporative emissions, cold-start emissions, or brake-, tire-, and road-wear emissions.

In this analysis, light-duty vehicles (LDVs), buses, and heavy-duty trucks (HDTs, subdivided into light-, medium- and heavy-HDTs) were considered for on-road transportation emissions, as well as related health effects. The structure of the model offers flexibility in terms of expanding the modes that can be simulated, including two-wheelers (motorcycles and the like), three-wheelers, low-speed trucks, passenger and freight rail, marine transport, and aviation.

Health impacts—the incidence of premature mortality and total years of life lost as a result—were estimated from exposure to primary $PM_{2.5}$ emissions from on-road vehicles in urban areas. Regional $PM_{2.5}$ emissions were allocated to urban areas based on population and road density. Urban emissions were then translated to urban $PM_{2.5}$ concentrations using a set of precalculated, region-specific intake fractions that account for local meteorological conditions, population density, and city size (Apte et al., 2012). Concentration values in turn are fed into a set of concentration-response functions from the published literature that estimate the number of early deaths and years of life lost caused by transportation pollution (Krewski et al., 2009; Cohen et al., 2004). Detailed methodology can be found in a previous ICCT study (Chambliss et al., 2013).

The study's calculations of cases of premature mortality averted and overall public health benefits would be substantially boosted if exposure to secondary pollutants formed in the atmosphere (including larger particulate matter and ozone) were taken under consideration. Thus, the results should be viewed as highly conservative estimates that do not reflect the full contribution from future clean-fuel and vehicle standards.

The health impacts were further quantified in terms of the economic value of reduced health burdens. Value of a statistical life (VSL) is a concept used to ascertain the extent of people's willingness to pay or sacrifice in order to lower the risk of dying. The value covers a wide range of considerations including economics, health care, environmental impact assessment, and globalization. In this analysis, estimates from U.S. Environmental Protection Agency (EPA) were used and were customized to China's level of development by using gross national income purchasing power parity (U.S. EPA, 2014a).

The implications for the global climate of the introduction of advanced vehicle emission and fuel quality standards were evaluated for the study by examining the net warming (or cooling) caused by tailpipe emissions of non-CO_2 climate pollutants, notably, black carbon, organic carbon, and methane. The central estimate of climate impacts was estimated applying a 100-year time horizon for global warming potential (shown in Table 12). Additional sensitivity analysis was performed using a 20-year time horizon as well as the alternative global temperature potential. The economic rewards of climate mitigation were calculated based on the social cost of carbon, which is a useful concept for measuring the benefits stemming from CO_2-equivalent reductions in greenhouse gases (U.S. EPA, 2013).[19]

Table 12. Emissions included in climate impacts calculation and GWP values to estimate CO_2 equivalence

	GWP20	GWP100
Black Carbon	3,200	900
Organic Carbon	-154	-42
Methane	72	25
Carbon Dioxide	1	1

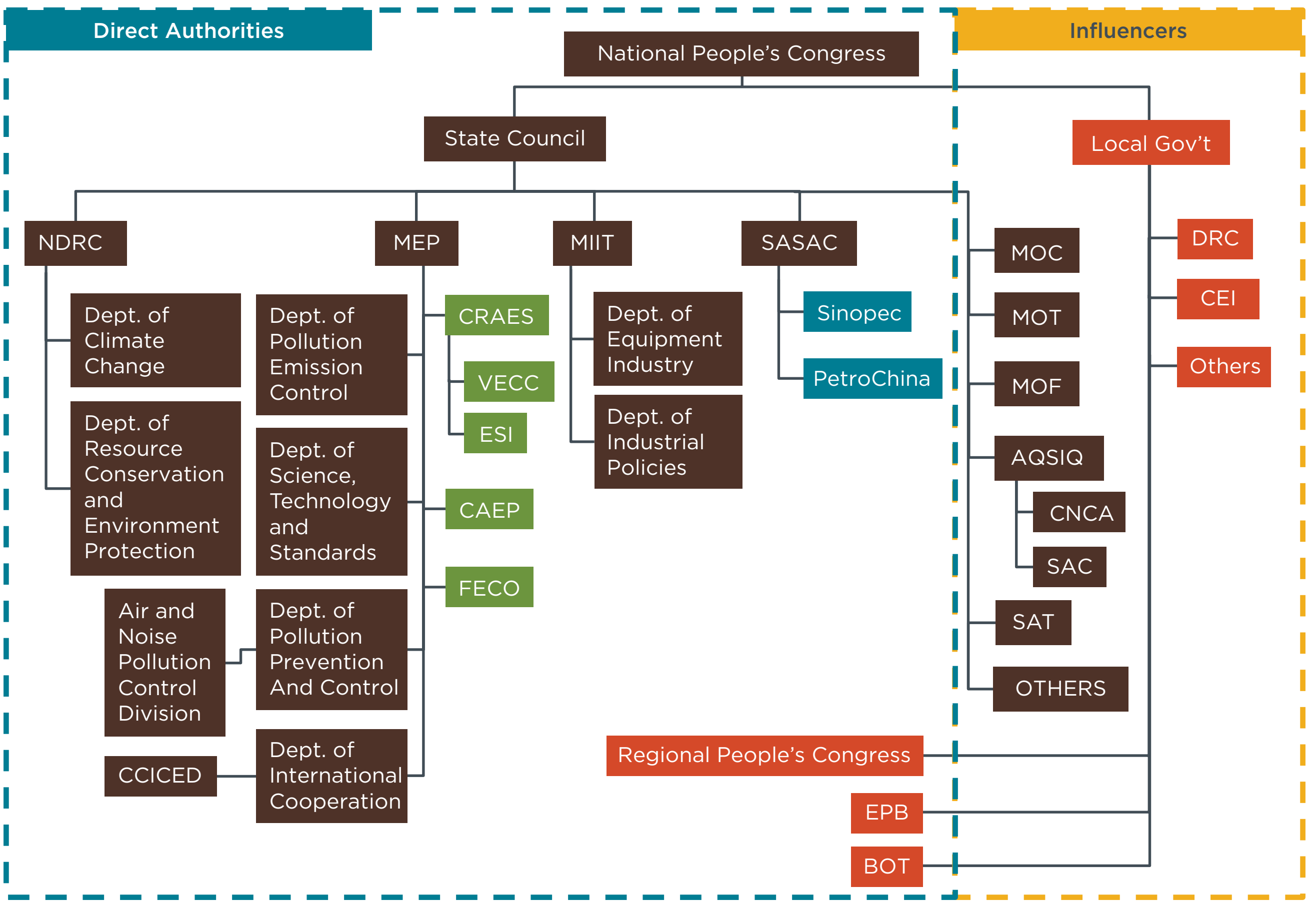
Sources: Black carbon global warming potential from Bond et al., 2013; organic carbon GWP from Bond et al., 2011; and methane GWP from Forster et al., 2007.

The economic value of the gains from improved public health and a more stable climate was then compared with the additional costs needed to put into place advanced vehicle emission and fuel quality standards, and the long-term trend of the benefit-cost ratio for various policy strategies was plotted. The relationship between the discounted benefits and costs was used to examine the strengths and weakness of the proposed standards.

19 Climate benefits here include only the valuation of the reduction in emissions of short-lived climate pollutants such as black carbon, and do not include CO_2 reductions from fuel efficiency gains.

APPENDIX B: OVERVIEW OF REGULATORY AUTHORITIES IN CHINA

The authority to develop, implement, and enforce motor vehicle emission control programs in China is spread among multiple governmental bodies at the national and local levels. A brief overview of the primary players and their roles is presented here.



National department or agency | Government-affiliated organization | State-owned enterprise | Provincial and municipal agencies

AQSIQ	General Administration of Quality, Supervision, Inspection and Quarantine
BOT	Bureau of Transportation
CAEP	Chinese Academy for Environmental Planning
CCICED	China Council for International Cooperation on Environment and Development
CNCA	Certification and Accreditation Administration of China
CEI	(Municipal) Commission of Economy and Information Technology
CRAES	Chinese Research Academy of Environmental Sciences
DRC	(Municipal) Development and Reform Commission
EPB	(Municipal) Environment Protection Bureau
ESI	Environmental Standards Institute of MEP
FECO	Foreign Economic Cooperation Office of MEP
MEP	Ministry of Environmental Protection
MIIT	Ministry of Industry and Information Technology
MOC	Ministry of Commerce
MOF	Ministry of Finance
MOT	Ministry of Transportation
NDRC	National Development and Reform Commission
SASAC	State-Owned Assets Supervision and Administration Commission
SAC	Standardization Administration of China
SAT	State Administration of Taxation
VECC	Vehicle Emission Control Center of MEP

Figure 19. Organization chart of the regulatory authorities and other institutions concerned with emission control programs in China

State Council

The State Council is China's highest executive body and most powerful government institution. It issues macro-level planning documents such as the five-year plans, coordinates among ministries in cases of institutional disagreements or unclear lines of authority, and occasionally releases issue-specific directives in response to major events such as air pollution crises. The State Council must issue approvals for local environmental policy actions that go beyond existing national standards.

National Development and Reform Commission (NDRC)

One of the most powerful ministry-level bodies in China, the NDRC is in charge of macroeconomic planning, and holds some important specific responsibilities such as setting of fuel prices. It actively guides policies that involve multiple ministries and regularly comments on other ministries' regulatory proposals. In addition, China's climate change mitigation efforts, extending to international negotiations, are managed by the NDRC. The NDRC originally was charged with establishing fuel consumption standards, until that authority was given to MIIT (see below) in 2008.

Ministry of Environmental Protection (MEP)

MEP has the power to set and enforce environmental standards, including ambient air quality and vehicle tailpipe emission standards. MEP issues all environmental standards jointly with the Standardization Administration of China (SAC). Within MEP, much of the day-to-day policy development and implementation is conducted by supporting research institutions, especially the Vehicle Emission Control Center (VECC-MEP) and the Environmental Standards Institute (ESI-MEP). MEP also outsources some vehicle-related policy development to an independent research institution, the China Automotive Technology and Research Center (CATARC). MEP is not currently authorized to set fuel quality standards, even as related to environmental performance; this is a key cause of tailpipe emission/fuel quality standard mismatches in China and the resulting delays in emission standard implementation.

Ministry of Industry and Information Technology (MIIT)

MIIT, established in 2008, oversees industrial policy and the development of Chinese domestic industries. With regard to vehicle environmental performance, MIIT is responsible for establishing and enforcing fuel consumption standards for light- and heavy-duty vehicles. Like MEP, MIIT commonly outsources the technical development of such standards, usually to CATARC.

General Administration of Quality, Supervision, Inspection and Quarantine (AQSIQ)

AQSIQ oversees the Standardization Administration of China (SAC), which issues all standards in China, including fuel quality standards. Environmental standards such as vehicle emission standards are unique in that they are the only ones jointly issued by SAC and another institution, MEP. SAC convenes and oversees technical committees to draft standards as necessary. The committee responsible for drafting fuel quality standards is called TC280.

Sinopec and PetroChina

Sinopec and PetroChina are China's largest state-owned oil companies. They are institutionally managed by the State-owned Assets Supervision and Administration Commission but in practice have powers equivalent to those of other ministry-level bodies. Representatives from Sinopec and PetroChina compose most of SAC's fuel quality standards-drafting technical committee, TC280.

Provincial and municipal Environmental Protection Bureaus

Local Environmental Protection Bureaus may apply to the State Council for permission to implement tailpipe emission standards more stringent than the current national standards. In most cases, the more exacting standard must already have been agreed upon at the national level before local governments can consider implementing it. As for fuel quality, local EPBs may negotiate directly with oil refineries to secure supplies of higher-quality fuel, although the NDRC must approve any price changes. Local EPBs are also charged with designing and implementing in-use motor vehicle emission control programs, such as remote sensing and scrappage.

APPENDIX C: SUBNATIONAL (CRITICAL REGIONS) EMISSIONS

The following graphs highlight 2000–2030 emission projections in some of the most important subnational regions modeled.

Beijing

As the capital of China, Beijing has a leading role in vehicle emission control. The city has already adopted 10 ppm fuel in 2012 and the China 5/V tailpipe emission standards[20] starting from early 2013. The results depicted in the charts below are tribute to the municipal government's significant achievements in recent decades. Faced with the headwind of a rapidly expanding vehicle market, Beijing still has managed consistently to lower emissions of all types, along with premature mortality. Compared with the nation as a whole, the reductions in Beijing have been more impressive. Emissions would rise slightly if Beijing were to stop at today's policies (the Current scenario). The incidence of early deaths would increase sharply because of rapid urbanization. However, this is not going to happen since Beijing has been a leader in pushing to have the next phase of emission standards in place as early as 2016. Figure 20 illustrates the marked drop in all major emissions species as well as in the incidence of premature mortality thanks to the effectiveness of tighter standards. Again, the health benefits considered in this analysis would look substantially greater if secondary emissions were considered.

Figure 20. Emissions and health impact trends in Beijing, 2000–2030

20 Beijing 5/V was proposed by the Beijing EPB in 2014 and went into effect on February 1, 2013. In September 2013, the Ministry of Environmental Protection released the national counterpart standards, which automatically superseded Beijing's.

Beijing's efforts have successfully stemmed emissions growth, delivering significant environmental and health benefits, and, more important, set a great example for rest of the county. Even though other cities lack the unique concentration of resources and power that inhere in the capital, they can still replicate some of its actions, such as early adoption of national standards for both tailpipe emissions and fuel quality.

Shanghai, Guangzhou, and Shenzhen

Shanghai, Guangzhou, and Shenzhen have followed Beijing closely in controlling vehicle emissions and fuel sulfur levels. China 5/V and 10 ppm fuel are fully in place in Shanghai as of mid-2014 (the Current scenario) and will phase in in Guangzhou and Shenzhen in 2015 (the Baseline scenario). These three cities have undergone population explosions similar to Beijing's, with the corresponding growth in the vehicle fleet. Thus, the patterns shown in Figure 21 echo those of Beijing (Figure 20), even if the curves are less steep. Both emissions and premature mortality cases have been tempered for the past several years but will soon start to increase again under both the Current and Baseline scenarios, especially for nitrogen oxide (NO_x) emissions and premature deaths. This reinforces the conclusion that neither China 4/IV or China 5/V can effectively diminish emissions in the long term; only China 6/VI (the Improved and World-Class scenarios) can prevent emissions and instances of early death from rising again.

Shanghai, Guangzhou and Shenzhen ought to be strongly encouraged to commit to the same China 6/VI timeline as Beijing. By adopting China 6/VI in 2016 (the World-Class scenario), hundreds of kilotons of emissions and thousand of early deaths could be avoided in those cities, and the benefits would certainly last beyond 2030. Cumulative emission reductions could reach as much as 4.9 metric kilotons for fine particulate matter (PM), 2.8 kilotons for black carbon (BC), and 308 kilotons for NO_x between 2016 and 2030. Further, the most forward-looking policies could prevent at least 3,659 early deaths in total for those three cities over the same period. Since this estimate of health impacts must considered conservative—after all, only the effects of primary PM in urban areas are taken into account—the actual number of early deaths avoided will likely be much larger.

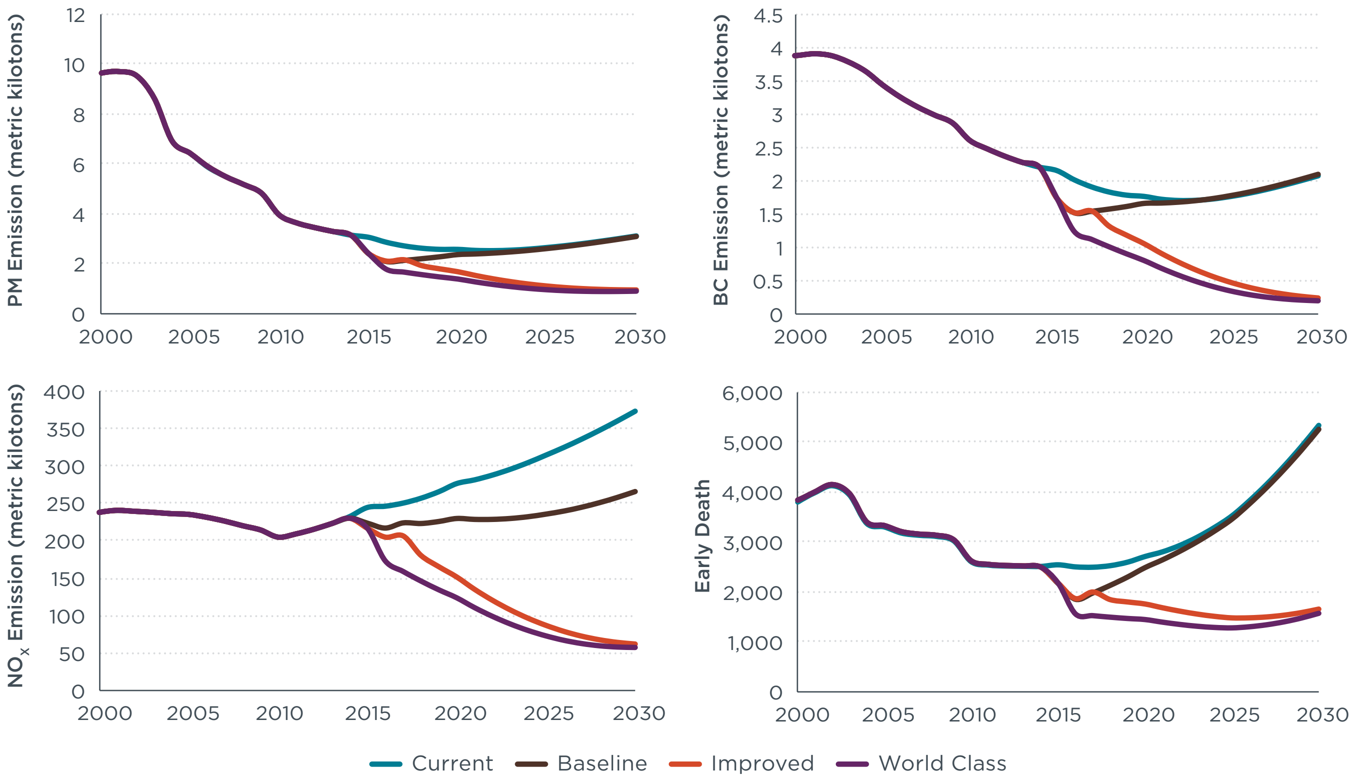


Figure 21. Emissions and health impact trends in Shanghai, Guangzhou, and Shenzhen, 2000–2030

Shanghai, Guangzhou, and Shenzhen should join Beijing in spearheading emission control for the three major conurbations of which they are a part—the "Jing-Jin-Ji," the Yangtze River delta, and the Pearl River delta. There are a fair number of vehicles in these four cities that are registered or refueled in neighboring cities, where both vehicle and fuel standards still follow the slower national schedule. Emissions from those vehicles are typically higher. Moreover, vehicles registered in these four cities but refueled elsewhere emit higher amounts because of the looser fuel quality controls. Critically, substandard fuel quality raises the risk of damaging the after-treatment systems installed, which would lead to a significant rise in emissions. Some efforts have been made to limit vehicle travel between cites in a metropolitan cluster,[21] but this is not recommended as a way to lower regional emissions. Surrounding cities in areas of concern have shown strong interest in speeding up their progression through the stages of vehicle emission control, but so far their efforts have been hampered by a lack of resources. Beijing, Shanghai, Guangzhou, and Shenzhen can advance the goal of regional emission control by providing essential technical and other resource support to neighboring jurisdictions.

Three prominent regions (excluding Beijing, Shanghai, Guangzhou, and Shenzhen)

The Jing-Jin-Ji, Yangtze River delta, and Pearl River delta regions are the three premier economic centers in China, but they also suffer the worst air quality. The State Council's Action Plan on Prevention and Control of Air Pollution emphasizes the

21 Beijing has instituted a temporary entry pass system for vehicles coming from other jurisdictions, as well as labeling requirements on vehicles entering the center of the city. Detailed information can be found in Yang, Wang, and Shao (2015).

urgency of establishing concrete environmental targets, including reducing emissions from transportation. Even though progress in these areas (outside the central cities themselves) still mostly follows an agenda/schedule set nationally, there is great potential for them to jump ahead by following the lead of the four cities at their core. As mentioned earlier, these three regions will claim almost half of the vehicle market in China over the next decade. Thus, by moving to the most advanced standards on emission control, the regions can speed up reductions in vehicle emissions nationwide.

Emission trends in these three regions largely match those of the nation as a whole (Figure 8, Figure 9, and Figure 10) for the Current and Baseline scenarios. Neither China 4/IV (the Current scenario for these areas) nor China 5/V (Baseline) is bound to prevent emission growth from resuming over the long term. China 6/VI (the Improved and World-Class scenarios) could effectively curtail emissions even figuring in the rapid expansion of the vehicle market. As a result, many instances of premature mortality could be avoided.

More important, early adoption by these three regions would lead to swifter and still more sweeping improvements in emission reduction. For these areas, the World-Class scenario envisions phasing in China 6/VI by 2016 (in doing so, keeping up with Beijing), which is two years earlier than national timeline in that scenario. The early adoption of China 6/VI in 2016 would yield significant additional benefits when compared with adoption in 2018 (in accordance with the Improved scenario), as shown in Figure 22, not to mention the potential savings when compared with the pace of national implementation (China 6/VI in 2021, in the same scenario).

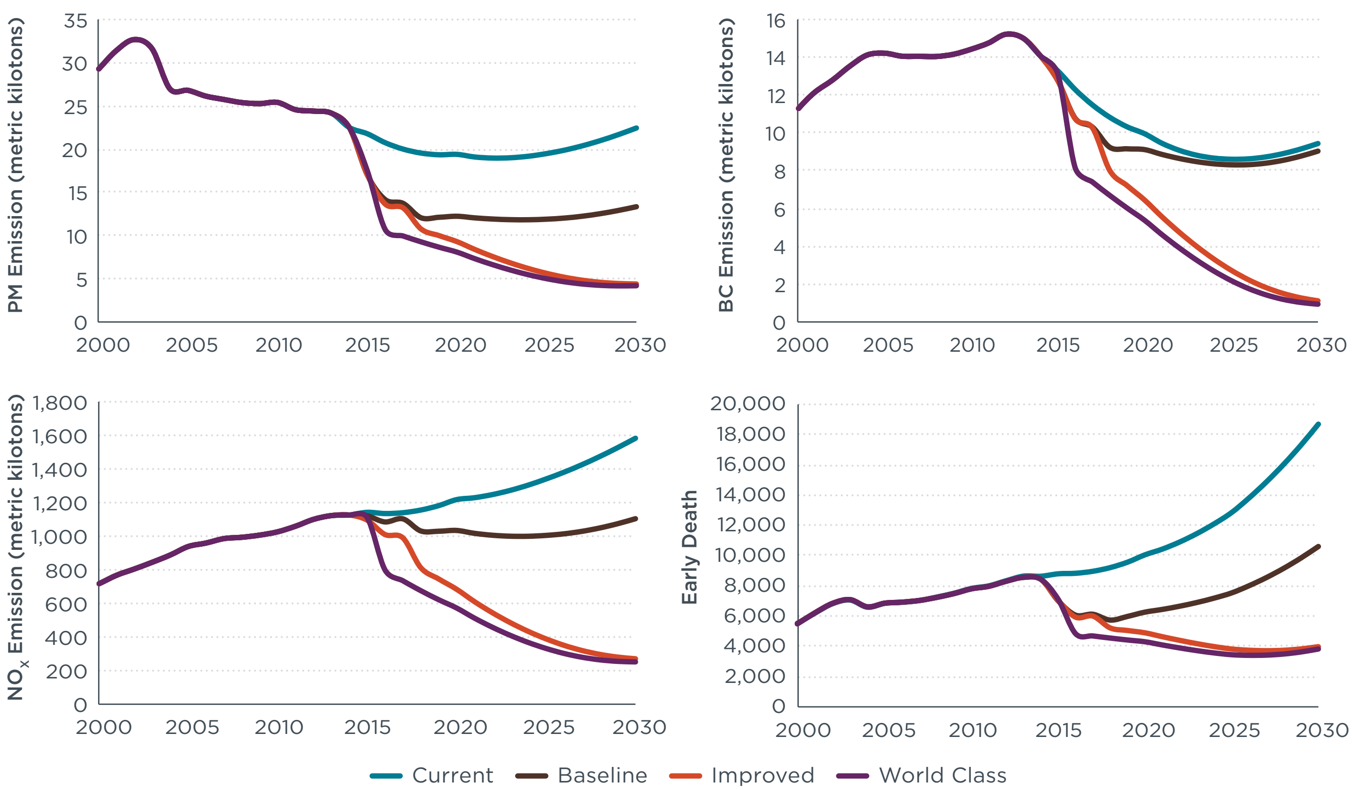


Figure 22. Emissions and health impact trends in three critical regions, 2000—2030

The ICCT's recommendation that the three regions surrounding China's leading cities—containing the bulk of the country's high-density zones, whether the urban population is still proliferating—adopt the most demanding emission standards at the same pace as the city of Beijing clearly would maximize the public health and climate benefits of emission reductions in China. These benefits could last well beyond 2030. With effectively half the fleet equipped to meet the China 6/VI standards, regional governments could more readily hit the State Council's air quality targets, in turn , reaping savings by averting a spate of early deaths in those areas and making everyone better off.

However, relying on regional actions is not enough. Far-reaching steps by these three regions could impel the entire nation to move toward China 6/VI more quickly. Both oil companies and car/truck manufacturers say they will be technologically positioned to satisfy fuel quality and vehicle/engine redesign demands springing from trailblazing local policy initiatives. China should take the advantage of this and accelerate its timetable on next steps. Only by doing so can emissions in China be reined in and the air quality improved.

APPENDIX D: UNCERTAINTY REGARDING THE EMISSION FACTORS

The emission factors (EFs) used in this analysis are generated from COPERT, an emissions model developed for official road transport emission inventory preparation in European Environment Agency member countries and widely adopted by research and academic institutions (EMISIA S.A., 2014). Following European Union procedure, the EFs from COPERT are derived based on real-world testing in Europe. The ICCT has adopted COPERT 4 as the most reliable source, mainly because the emission standards in the model are defined based on the European classification scheme for vehicle/engine regulations (Euro 1/I through Euro 6/VI). Additionally, COPERT 4 is well developed and supported by a strong research and academic team, which ensures that it reflects up-to-date standards and technologies. The comprehensive and public documentation provides information on methodologies and calculation processes. Comparison with other models seems to indicate that COPERT 4's emission factors are broadly in line, even though differences are always expected depending on the vehicle type, pollutant, and certification level.

However, recently released EFs from the Ministry of Environmental Protection (MEP, 2014a) yield some differences from the ones adopted in the ICCT model. As noted, most of the emissions come from heavy-duty vehicles (HDVs), so Figures 23 and 24 below compare the EFs of fine particulate matter ($PM_{2.5}$) and nitrogen oxides (NO_x) for diesel-powered buses and heavy heavy-duty trucks (HHDTs). The brown and black lines (solid for HHDTs, dashed for buses) represent the EFs adopted used in the model, and the light and dark blue ones (likewise) show the EFs recommended by MEP. Though the EFs in the COPERT-derived model are routinely lower than the ones from MEP, especially for PM at the initial stage, the trend lines are consistent. The gap between the lines gradually disappears following the introduction of China III, except in the case of bus NO_x EFs. The NO_x EFs of buses remain high for China IV in MEP's data, while the rates drop based on COPERT's numbers.

China IV buses were not in the fleet nationwide until July 2013, and the bus fleet is small compared with LDVs and heavy-duty trucks (HDTs). Thus, the impact of underestimating EFs is relatively small. More than 85 percent of the activity (in terms of vehicle kilometers traveled, or VKT) of the fleet is accounted for by LDVs and HDTs in China after 2013, and these contribute more than 80 percent of the primary pollutant emissions—PM, black carbon (BC), and NO_x. The difference in EFs between MEP and ICCT/COPERT would not change the results significantly. More significantly, the conclusion that NO_x emissions would soon show a renewed increase in the Current and Baseline scenarios, as displayed in Figure 10, would still hold true, though the rebound would happen faster using MEP's EF numbers.

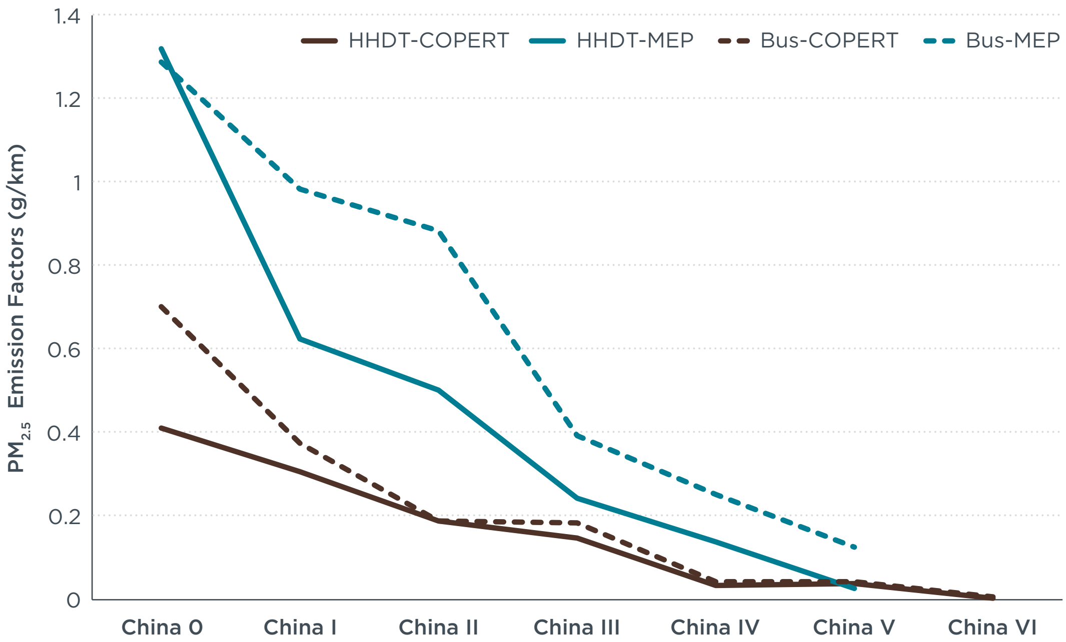


Figure 23. $PM_{2.5}$ EFs comparison for diesel buses and HHDTs

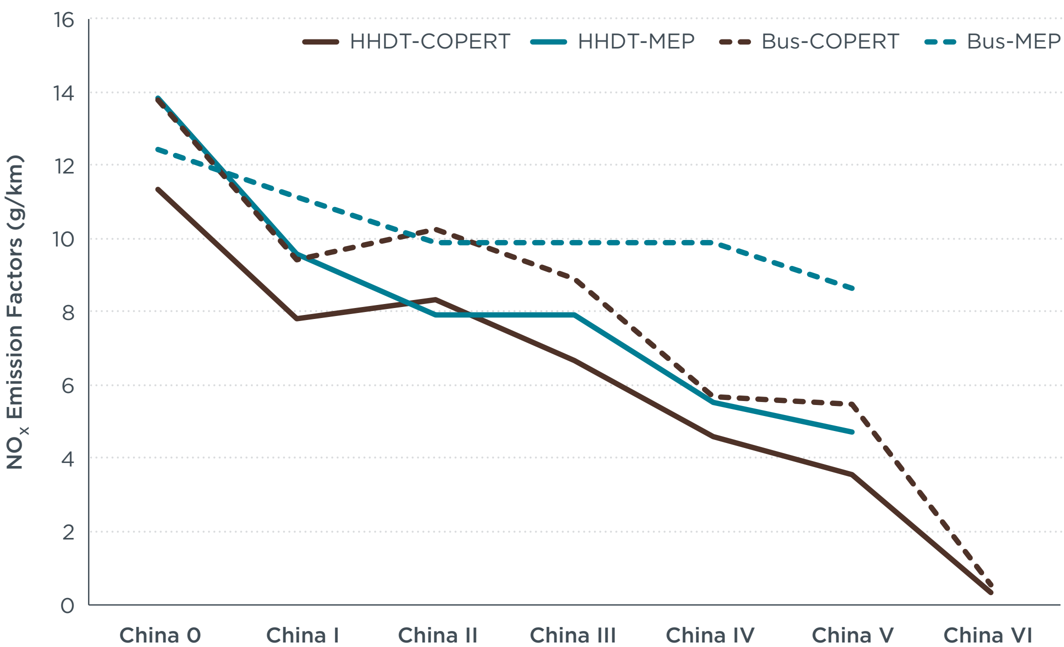


Figure 24. NO_x EFs comparison for diesel buses and HHDTs

The overall emission levels will increase if the MEP EFs are adopted; on average, the EFs for NO_x from MEP are 20 percent higher than the ones from COPERT, and those for $PM_{2.5}$ are almost twice as high. However, as shown in Figures 23 and 24 above, the trend lines of the two sets of EFs are consistent overall, demonstrating that stringent emission standards can effectively remove tailpipe pollutants. Thus, the conclusions for the four scenarios discussed above remain the same: only China 6/VI can save China from long-term emissions increases.

In addition, the MEP EFs are not comprehensive enough for this study. As shown in Figures 23 and 24, no China 6/VI EFs are provided in the MEP's dataset. However, the emission reduction that would result from implementing China 6/VI is central to the benefit-cost analysis. The other missing element is the EFs for BC, which is a primary contributor to both pollution and public health problems. Using BC EFs from different sources could result in discrepancies in understanding the emission inventory in China. Thus, it would be preferable to use consistent sets of EFs for all pollutants at all stages.

The ICCT is confident in using the COPERT EFs for China. The comparisons made in this Appendix confirm that the COPERT-derived EFs can effectively represent the impacts on China's emission inventory from advanced emission standards. COPERT provides comprehensive EFs from Euro 0 (uncontrolled) all the way to Euro 6/VI, which is essential to projecting emission trends. The EFs from MEP, by contrast lack values for China 6/VI. It is preferable to use one set of EFs from a consistent source, so that no further adjustment is required based on the data.

REFERENCES

Apte, J. S., Bombrun, E., Marshall, J. D., and Nazaroff, W. W. (2012). Global intraurban intake fractions for primary air pollutants from vehicles and other distributed sources. *Environmental Science and Technology, 46*(6), 3415–3423.

Bansal, G., and Bandivadekar, A. (2013). Overview of India's vehicle emissions control program: Past successes and future prospects. International Council on Clean Transportation. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_IndiaRetrospective_2013.pdf

Beijing Municipal Commission of Transport (2014) Notice on traffic management measures on motor vehicles to reduce pollutant emissions (in Chinese). Retrieved from http://www.bjjtw.gov.cn/gzdt/ywsds/201403/t20140328_86404.htm

Beijing Municipal Environmental Protection Bureau (Beijing EPB). (2011). Beijing 2010 environmental report (in Chinese). Retrieved from http://www.bjepb.gov.cn/bjepb/323474/331443/331616/331634/444594/index.html

Beijing Municipal Environmental Protection Bureau (Beijing EPB). (2012). Beijing further promoting the old vehicle scrappage program (in Chinese). Retrieved from http://www.bjepb.gov.cn/bjepb/323474/331443/331834/331850/451670/index.html

Beijing Municipal Environmental Protection Bureau (Beijing EPB). (2014). Beijing published four heavy-duty vehicle and nonroad engine emission control local standards. Retrieved from http://zhengwu.beijing.gov.cn/zfjd/hj/t1304290.htm

Beijing Municipal Government (2011). Update plan to further encourage aged vehicle scrappage (in Chinese). Retrieved from http://zhengwu.beijing.gov.cn/gzdt/gggs/t1190048.htm

Beijing Municipal Government (2013). Beijing Clean Air Initiative for 2013–2017 (in Chinese). Retrieved from http://zhengwu.beijing.gov.cn/gzdt/gggs/t1322955.htm

Bond, T. C., and Sun, H. (2005). Can reducing black carbon emissions counteract global warming? *Environmental Science and Technology, 39*(16): 5921–5926.

Bond, T. C., Zarzycki, C., Flanner, M. G., and Koch, D. M. (2011). Quantifying immediate radiative forcing by black carbon and organic matter with the Specific Forcing Pulse. *Atmospheric Chemistry and Physics, 11*(4): 1505–1525.

Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T. K., DeAngelo, B. J., … Zender, C. S. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research: Atmospheres, 118*(11), 5380–5552.

Borken-Kleefeld, J. (2013). Guidance note about on-road vehicle emissions remote sensing. Report commissioned by the International Council on Clean Transportation. July. Retrieved from http://www.theicct.org/sites/default/files/publications/RSD_Guidance_BorKlee.pdf

Chambliss, S., Miller, J., Façanha, C., Minjares, R., and Blumberg, K. (2013). *The impact of stringent fuel and vehicle standards on premature mortality and emissions.* Global Transportation Health and Climate Roadmap Series. International Council on Clean Transportation. October. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_HealthClimateRoadmap_2013_revised.pdf

CENEWS. (2014). The loopholes for the fake China IV vehicles (in Chinese). June 10. Retrieved from http://www.cenews.com.cn/sylm/hjyw/201406/t20140610_775569.htm

China Automotive Technology and Research Center (CATARC) (2014). *China automotive industry yearbook 2014.* Tianjin: China Automotive Technology and Research Center.

Cohen, A. J., Anderson, H. R., Ostro, B., Pandey, K. D., Krzyzanowski, M., Künzli, M., … Smith, K. R. (2004). "Urban Air Pollution." Chapter 17 in M. Ezzati, A. D. Lopez, A. Rodgers, and C. J. L. Murray (Eds.), *Comparative quantification of health risks: Global and regional burden of disease attributable to selected major risk factors.* Vol. 2 (pp. 1353–1433). Geneva: World Health Organization.

Corro, G. (2001). Sulfur impact on diesel emission control—A review. *Reaction Kinetics and Catalysis Letters, 75*(1), 89–106.

EMISIA S.A. (2014). COPERT 4 version 11.0—September 2014. Retrieved from http://emisia.com/content/copert-4-versions

Façanha, C., Blumberg, K., and Miller, J. (2012). Global transportation energy and climate roadmap: The impact of transportation policies and their potential to reduce oil consumption and greenhouse gas emissions. International Council on Clean Transportation. November. Retrieved from http://www.theicct.org/global-transportation-energy-and-climate-roadmap

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D. W., … Van Dorland, R. (2007). Changes in atmospheric constituents and in radiative forcing. Chapter 2 in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, … H. L. Miller (Eds.), *Climate change 2007: The physical science basis—Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 129–234). Cambridge, U.K.: Cambridge University Press.

Fung, F., He, H., Sharpe, B., Kamakaté, F., and Blumberg, K. (2010). Overview of China's vehicle emission control program: Past successes and future prospects (in Chinese). The International Council on Clean Transportation. December. Retrieved from http://www.theicct.org/sites/default/files/publications/Retrosp_final_bilingual.pdf

General Administration of Quality, Supervision, Inspection and Quarantine ([G]AQSIQ) (2014). Notice on the distribution of suggestions on enhancing and improving vehicle inspection (in Chinese). Retrieved from http://www.aqsiq.gov.cn/xxgk_13386/zxxxgk/201405/t20140516_412726.html

Glover, E. L., and Cumberworth, M. (2003). MOBILE6.1 particulate emission factor model: Technical description. Final report/M6.PM.001. EPA420-R-03-001. U.S. Environmental Protection Agency. January.

Huo, H., and Wang, M. (2012). Modeling future vehicle sales and stock in China. *Energy Policy, 43,* 17–29.

IBM (2011). IBM Global Commuter Pain Survey: Traffic congestion down, pain way up. IBM news release. September 8. Retrieved from http://www-03.ibm.com/press/us/en/pressrelease/35359.wss

International Council on Clean Transportation (ICCT) (2009). A policy-relevant summary of black carbon climate science and appropriate emission control strategies. June. Retrieved from http://www.theicct.org/sites/default/files/publications/BCsummary_dec09.pdf

International Council on Clean Transportation (ICCT). (2012). Technical and economic analysis of the transition to ultra-low sulfur fuels in Brazil, China, India, and Mexico. Report prepared for the International Council on Clean Transportation by Hart Energy and MathPro Inc. October. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_ULSF_refining_Oct2012.pdf

International Council on Clean Transportation (ICCT). (2013a). China announces breakthrough timeline for implementation of ultra-low sulfur fuel standards. Policy update. March. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCTupdate_CH_fuelsulfur_mar2013_rev.pdf

International Council on Clean Transportation (ICCT) (2013b). Supplemental NO_x standards for Euro IV and V heavy-duty vehicles in Beijing. Policy update. July. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCTupdate_BeijingNOx_July2013.pdf

International Council on Clean Transportation (2014a). Global Transportation Roadmap Model. Retrieved from http://www.theicct.org/global-transportation-roadmap-model

International Council on Clean Transportation (ICCT) (2014b). Supplemental WHTC testing for Euro IV/V heavy-duty vehicles in China. Policy update. February. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCTupdate_ChinaWHTC_feb2014.pdf

International Council on Clean Transportation (ICCT) (2015). Early adoption of China 5/V vehicle emission standards in Guangdong province. Policy update. Retrieved from http://theicct.org/update-early-adoption-china-5-v-guangdong.

Jiang, X. (2013). New energy vehicles await fuel injection. *China Daily USA.* August 5. Retrieved from http://usa.chinadaily.com.cn/china/2013-08/05/content_16869956.htm

Krewski, D., Jerrett, M., Burnett, R. T., Ma, R., Hughes, E., Shi, Y., ... Thun, M. J. (2009). Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. HEI Research Report no. 140 (press version). Health Effects Institute. May. Retrieved from http://pubs.healtheffects.org/view.php?id=315

Ministry of Commerce (MOC), Department of Market System Development, China (2010). Notification on extended car trade implementation (in Chinese). June 25. Retrieved from http://scjss.mofcom.gov.cn/aarticle/cx/201006/20100606987758.html

Ministry of Environmental Protection, China (MEP) (2000). Air Pollution Prevention and Control Law (in Chinese). April 29. Retrieved from http://www.envir.gov.cn/law/air.htm

Ministry of Environmental Protection, China (MEP) (2005). In-use vehicles exhaust inspection and maintenance standards (in Chinese). Retrieved from http://www.mep.gov.cn/image20010518/4441.pdf

Ministry of Environmental Protection, China (MEP) (2008). Technical requirement for environmental protection product: Aftertreatment devices for diesel vehicle exhaust (in Chinese). HJ 451. December 10. Retrieved from http://www.zhb.gov.cn/info/bgw/bgg/200812/W020081217329302897170.pdf

Ministry of Environmental Protection, China (MEP) (2011). Announcement of the implementation of the fourth stage of the national car compression-ignition engine and vehicle emission standards (in Chinese). December 29. Retrieved from http://www.zhb.gov.cn/gkml/hbb/bgg/201201/t20120110_222376.htm

Ministry of Environmental Protection, China (MEP) (2013). National Environmental Statistic Report (in Chinese). March 16. Retrieved from http://zls.mep.gov.cn/hjtj/qghjtjgb/201503/t20150316_297266.htm

Ministry of Environmental Protection (MEP), China (2014a). Air pollutant emission inventory guide for on-road vehicles (in Chinese). December 31. Retrieved from http://www.zhb.gov.cn/gkml/hbb/bgg/201501/t20150107_293955.htm

Ministry of Environmental Protection (MEP), China (2014b). China Vehicle Emission Control Annual Report 2013 (in Chinese). Retrieved from http://www.vecc-mep.org.cn/news/sytz_zfxx/2013year.pdf

Ministry of Environmental Protection (MEP), China (2014c). Limits and measurement methods for exhaust pollutants from diesel engines of urban vehicles (WHTC) (in Chinese). HJ 689. Retrieved from http://kjs.mep.gov.cn/hjbhbz/bzwb/dqhjbh/dqydywrwpfbz/201401/t20140126_266957.htm

Ministry of Environmental Protection (MEP), Ministry of Industry and Information Technology (MIIT), Ministry of Public Security (MPS), State Administration for Industry and Commerce (SAIC), and General Administration of Quality Supervision, Inspection, and Quarantine (AQSIQ), China (2014). Environmental regulatory compliance work program for new vehicles (in Chinese). Retrieved from http://www.mep.gov.cn/gkml/hbb/bwj/201408/W020140813378465904664.pdf

Ministry of Environmental Protection (MEP), National Development and Reform Commission (NDRC), Ministry of Public Security (MPS), Ministry of Finance (MOF), Ministry of Transportation (MOT), and Ministry of Commerce (MOC), China (2014). The 2014 Implementation Plan of eliminating YLVs and old vehicles (in Chinese). September 18. Retrieved from http://www.gov.cn/xinwen/2014-09/18/content_2752665.htm

Ministry of Finance (MOF) and Ministry of Commerce (MOC), China (2010). Notice about adjusting subsidy standards and related matters for vehicle scrappage and replacement (in Chinese). January 19. Retrieved from http://www.vecc-Mep.org.cn/news/news_detail.jsp?newsid=36388

Ministry of Finance (MOF), Ministry of Commerce (MOC), Publicity Department of the Communist Party of China (CCPPD), National Development and Reform Commission (NDRC), Ministry of Industry and Information Technology (MIIT), Ministry of Public Security (MPS), Ministry of Environmental Protection (MEP), Ministry of Transportation (MOT), State Administration for Industry and Commerce (SAIC), and General Administration of Quality Supervision, Inspection, and Quarantine (AQSIQ), China (2009). Notice about issuing of implementation methods for vehicle scrappage and replacement (in Chinese). July 14. Retrieved from http://www.vecc-mep.org.cn/news/news_detail.jsp?newsid=33844.

Minjares, R., and Hon, G. (2012). Definition and measurement of marine black carbon emissions. Presentation to the International Maritime Organization. London. January 30. Retrieved from http://www.theicct.org/definition-and-measurement-marine-black-carbon-emissions

Posada Sanchez, F., Bandivadekar, A., and German, J. (2012) Estimated cost of emission reduction technologies for light-duty vehicles. The International Council on Clean Transportation. March. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_LDVcostsreport_2012.pdf

Posada, F., Wagner, D. V., Bansal, G., and Fernandez, R. (2015). Survey of best practices in reducing emissions through vehicle replacement programs. White paper. The

International Council on Clean Transportation. March. Retrieved from http://www.theicct.org/vehicle-replacement-program-best-practices-mar2015

State Council, China (2013a). Ten measurements of Atmospheric Pollution Prevention Action Plan (in Chinese). June 14. Retrieved from http://www.gov.cn/ldhd/2013-06/14/content_2426237.htm

State Council, China (2013b). Action Plan on Prevention and Control of Air Pollution (in Chinese). September 12. Retrieved from http://www.gov.cn/zwgk/2013-09/12/content_2486773.htm.

State Council, China (2015). The measures of speeding up the fuel quality upgrade (in Chinese). April 28. Retrieved from http://www.gov.cn/guowuyuan/2015-04/28/content_2854625.htm

U.S. Environmental Protection Agency (U.S. EPA) (1999). Tier 2 motor vehicle emission standards and gasoline sulfur control requirements: Response to comments. EPA420-R-99-024. December.

U.S. Environmental Protection Agency (U.S. EPA) (2013). Climate change: The social cost of carbon. November 26. Retrieved from http://www.epa.gov/climatechange/EPAactivities/economics/scc.html

U.S. Environmental Protection Agency (U.S. EPA), National Center for Environmental Economics (2014a). Frequently asked questions on mortality risk valuation. Retrieved from http://yosemite.epa.gov/EE%5Cepa%5Ceed.nsf/webpages/MortalityRiskValuation.html#whatvalue

U.S. Environmental Protection Agency (U.S. EPA), Office of Transportation and Air Quality (2014b). EPA sets Tier 3 motor vehicle emission and fuel standards. Regulatory announcement. EPA-420-F-14-009. March. Retrieved from http://www.epa.gov/otaq/documents/tier3/420f14009.pdf

Wagner, V., and Rutherford, D. (2013). Survey of best practices in emission control of in-use heavy-duty diesel vehicles. The International Council on Clean Transportation. August. Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_HDV_in-use_20130802.pdf

Wang, M., Huo, H., Johnson, L., and He, D. (2006). Projection of Chinese motor vehicle growth, oil demand, and CO_2 emissions through 2050. ANL/ESD/06-6. Energy Systems Division, Argonne National Lab. December. Retrieved from http://www.transportation.anl.gov/pdfs/TA/398.pdf

Wang, Y., Teter, J., and Sperling, D. (2011). China's soaring vehicle population: Even greater than forecasted? *Energy Policy, 39*(6), 3296–3306

World Bank. (2014). Reducing black carbon emissions from diesel vehicles: Impacts, control strategies, and cost-benefits analysis. No. 86485. The World Bank. Retrieved from http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/04/04/000442464_20140404122541/Rendered/PDF/864850WP00PUBL0l0report002April2014.pdf

Xinhua (2010). MIIT: The vehicle stock in China will be over 200 million by 2020 (in Chinese). September 5. Retrieved from http://news.xinhuanet.com/auto/2010-09/05/c_12520150.htm

Yang, Z., Wang, H., and Shao, Z. (2015). Beijing case study. International Council on Clean Transportation. Forthcoming.