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# REVIEW OF BEIJING'S COMPREHENSIVE MOTOR VEHICLE EMISSION CONTROL PROGRAMS

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# ABBREVIATIONS

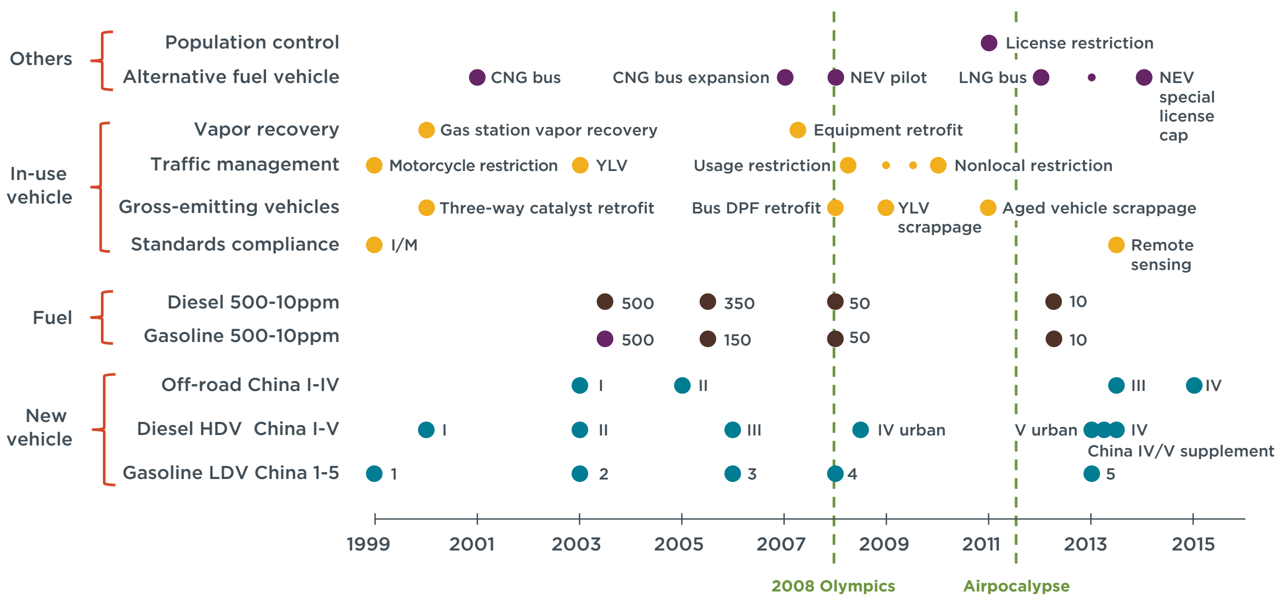
| | |
|---|---|
| ASM | Acceleration Simulation Mode |
| BAU | Business as usual |
| BC | Black carbon |
| BEPB | Beijing Environmental Protection Bureau |
| BEV | Battery electric vehicle |
| BTAB | Beijing Traffic Administration Bureau |
| CNG | Compressed natural gas |
| CO | Carbon monoxide |
| COP | Conformity of production |
| DOC | Diesel oxidation catalyst |
| DPF | Diesel particulate filter |
| EGR | Exhaust gas recirculation |
| ETC | European Transient Cycle |
| FCV | Fuel cell vehicle |
| FFV | Flexible fuel vehicle |
| HC | Hydrocarbon |
| HDDV | Heavy-duty diesel vehicle |
| HDV | Heavy-duty vehicle |
| I/M | Inspection and maintenance |
| LDV | Light-duty vehicle |
| LDGV | Light-duty gasoline vehicle |
| LEZ | Low emission zone |
| LNG | Liquefied natural gas |
| LNT | Lean $NO_x$ traps |
| LPG | Liquefied petroleum gas |
| MEP | Ministry of Environmental Protection |
| MMT | Methylcyclopentadienyl manganese tricarbonyl |
| NDRC | National Development and Reform Commission |
| NEV | New energy vehicle |
| $NO_x$ | Nitrogen oxide |
| OBD | On-board diagnostics |
| ORVR | Onboard refueling vapor recovery |
| PEMS | Portable Emissions Measurement System |
| PHEV | Plug-in hybrid electric vehicle |
| PM | Particulate matter |
| $PM_{2.5}$ | Particulate matter smaller than 2.5 micrometers |
| ppm | Parts per million |
| RVP | Reid vapor pressure |
| SCR | Selective catalytic reduction |
| THC | Total hydrocarbons |
| TWC | Three-way catalyst |
| VOC | Volatile organic compound |
| WHTC | World Harmonized Transient Cycle |
| YLV | Yellow label vehicle |

# EXECUTIVE SUMMARY

Transportation is a major source of pollutants in many urban areas. Currently in Beijing, on-road vehicles account for a significant percentage gaseous pollutants (CO, HC, $NO_x$), particulate matter and black carbon. Black carbon, as one of the main components of PM emissions, not only threaten public health, degrade air quality, but also contribute significantly to climate change as a short-lived climate pollutant. To reduce the environmental impact, Beijing has introduced a wide variety of emission control programs to reduce emissions from on-road fleet.

The ICCT conducted a review of Beijing's motor vehicle emission control efforts and experience, and a cost-benefit analysis of the introduction of stringent new vehicle emission and fuel quality standards in Beijing.

The retrospective summarizes Beijing's vehicle emission control programs, including new vehicle emission standards, fuel quality standards, in-use vehicle emission control, and other programs such as alternative fuel vehicles and vehicle population control that have been adopted as of January 1, 2015. Beijing has shown leadership by adopting new vehicle emission and fuel quality standards one to six years ahead of the countrywide timeline. Meanwhile, Beijing has been especially innovative in introducing a number of in-use vehicle control programs. Figure ES-1 illustrates the timeline of the implementation of various policies and regulations targeting vehicle emissions.




*Unmarked events are the updates of existing events*
*YLV= yellow label vehicle; NEV=new energy vehicle; CNG= compressed natural gas; LNG= liquefied natural gas; I/M=inspection and maintenance*

**Figure ES-1** Major emission control regulations in Beijing, 1999 to 2014

The cost-benefit analysis estimates future emissions, health and climate impacts, and costs associated with the three scenarios summarized in Table ES-1.[1]

**Table ES-1.** The three scenarios and relevant assumptions used in modeling for this analysis

| Scenarios | Emission Standards | Fuel Standards | Scrappage |
|---|---|---|---|
| **Beijing BAU** | China 5/V in 2013 | 10 ppm fuel sulfur in 2012 | Voluntary YLVs scrapped by 2010 |
| **China BAU** | Follows national steps: LDGV China 4 in 2011; HDDV China IV in 2013 | 350 ppm sulfur diesel in 2011<br>50 ppm sulfur gasoline in 2014 | N/A |
| **Beijing 6/VI** | Beijing 6/VI in 2016 | 10 ppm fuel sulfur in 2012 | Based on voluntary scrappage, 1 million older vehicles retired by 2018 |

The results show that early implementation of the China 5/V emission standards and ultralow sulfur fuel standards in Beijing have yielded immediate emission reductions from the vehicle fleet. In 2010, the annual $NO_x$ emissions in the Beijing BAU scenario were 40,795 tons or 41 percent lower than in the China BAU scenario. The $PM_{2.5}$ emissions in the Beijing BAU scenario were 1,334 tons or 68 percent lower while the black carbon emissions were 40 percent lower than in the China BAU scenario. However, with vehicle demand growing inexorably, emissions will soon start to increase again if more stringent standards are not implemented. With the introduction of the Beijing 6/VI (or potentially China 6/VI) standards, emissions from motor vehicles would continue to decline through 2030. The scrappage program would further accelerate decline in emissions. By 2030, $NO_x$, $PM_{2.5}$, and black carbon emissions would be reduced by as much as 77 percent, 64 percent, and 88 percent, respectively, compared with the Beijing BAU scenario. Furthermore, the Beijing 6/VI standards are extremely cost-effective. A conservative estimate of the benefits of the Beijing 6/VI standards is that, in 2040, they would outweigh the costs by a factor of 4 to 1, with most of the benefit coming from sounder public health. The results indicate the effectiveness of Beijing 6/VI in controlling vehicle tailpipe emissions.

Three main conclusions are drawn from this analysis. First, Beijing's vehicle emission control regime has delivered significant environmental and health benefits, but only Beijing 6/VI can help Beijing prevent long-term emission growth. Second, accelerating the pace of emission control in the areas surrounding Beijing will maximize the regional environmental impact. The city should focus on cooperating with the surrounding Jing-Jin-Ji (Beijing-Tianjin-Hebei) capital region to push for various emission control programs. Third, Beijing's vehicle emission control experience can be an inspiration for other cities. With the legal power to carry out most of the same actions as Beijing, other cities in China can draw lessons from not just the success stories but also the hard choices and tradeoffs made as those cities seek out the routes most appropriate to their own situations to realize emission reductions.

1 Note: In this table and throughout this report, 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. Nonroad engines and equipment standards also use Roman numerals, but will be clarified in the paper to distinguish from heavy-duty vehicles.

# 1. INTRODUCTION

## 1.1. BACKGROUND

Three decades of economic reform and development have enabled a great expansion of China's automobile fleet. The pace of growth began accelerating in 2000, the year the Chinese government declared the automotive industry to be one of the pillars of the national economy. No other city better illustrates this dramatic change than Beijing, the capital. Since becoming China's political center in 1949, the city saw little change in the number of cars on the road until 1997. At that point the total number of vehicles registered in Beijing was less than 1 million. Since then, growth in the city's vehicle fleet sent the total higher than 5 million by 2012, with the vehicle ownership rate reaching 240 per 1,000 people, about three times the national average (NBS, 2013).

Transportation is a major source of pollutants in many urban areas. Currently in Beijing, on-road vehicles account for around 86 percent of carbon monoxide (CO), 25 percent of total hydrocarbon (THC), 57 percent of nitrogen oxide ($NO_X$), and 31 percent of small particulate matter ($PM_{2.5}$) concentration (BEPB, 2014a). These pollutants threaten public health, degrade air quality, and contribute significantly to climate change. One climate pollutant of key importance is black carbon (BC), a fraction of $PM_{2.5}$ that mainly originates from incomplete combustion of carbon fuels (see Box 1).

### BOX 1: DEFINITION OF BLACK CARBON

Black carbon (BC) is light-absorbing, carbonaceous material emitted as solid particulate matter created through incomplete combustion of carbon-based fuels. BC contains more than 80 percent carbon by mass and, when emitted, forms aggregates of primary spherules between 20 and 50 nanometers in aerodynamic diameter (Minjares and Hon, 2012).

BC absorbs solar radiation across all visible wavelengths and converts that energy to heat. Because BC is a fraction of $PM_{2.5}$, exposure also threatens public health (ICCT, 2009). According to ICCT's China Roadmap model, BC accounts for about half of $PM_{2.5}$ emissions from on-road transportation each year in Beijing.

As the capital of China, Beijing's air quality draws a great deal of attention (for example, prior to the 2008 Olympic Games and during the "Airpocalypse" of 2012-13) and the city possesses unparalleled powers and resources to combat air pollution. For years, Beijing has outpaced the national government in adopting and implementing multiple emission control measures to reduce emissions from the transportation sector. While learning from best practices in emission control from initiatives around the world, Beijing has customized many programs to address local issues.

In September 2013, Beijing issued its Clean Air Action Plan (2013-17), which pushes for the adoption of more stringent vehicle emission control policies in the five-year time frame. In January 2014, the Beijing People's Congress passed the Statute on Beijing Air Pollution Prevention and Control. This statute replaced the Method of Beijing Municipality for Implementing the National Air Pollution Prevention and Control Law and established a more comprehensive and powerful regional legislative framework for air pollution control. It is clear that Beijing has taken a leadership position within China regarding vehicle emission reduction. It is to be hoped that Beijing's experience and achievements in pollution control may inspire other cities in China and elsewhere in the world to intensify their efforts in the area of vehicular emission management.

## 1.2. PURPOSE OF THE REPORT

This report gives an overview of Beijing's comprehensive emission control programs, including the development and evolution of major regulations, implementation practices, and outcomes. Its purpose is to review a variety of existing approaches and highlight best practices as well as the potential challenges of each approach. Since emission control programs include a broad range of means, the report covers most initiatives related to new vehicle standards, fuel quality standards, in-use vehicle emission control, and other programs such as alternative fuel vehicles and vehicle population control. It does not cover programs such as infrastructure improvement, modal shifting[2], or urban planning.

The report starts with a brief history of Beijing's strategies to limit motor vehicle emissions, followed by an assessment of the city's vehicle population and composition. It then reviews each type of regulatory initiative mentioned in the previous paragraph. The report ends with a modeling analysis of the environmental (inventory of airborne $NO_X$, $PM_{2.5}$, BC, CO, HC emissions) and health (in terms of premature mortality) impacts of Beijing's adoption of vehicle emission and fuel quality standards and the cost effectiveness of adopting more stringent standards.

2 E.g., encouraging greater use of public transit, shifting freight carriage from trucks to rails, etc.

# 2. BACKGROUND

## 2.1. VEHICLE POPULATION AND FLEET STRUCTURE

As shown in Figure 1, the vehicle population in Beijing increased rapidly from 2000 to 2010. From 2011 forward, the growth rate slowed noticeably as a result of the new mandatory license plate control program for passenger vehicles (discussed in further detail in Subsection 6.2).

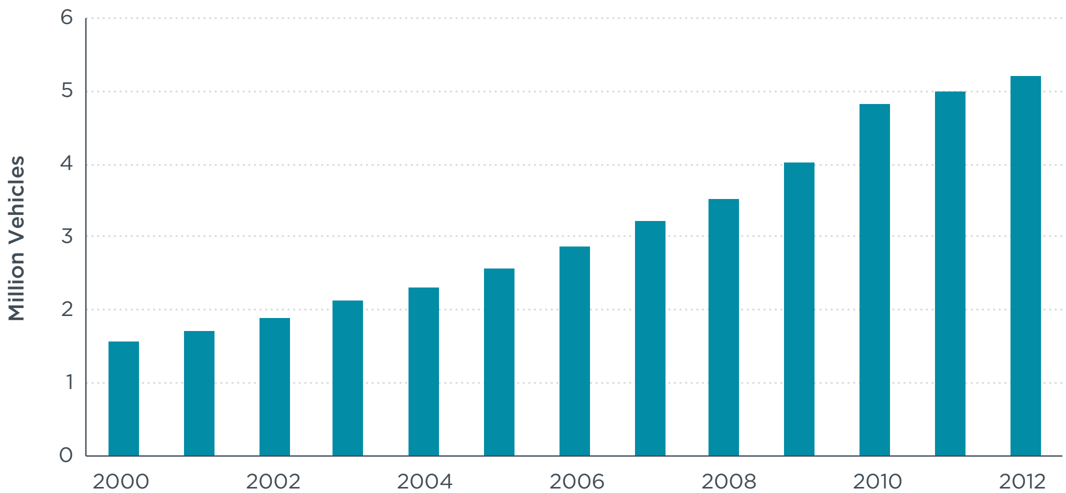



**Figure 1** Automobile ownership in Beijing *(Source: Beijing Government, 2014d)*

Figure 2 illustrates that on-road vehicles in Beijing are mostly light-duty vehicles (LDVs). The percentage of LDVs has increased from 74 percent in 2001 to 93 percent in 2013. Beijing has banned the development of diesel LDVs; thus, nearly all on-road LDVs are light-duty gasoline vehicles (LDGVs). In contrast, most heavy-duty vehicles (HDVs) in Beijing are heavy-duty diesel vehicles (HDDVs). Therefore, the emission control regulations discussed in this paper mainly focus on LDGVs and HDDVs.

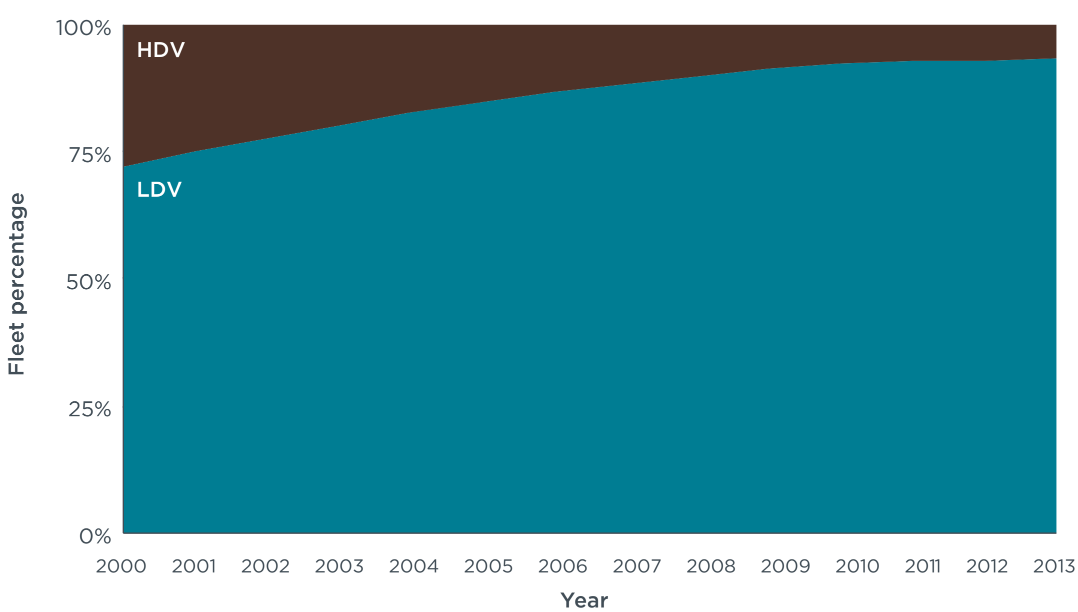



**Figure 2** Beijing on-road fleet by vehicle category *(Source: ICCT, 2014)*

LDVs and HDVs contribute differently to the accumulation of conventional pollutants, as indicated in Figure 3; fleet size is not proportional to emissions. Though heavy-duty diesel vehicles account for only 7 percent of the total stock, it is estimated that they were to blame for more than 85 percent of $NO_x$ emissions and more than 80 percent of $PM_{2.5}$ emissions from on-road vehicles between 2010 and 2013. LDVs were responsible for more than half of CO and HC emissions.[3] Note that the pollutant emissions in this paper only reflect tailpipe emissions from vehicles registered in Beijing.

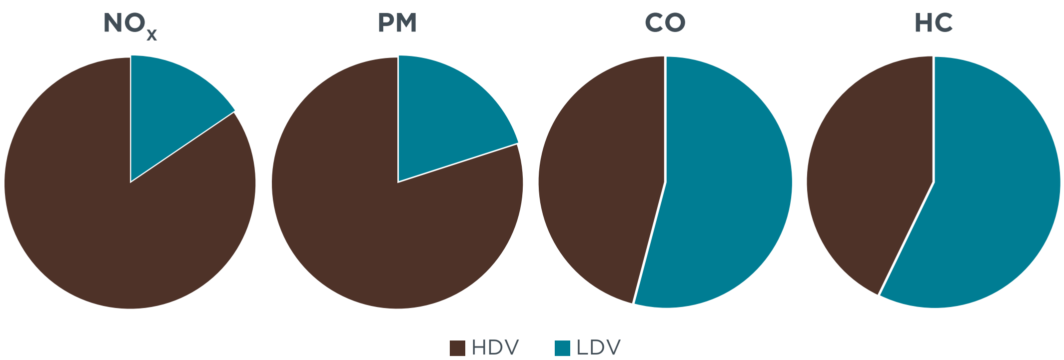



**Figure 3** 2010-13 Emission percentage by vehicle category *(Source: ICCT, 2014)*

## 2.2. LOCAL AGENCY'S ROLE IN VEHICLE EMISSION CONTROL

In China, environmental protection agencies are mainly empowered by the Environment Protection Law, the Air Pollution Prevention and Control Law, and the Statute on Beijing Air Pollution Prevention and Control. For vehicle emission control, the roles of the national government (i.e., the Ministry of Environmental Protection, or MEP) and the local government (Beijing Environmental Protection Bureau, or BEPB) are distinct.

Under most circumstances, the MEP promulgates vehicle emission standards while the State Council promulgates national fuel quality standards with assistance from MEP. With approval from the State Council and National Development and Reform Commission (NDRC)[4], local governments can implement national standards earlier than the timeline dictates for the country as a whole (this accelerate timeline is known as "early adoption"). Local governments also are legally allowed to develop more stringent standards that are applicable regionally. Nevertheless, such cases are extremely rare in practice since local emission standards require national-level approval, while fuel quality standards require NDRC approval for price changes. However, exceptions have been made for the BEPB. For example, in 2013, the BEPB developed and issued its own "Beijing 5/V"[5] standards ahead of the MEP. Comparatively, local governments have more autonomy and flexibility in designing and implementing in-use control programs. As noted in Section 5, the BEPB has been especially innovative in introducing a number of in-use vehicle control programs.

3 The difference between the emission percentages from the ICCT China model and other reports can be explained by the different sets of emission factors adopted. Nevertheless, the conclusions stay consistent for Beijing.

4 The NDRC regulates fuel price.

5 Throughout this report, 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. Nonroad engines and equipment standards also use Roman numerals, but will be clarified in the paper to distinguish from heavy-duty vehicles.

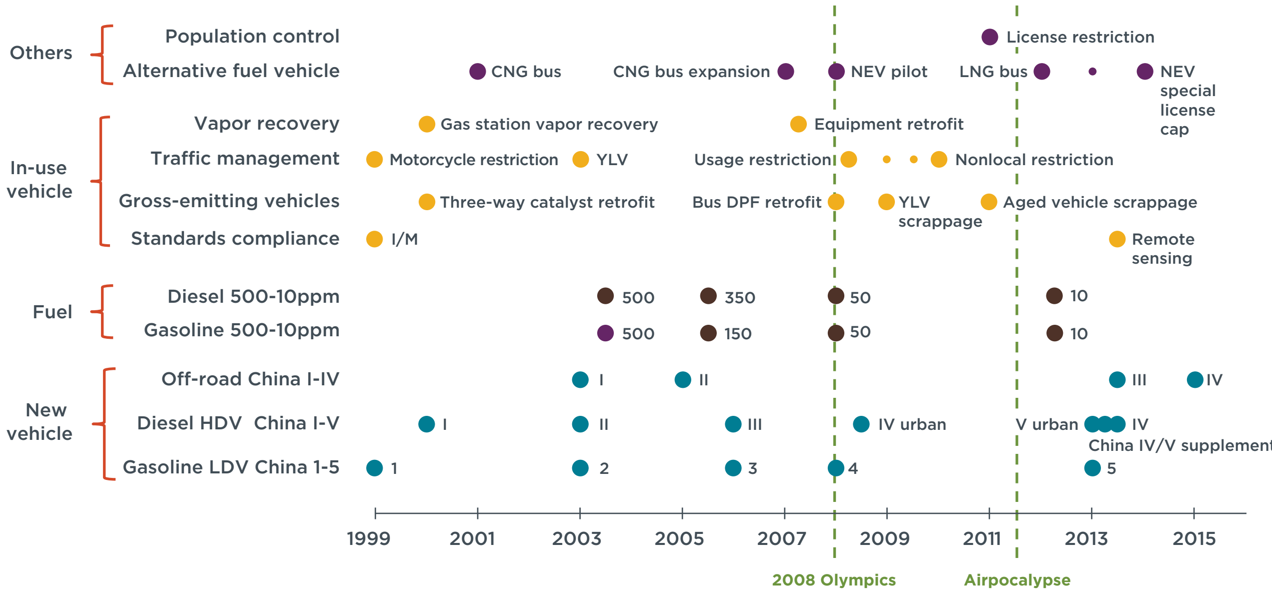
Beijing also strengthened the agency's power of enforcement and punishment by revising the Statute on Beijing Air Pollution Prevention and Control in 2014 with more detailed provisions. The revision of the statute empowers the BEPB to do more than other local EPBs. For example, it enables BEPB to conduct roadside tests on vehicles being driven in addition to selective tests on vehicles in parking lots. The revision also prioritizes vehicle emission tests to safety tests, which means the vehicle must pass an emission test before the safety test. This is done to save time in case the vehicle fails the emission test. The revised statute adds more penalties for violations to reinforce compliance and decentralizes the power of penalties to traffic police for certain violations of vehicle-related regulations.

## 2.3. OVERVIEW OF BEIJING'S VEHICLE EMISSION CONTROL STRATEGIES

Beijing confronted the issue of vehicle emissions even before the rapid increase in highway vehicles. In 1997, the city launched a program, entitled Strategies and Implementation Plan for Controlling Motor Vehicle Emissions in Beijing, that aimed to adopt European emission standards step by step (Wu et al., 2011). This program became the cornerstone as the city started applying advanced Euro standards to new vehicles registered in the city. Beijing first implemented Beijing 1 emission standards (equivalent to Euro 1, later replaced by China 1) in 1999. At the same time, the city embarked on a highly successful labeling program to supplement the vehicle emission standards. The green and yellow labels[6] reflecting vehicles' compliance with emission standards under this program paved the way for numerous other in-use vehicle emission control programs. In parallel with the adoption of new vehicle emission standards, Beijing has led the nation in adopting higher quality fuel for on-road vehicles.

Figure 4 illustrates the implementation timeline of various policies and regulations targeting vehicle emissions through Dec. 31, 2014. Note that Beijing in 2015 has adopted additional regulations to reduce vehicle emissions, which are not reflected in this paper. Table 1 briefly explains the terms used in Figure 4.

6 Yellow-label vehicles are LDVs not meeting China 1 emission standards and HDVs not meeting China III emissions standards. Green-label vehicles meet these or more advanced standards. See more details in Subsection 5.2.1.




*Unmarked events are the updates of existing events*
*YLV= yellow label vehicle; NEV=new energy vehicle; CNG= compressed natural gas; LNG= liquefied natural gas; I/M=inspection and maintenance*

**Figure 4** Major emission control regulations in Beijing from 1999 to 2014

**Table 2.** Explanation of program terms in Figure 4

| Issue | Name | Policy or initiatives details |
|---|---|---|
| **Standards compliance** | I/M | Vehicle inspection and maintenance |
| | Remote sensing | Set up remote sensors to test vehicle on-road emissions |
| **Gross-emitting vehicles** | Three-way catalyst retrofit | Retrofit taxis with three-way catalytic converters |
| | Bus DPF retrofit | Retrofit buses with diesel particulate filters |
| | YLV scrappage | Subsidize early scrappage of yellow-label vehicles |
| | Aging vehicle scrappage | Subsidize early scrappage of older vehicles (6 years+) |
| **Traffic management** | Motorcycle restriction | Forbid motorcycles within the Fourth Ring Road |
| | YLVs | Zone restriction for yellow-label vehicles |
| | Usage restriction | Limited vehicle usage on certain days |
| | Nonlocal restriction | Zone restriction for nonlocal vehicles |
| **Vapor recovery** | Gas station vapor recovery | Regulation for Stage I and II recovery |
| | Equipment retrofit | Retrofit equipment on tanker trucks and at gas stations |
| **Alternative fuel vehicle** | CNG bus | Introduction of compressed natural gas buses |
| | CNG bus expansion | Expansion of compressed natural gas bus fleet |
| | NEV pilot | Promotion of new energy vehicles[1] |
| | LNG bus | Introduction of liquefied natural gas buses |
| | NEV special license cap | Set separate license cap for new energy vehicles |
| **Population control** | License restriction | Set lottery system to limit new vehicle purchases |

1. New energy vehicles include battery-electric vehicles, plug-in hybrid electric vehicles, and fuel-cell vehicles.

It is interesting to look at the impact of measures instituted in the course of the buildup to the 2008 Olympic Games. To provide visitors with improved air quality during the Olympics, Beijing put in place a slew of policies and programs to curb air pollutant emissions from transportation. Some of these measures were temporary while others were not. For example, the city ordered 70 percent of government vehicles off the road and limited the access of trucks inside the Sixth Ring Road for the duration of the Olympics. Both restrictions were lifted after the event. The city also introduced a usage restriction program that required private vehicles to operate only on odd or even days depending on the last digit of their license plate; that program, with a slight change in design, continues. Usage restrictions are discussed further in Subsection 5.3.1 below.

After the Olympic Games, and especially after 2012, when adverse environmental conditions (the so-called Airpocalypse) began to attract national (and international) attention, Beijing initiated a variety of in-use vehicle emission control programs, such as yellow-label vehicle scrappage, aging vehicle scrappage, non-local vehicle restrictions, and a remote-sensing initiative[7]. Starting in 2011, the city pioneered a license plate lottery program to limit the number of new vehicles registered in Beijing. Additionally, the city has instituted policies and subsidies to promote alternative fuel vehicles in a bid to lower tailpipe emissions. In-use emission control initiatives focusing on scrappage and compliance programs, vehicle population limits, and alternative fuel vehicles are discussed further in subsections 5.2, 6.2, and 6.1, respectively.

Along with other new approaches, the BEPB enforced China 4/IV, China 5/V, and supplementary standards to reduce emissions from new vehicles. Currently, evaluation of the merits and costs of implementing the more stringent Euro 6/VI standards is under way. As most emission control technologies cannot function properly without lower fuel sulfur content, matching fuel quality with emission control technology is necessary to maximize the effectiveness of vehicle emission control efforts. Beijing has vigorously promoted lower-sulfur fuel in parallel with the advanced emission standards. New vehicle emission standards and fuel quality standards are discussed further in sections 3 and 4, respectively.

Building on the success and lessons learned over the past 15 years, Beijing published its Clean Air Action Plan (2013-17) in 2013, putting forth a roadmap to tackle comprehensively the air quality quandary that has been haunting the nation's capital for years. Highlights from the Clean Air Action Plan include plans to study the similarities and differences between U.S. and EU standards (which are currently in use) in order to establish standards that are better customized to the situation at hand. Beijing also plans to promote new energy and alternative fuel vehicles, including battery-powered and natural-gas-powered vehicles.

7 The remote-sensing initiative is a program set up to identify high-emission vehicles by testing on-road vehicle pollutant emissions with remote sensors.

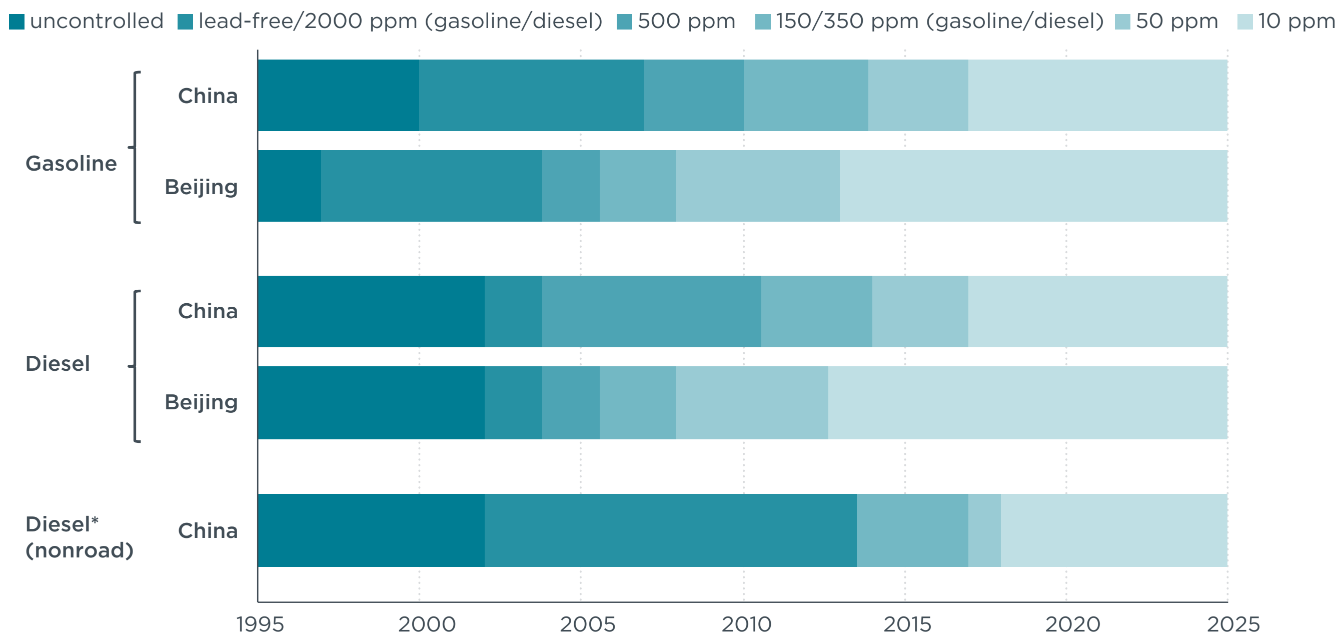
# 3. FUEL QUALITY STANDARDS

Fuel quality and emission standards are usually developed in parallel. The characteristics of fuel, such as lead and sulfur content, may constrain the effectiveness of emission control technologies. Fuel sulfur in particular is a major culprit in the sharp rise of emission levels, especially $PM_{2.5}$, seen in Beijing and other major cities across China (He, 2013a).

As the MEP set a general implementation timeline for each phase of fuel standards, some large cities have adopted stricter fuel quality standards early with approval from the State Council and NDRC about the price changes involved. For instance, Beijing, Shanghai, and cities around the Pearl River Delta (such as Guangzhou) have taken the lead in aggressively adopting their own fuel standards after negotiating a dedicated fuel supply with China's major state-owned oil companies: Sinopec and PetroChina.

Figure 5 illustrates the timeline for national fuel standards and Beijing's local standards. The figure shows that the Beijing standard is consistently ahead of the national counterpart, serving as a bellwether for Chinese fuel quality regulatory efforts.

**Sulfur content in the fuel (parts per million, i.e. ppm)**




** Sulfur requirement for nonroad diesel before January 1, 2002, was 10,000 ppm.*

**Figure 5** Gasoline and diesel standard implementation timeline for China and Beijing

The first major step to improve fuel quality in Beijing and across China was the gradual elimination of lead in gasoline. This paved the way for the adoption of the Euro 1 standards. Lead can cause damage to many organs in the human body, especially in infants, and can permanently harm the Intelligence Quotient of children (Woof et al., 2007). In addition, lead may poison catalysts in three-way catalytic (TWC) converters by deactivating catalysts and impeding them from working effectively, which is essential to reducing $NO_x$, CO, and HC in the exhaust. Eliminating lead from gasoline thus became a prerequisite for implementing Euro standards. In 1997, Beijing became the first city in China to ban the sale of leaded gasoline and required all gasoline sold locally to have lead content below 0.013 grams per liter (Wu et al., 2011). This was three months before Shanghai and Guangzhou, and two years ahead of the national deadline. One year later, the average lead content in the gasoline sold in Beijing was about 0.005 g/L (Wu et al., 2002; ICCT, 2013). Since the implementation of China I (equivalent to Euro I) fuel quality standards, both the MEP and the BEPB have periodically upgraded fuel quality.

For years, fuel quality has been seen as the bottleneck hampering the upgrading of China's fleet with more advanced emission control technologies (Table 3). Without fuel that is sufficiently free of impurities to ensure the functioning of after-treatment technologies, nationwide implementation of the China IV heavy-duty diesel vehicle emission standard has been delayed three times over the past three years and come into effect in 2015. The implementation of China IV standards can reduce PM and $NO_x$ emissions by 80 percent and 30 percent, respectively. Following repeated incidences of severe pollution in Beijing and across China since 2012, China's State Council (cabinet) called for nationwide desulfurization of gasoline and diesel fuels and set a deadline for the adoption of China V gasoline and diesel (10 ppm) fuel standards by the end of 2017. The China V diesel and gasoline standards were issued in June and December 2013, respectively.

**Table 3.** Fuel quality and pollutant control technologies

| Emission Control Technology | Vehicles used on | Pollutants controlled | Fuel Sulfur Requirements |
|---|---|---|---|
| **Three-way catalyst (TWC)** | Euro 1 gasoline | HC, CO, $NO_x$ | <500 ppm, conversion efficiency optimized with <30 ppm; emissions increase with higher sulfur levels but effects are reversible |
| **Diesel oxidation catalyst (DOC)** | Euro 3/III diesel | HC, CO, PM | <350 ppm variable<br><50 preferred |
| **Diesel particulate filter (DPF)** | Euro 5 diesel<br>Euro VI diesel | HC, CO, PM | <15 ppm |
| **Exhaust gas recirculation (EGR)** | Euro 3/III diesel | $NO_x$ | <350 ppm |
| **Selective catalytic reduction (SCR)** | Euro 6 diesel<br>Euro IV diesel | $NO_x$ | <350 ppm (vanadium-based)<br><50 ppm (zeolite-based) |
| **Lean $NO_x$ traps (LNT)** | Euro 6 diesel | $NO_x$ | <15 ppm |

Beijing was the trailblazer by adopting the Beijing 5/V fuel quality standard in 2012 (phased out when China 5/V was promulgated), followed by Shanghai in 2013. The surrounding region of Beijing (i.e. Tianjin and Hebei in the "Jing-Jin-Ji" area) is required to implement the China 5/V standard by the end of 2015, two years ahead of the nationwide deadline[8]. The sulfur level requirement of China V (10 ppm) enables the use of a diesel particulate filter (DPF) to dramatically reduce the primary cause of air quality woes in Beijing: emissions of $PM_{2.5}$, including black carbon, a key short-lived contributor to climate change.

Besides the changes in sulfur content, another notable development is the steep reduction of the chemical MMT[9] from 8 milligrams per liter (mg/L) to 2 mg/L for

8 Tianjin adopted China 5/V on September 1, 2015.

9 Methylcyclopentadienyl manganese tricarbonyl

gasoline required under the China 5 (10 ppm) standard. This standard is now aligned with the European limit value for MMT and reflects international best practices for controlling this metallic additive. MMT is a gasoline fuel additive based on manganese, a neurotoxin and heavy metal, that was first used in the 1970s to replace tetraethyl lead as an octane enhancer. Exposure to vehicle emissions of manganese not only poses a health risk (Minjares and Walsh, 2009), but the use of metallic additives like MMT can accelerate the degradation of the vehicle engine and affiliated systems, including corrosion of spark plugs, valves, and oxygen sensors, as well as catalyst plugging[10]. Other low-cost forms of maintaining fuel octane levels are widely used and have been implemented in all countries with modern refining operations including those in North America and Europe. Such actions have been taken voluntarily by refiners and are widely supported by global automakers. In the process of meeting the China V standard, Beijing lowered octane rating requirements for the fuel grading system from 90, 93, and 97 to 89, 92, and 95. This reflects a new precedent for other key regions in China to minimize the cost to refineries of maintaining fuel octane.

To incentivize the rollout of China IV- and China V-compliant fuels, the NDRC announced a new pricing policy for higher-quality fuels, increasing the prices of China IV gasoline and diesel (50 ppm sulfur content) by 290 and 370 renminbi (RMB)/metric ton ($47 to $60 per ton), respectively (NDRC, 2013). The prices of China V gasoline and diesel (10 ppm) are to be raised a further 170 and 160 RMB/ton, respectively. The total price increases for upgrading from China III to V gasoline and diesel are 460 and 530 RMB/ton ($75 to $86 per ton), respectively, equivalent to about 0.33 RMB/liter ($0.05 per liter) for gasoline and 0.45 RMB/liter for diesel. The price increases will result in about a 4.8 percent price increase for gasoline and a 6.0 percent price increase for diesel at the pump, if all the increases are passed on to consumers (Wagner, 2013). An ICCT study suggested that the additional cost to produce China V (10 ppm) fuels in China would be just 0.04 and 0.11 RMB/liter for gasoline and diesel, respectively, meaning that the NDRC is leaving ample margin for big refineries to cover the required facility upgrades and increased production costs (ICCT, 2012).

In contrast to on-road vehicles, nonroad engines and equipment use general diesel, which is regulated separately from on-road vehicle fuel. As mentioned in Subsection 3.3, the standards for general diesel were loose until July 1, 2013, when China reduced its maximum permitted sulfur content from 2,000 ppm to 350 ppm (GB252-2011). The stricter standards are effectively supporting the implementation of China III standards for nonroad engines and equipment. Currently in Beijing, all gas stations only provide 10ppm diesel, which could effectively ensure the stable and efficient performance of after-treatment technology required by upcoming China IV standards in 2015 as well as maximum emission reduction from nonroad engines. Nevertheless, the nonroad vehicle owners may get diesel from other sources for lower prices, which is not tracked by BEPB and may reduce benefits from adopting stringent emission standards.

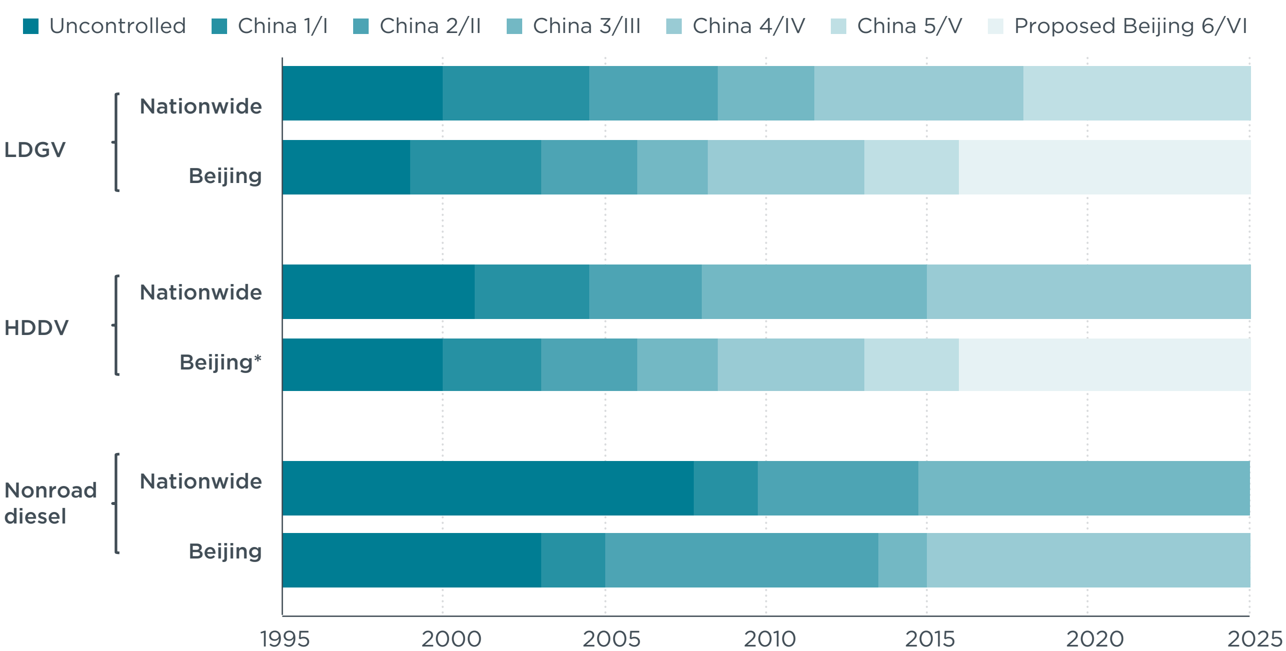
In summary, Beijing has been leading the nation in regulation aimed at advancing fuel quality. The higher fuel quality will not only substantially mitigate sulfur and PM emissions but will also facilitate the functioning of other emission reduction technologies, benefiting the environment and human health.

10 Catalyst plugging means that the channels of the catalyst get physically plugged so that exhaust gases cannot pass through

# 4. NEW VEHICLE EMISSION STANDARDS

Restricting tailpipe emissions from new vehicles is a key method used to improve local air quality in the long term. Over the past 25 years, China has been setting emission standards for various vehicle categories following the European pathway, including LDVs, HDVs, and nonroad vehicles. The most common approach for local governments that want to expedite the uptake of lower-emission vehicles into their fleet is to adopt the national standards with an accelerated timeline (known as early adoption). A number of cities have sped up the adoption of national standards (such as Beijing, Shanghai and Guangzhou). However, Beijing has gone a step further by establishing and implementing local standards ahead of national counterparts.

This trend is visualized in Figure 6, which compares the timeline of China's national standards for LDGVs, HDDVs, and nonroad diesel engines and equipment with Beijing's new vehicle emission standards. The timeline also includes predictions for new vehicle standards over the next 10 years. These standards together cover the majority of on-road and nonroad vehicles and engines in Beijing since all light-duty vehicles are powered by gasoline, while most heavy-duty vehicles are powered by diesel.[11] The figure points to Beijing's leading position in the adoption of vehicle emission standards over the past two decades. In general, Beijing has implemented new vehicle standards between one and five years ahead of the national government.




* *Beijing applied China IV to public HDDVs (buses, sanitation, and postal vehicles) since July 2008 and to other HDVs since July 2013*
*Beijing applied China V to public HDDVs since February 2013*

**Figure 6** Light-duty gasoline vehicle, heavy-duty diesel vehicle, nonroad diesel engine emission standard implementation dates

11 Note that Beijing and China also regulate other vehicles, including heavy-duty gasoline or alternative fuel vehicles, but these are not the focus of this report because of their limited presence within the vehicle fleet.

## 4.1. LIGHT-DUTY VEHICLES

The first emission standards for on-road vehicles date back to 1992. However, the standards were so lenient that most new vehicles could meet them without significant technical improvements (Wu et al., 2011). Beijing started to speed up LDV emission control by adopting the EU emission regulation pathway. In 1999, Beijing first implemented China 1 national LDV tailpipe emission standards (equivalent to Council Directive 91/441/1EEC of the European Economic Community, [i.e., Euro 1]). The standards were replaced by the China 1 national LDV tailpipe emission standards (China 1 matches Euro 1) in 2000. Since then, from China 1 to China 4, Beijing has been consistently adopting the national tailpipe emission standards ahead of the countrywide timeline.

Concomitant with the "Airpocalypse" in 2012, Beijing 5 (DB11/ 946-2013), which was proposed by the BEPB in 2013, was approved by the NDRC and came into effect on February 1, 2013 (BEPB, 2013). This marked the first time a local government was given leeway to establish its own standards ahead of national ones. In September 2013, the MEP released the national standard (China 5), which automatically superseded Beijing's local one. The emission limits in China 5 are the same as in Beijing 5. There are several other regions in China working toward early adoption of China 5 (such as Shanghai and Guangdong). The standards will be adopted nationwide in 2018.

In a deployment document issued by the Beijing government (2013a) on August 23, 2013, in response to the Beijing Clean Air Action Plan (2013-17), the municipal government set specific dates for future formulation and implementation of vehicle emission standards. For LDVs, the BEPB and Beijing Municipal Administration of Quality and Technology Supervision are drafting China 6 emission standards with a proposed implementation timeline in 2016. It is uncertain whether Beijing will be allowed to repeat its unique early adoption of Beijing 5 with Beijing 6, but, judging by previous experience and given the pressing environmental problems, approval from the national government is possible.

As seen in Figure 7, though China has been following the European precedent for vehicular emission standards, its implementation timeline lags the European equivalent by about five to eight years. Beijing, on the other hand, has moved much more quickly and has recently been trailing the EU standards by just one year. In sum, Beijing has shown leadership by adopting new vehicle emission standards for LDVs one to four years ahead of the countrywide timeline.

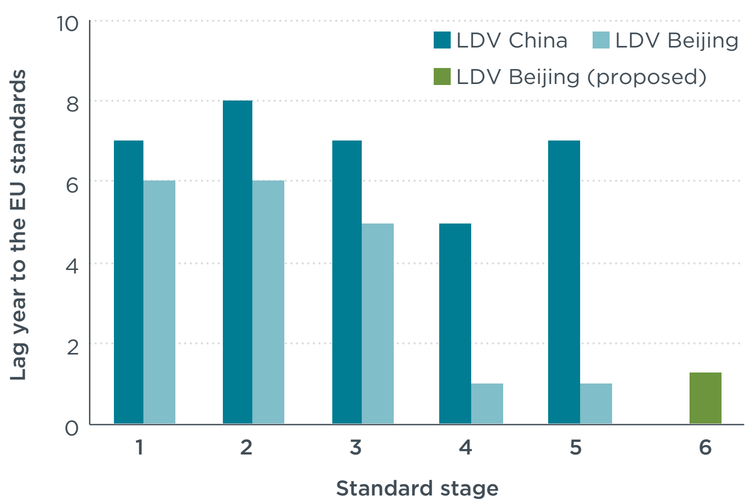



**Figure 7** Time lag with respect to Europe LDV tailpipe emission standards

## 4.2. HEAVY-DUTY VEHICLES

Similarly to the case for LDGVs, Beijing is also leading the adoption of HDDV emission standards in China. The first local HDDV emission standard for diesel and gasoline engines (China I) was released in 1999 and implemented in 2000, while the national standards came into effect in 2001. Beijing has followed the national HDDV emission standards from China II to China V but with a more aggressive implementation timeline. Regardless of the uncertainties about the timeline for the nationwide implementation of China V, Beijing has applied China V to new buses and city cleaning vehicles since February 2013 and to all HDVs operating in Beijing since June 2015. Moreover, eight types of HDVs that operate in Beijing, such as new buses and city cleaning vehicles, will need to install diesel particulate filters (DPFs), which would effectively reduce 70-99 percent of particulate matter (PM) emissions from those vehicles in urban areas (Sharpe et al., 2011).[12] The installation of DPFs will be checked at the time of the first registration.

In addition to the main tailpipe emission standards, Beijing in 2013 released two important testing standards, Limits and Measurement Methods for Exhaust Pollutants from Compression Ignition and Gas Fuelled Positive Ignition Engines of Vehicle (Bench mode methods) (DB11/964-2013) and Limits and Measurement Methods of Emissions from Heavy Duty Vehicle (DB11/965-2013) to supplement the national China IV and V HDDV standards. These local standards, implemented on March 1, 2013, were designed to prevent excess $NO_x$ emissions from HDDVs operating in the urban environment. The standards set requirements for HDDV engines through improved vehicle emission testing, including an additional test cycle (called the World Harmonized Transient Cycle [WHTC]), a requirement for both cold-start and hot-start tests, and a Portable Emissions Measurement System (PEMS) test for in-use compliance. These additional requirements ensure that manufacturers address the causes of off-cycle emissions[13] in order to receive the certification for type approval. The Beijing government predicted that per vehicle $NO_x$ emissions from new China IV and V HDDVs operating on urban cycles would be reduced by 60 percent (BEPB, 2014b).

By implementing this supplemental standard, Beijing becomes the first city in the world to attempt to solve a known deficiency in the Euro IV and V standards by requiring additional environmental testing (Tu and Wagner, 2013). But considering the difference in fuel quality requirements between Beijing and surrounding areas, the supplemental test is only required for HDVs operating in Beijing's urban area. Moreover, as many China IV and V vehicles have been introduced to the market before the promulgation of the supplemental standard, BEPB is also working on retrofitting or reprogramming earlier China IV/V vehicles to reduce their real-world emissions. For example, the BEPB has been working with the bus and engine companies reprogramming all 8800 China IV/V buses with SCR systems to keep up with the latest requirement (BEPB, 2015).

Following Beijing's actions, the MEP issued a supplemental policy at the national level (HJ689-2014), Limits and Measurement Methods for Exhaust Pollutants from Diesel Engines of Urban Vehicles (WHTC), which took effect on January 1, 2015. Given that urban excess $NO_x$ emissions from Euro IV and V vehicles have been commonly measured at two to three times that of the European Transient Cycle (ETC) limit value (Tu and Wagner, 2013), the supplementary limits should be effective at forcing manufacturers to adopt

12 DPF requires less than 50 parts per million sulfur content in fuel. Beijing has already adopted 50-ppm fuel.

13 Emissions that are not captured under certification test protocols

different $NO_x$ control strategies that function over a broader range of operating conditions and duty cycles. While the supplemental national and Beijing standards are similar in most respects, Beijing has a more stringent $NO_x$ emission standard for China IV vehicles.

Now Beijing intends to move forward to establish a world-class Beijing VI standard, drawing on experience from both the European Union and the United States. The Euro VI tailpipe emission standards could significantly reduce $PM_{2.5}$ emissions, by as much as 99 percent compared with those of uncontrolled vehicles (with a 50 percent reduction from Euro V PM limits). Beijing is also learning from the U.S. experience with on-board diagnosis (OBD) design and management. The city currently has a plan to apply Beijing VI in 2016 (BEPB, 2013).

As with LDGVs, as shown in Figure 8, Beijing has consistently adopted HDDV standards ahead of the national government (see Figure 8). The delay between the adoption of standards in the EU and in Beijing has tended to decrease over time (a three-year delay for Euro IV).

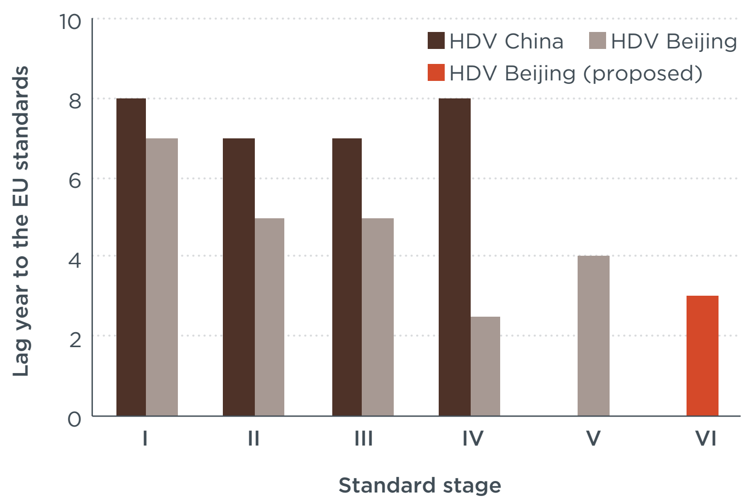



**Figure 8** Time lag with respect to European HDDV tailpipe emission standards

## 4.3. NONROAD ENGINES AND EQUIPMENT

Nonroad engines and equipment include vehicles and machines used for construction, agriculture, and gardening, such as excavators, loading machines, bulldozers, steamrollers, forklifts, compressors, and generators. In 2013, there were 100,000 construction machines operating in Beijing (Chinanews, 2013). Regulations to control nonroad engines and equipment have been lagging behind on-road vehicles, but emissions from this sector are extremely significant. Recent increases in urban construction (especially in major cities such as Beijing) have led to an increase in the quantity and emissions of nonroad engines and equipment. It is estimated that nonroad engines and equipment are responsible for 30.9 percent of the $NO_x$ and 26 percent of the PM emissions of total mobile sources (Ding, 2014).

Beijing promulgated and applied the Beijing I[14] standards for nonroad engines and equipment in 2003. Four years later, they were replaced by the national standard (China

14 Standards for nonroad engines and equipment are different from HDDVs, but the same Roman numerals are use to differentiate different phases of standards.

I), when it was implemented. In 2013, the nonroad Beijing III and IV standards, equivalent to Euro III Phase A and Phase B respectively, were issued with a specific implementation timeline. The China III and IV standards were issued one year later. As previously mentioned, once the national standards come out, they supersede the pre-existing Beijing standards.

As in the case of on-road vehicle regulations, the emission standards regulate CO, $NO_x$, PM, and THC emissions, as well as exhaust smoke (in China III/IV only). As discussed in detail in Section 4, a correspondingly low fuel sulfur level is necessary for the successful implementation of the more stringent emissions standards. Since July 1, 2013, the sulfur requirement for general diesel fuel for nonroad engines (GB252-2011) has been reduced to 350 ppm nationwide, effectively supporting the implementation of nonroad China III standards.

Figure 9 shows that, over the past 15 years, the delay in adopting standards between the EU and China was eight years for each stage from China I to China III. The average time delay for Beijing is closer to four years.

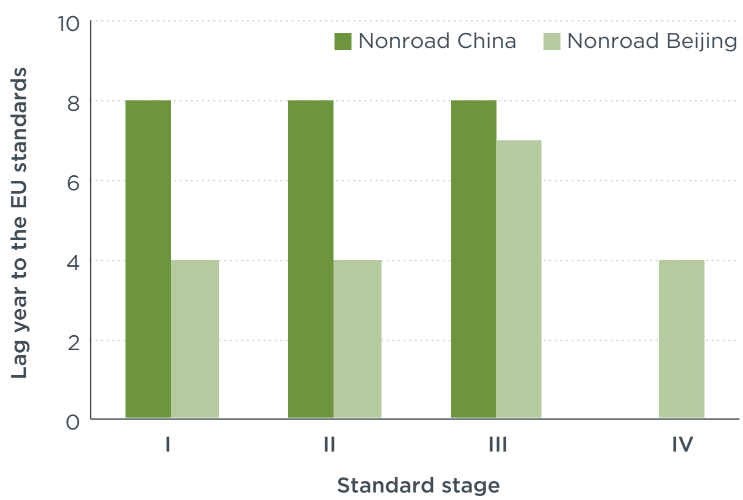



**Figure 9** Time lag with respect to European nonroad engines and equipment emission standards

The in-use compliance of nonroad engine and equipment emission standards has always been questionable. It is challenging to enforce conformity of production (COP) for the nonroad engines in China, which means the nonroad standards are weakly enforced in Beijing as well as other places in China. The real world emissions from the nonroad engines are likely higher than the estimated emission factors used in modeling. Therefore, nonroad engine and equipment emission control is becoming more and more pressing in regards to regional air quality control.

# 5. IN-USE VEHICLE EMISSION CONTROL PROGRAMS

Emission standards for new vehicles are critical for long-term pollution mitigation. At the same time, vehicles already on the road that comply with less stringent emission standards present a thorny challenge. Strong in-use vehicle emission control programs complement new vehicle emission standards to deliver immediate air quality improvements. These programs are especially important to Beijing, where more stringent emission standards are implemented rapidly. Figure 10 shows ICCT's estimates of historical on-road vehicle stock in Beijing, broken down by tailpipe emission standard. Despite the increasingly stringent standards that are coming into place for new vehicles, there is a large proportion (around 20 percent) of China 2/II or older vehicles in the 2013 fleet.

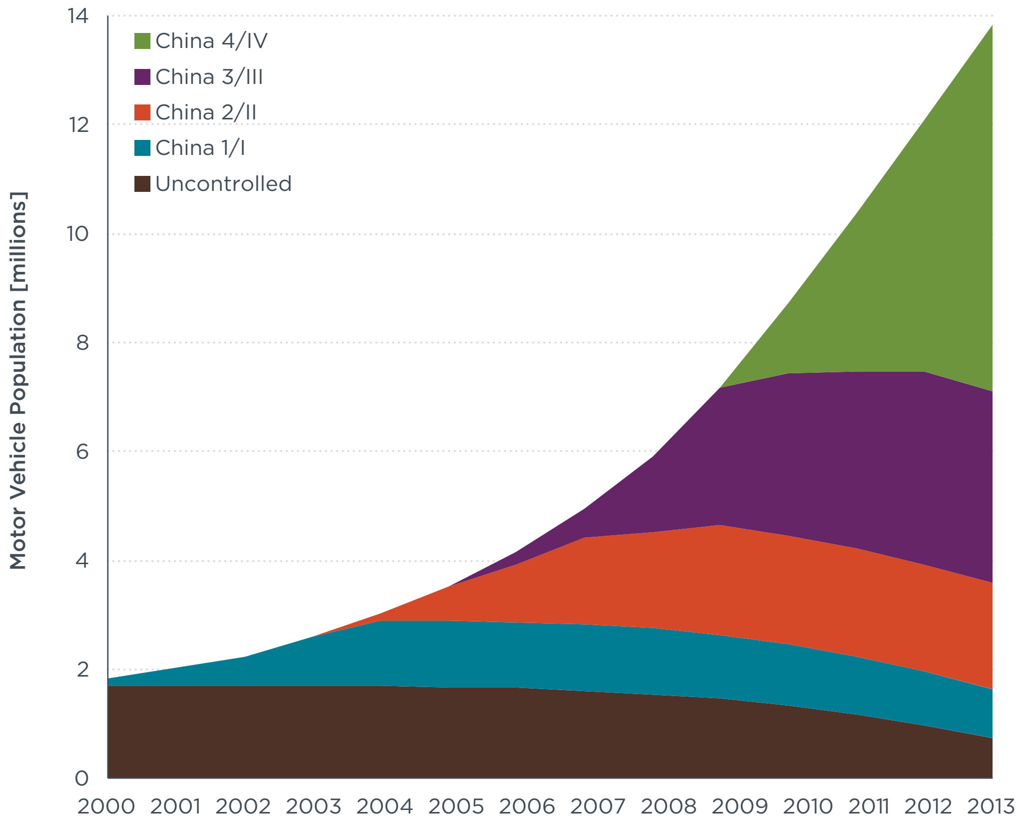



**Figure 10** Beijing's vehicle stock by tailpipe emission standard, 2000–2013

Since China has afforded its localities a great deal of autonomy when it comes to tackling the problem of in-use vehicle emissions, Beijing has been aggressive and innovative in its implementation of in-use vehicle controls with a wide range of regulatory tools. Strategies adopted by the city can be categorized according to three main purposes: 1) ensuring that on-road vehicle emissions do not exceed their certified level, such as through inspection and maintenance (I/M) and remote sensing; 2) reducing emissions from gross-emitting vehicles, by means of scrapping, replacing, or retrofitting older vehicles; and 3) reducing vehicle emissions in urban areas through traffic management: instituting low-emission zones, levying congestion charges, and applying vehicle usage restrictions.

## 5.1. ENSURING EMISSION STANDARDS COMPLIANCE OF ON-ROAD VEHICLES

### 5.1.1. Inspection and maintenance

One common practice used to manage in-use vehicle emissions is inspection and maintenance, which requires vehicles to go through certified safety and emissions testing periodically. Vehicles that fail the tests are required to undergo repair or maintenance before being allowed back on the road. Nevertheless, international experience shows that I/M programs have a hard time meeting expectations (Wagner and Rutherford, 2013). Local governments need to plan and implement their I/M programs carefully to be cost-effective and to ensure public support.

The Beijing Bureau of Transportation Management is in charge of the certification of inspection stations and issuance of I/M labels after vehicle safety inspections and emission testing. For I/M testing for LDVs and HDVs, the BEPB first adopted the two-speed idle test protocol in 1994 and evolved to the Acceleration Simulation Mode (ASM) test protocol in 2001 to better reflect real-world emissions (Wu et al., 2011). In 2005, the MEP released the *In-use Vehicle Emission Inspection Station Technique Manual*. Later on, the BEPB issued a local manual to specify the qualification and test procedures of inspection stations and regulatory agencies. During the inspections, technicians not only check vehicle emissions but also make sure major components are consistent with the type-approval requirements. The Beijing Development and Research Commission also sets the inspection fee that applies to all such stations. As of 2014, there are 43 inspection stations with more than 200 dynamometer testing lines adopting the ASM tests for gasoline vehicle and LUGDOWN tests for diesel vehicles (BEPB, 2014a). Moreover, Beijing has started a pilot project utilizing I/M OBD check for China 4/IV and China 5/V vehicles. Some inspectors are trained to check for emission control related malfunctions and to use an OBD scan tool to read the historical code.

Depending on vehicle type and age, vehicles are required to be tested once or twice a year (Table 4). Since September 1, 2014, according to a notice issued by the Ministry of Public Security and General Administration of Quality Supervision, Inspection, and Quarantine, private passenger cars are exempt from I/M tests for the first six years (AQSIQ, 2014).

**Table 4.** I/M frequency for some vehicle categories[15]

<table>
<tr><th></th><th colspan="20">Vehicle age</th></tr>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th></tr>
<tr><td>Light-duty passenger vehicle</td><td colspan="6">Exempt</td><td colspan="9">Every year</td><td colspan="5">Twice a year</td></tr>
<tr><td>Commercial passenger car</td><td colspan="5">Every year</td><td colspan="15">Twice a year</td></tr>
<tr><td>Commercial truck</td><td colspan="10">Every year</td><td colspan="10">Twice a year</td></tr>
<tr><td>Medium/heavy-duty passenger vehicle</td><td colspan="10">Every year</td><td colspan="10">Twice a year</td></tr>
<tr><td>School bus</td><td colspan="20">Twice a year</td></tr>
<tr><td>Others</td><td colspan="20">Every year</td></tr>
</table>

*Source*: Beijing Bureau of Transportation Management, http://www.bjjtgl.gov.cn/publish/portal0/tab90/info5653.htm

15 Inspections are required for all vehicles at the first time of registration, including checking fuel injection, catalyst, etc.

### 5.1.2. Remote sensing

To ensure that on-road vehicles are actually meeting their certified emission level, roadside tests are a powerful approach to supplement I/M programs. Remote sensing is a technology that carries out roadside inspections, especially at night. By scanning traffic from a distance, the remote sensing systems can test vehicle tailpipe emissions and the camera takes a snapshot of the license plate and matches the test data with the environmental label in the database. For the inspection of other elements, such as after-treatment devices, OBD malfunctions and codes, and Adblue injection (a liquid urea solution added to cut down on $NO_x$ emissions), a roadside test is required (BEPB, 2014a).

In June 2013, Beijing started an initiative to test tailpipe emissions from on-road vehicles. There are nine remote-sensing vehicles and more than 20 remote sensors working at different monitoring spots throughout the city. After identifying unqualified vehicles, the BEPB will send notices to the vehicle owners to inform them of the penalty and will publish the monitoring results on its website.

At present, remote sensing is not precise enough to test discrete emission factors for individual vehicles with high accuracy, but it is an efficient method to identify gross emitters, to evaluate fleet-wide trends over time, and to assess the effectiveness of I/M programs (Wagner and Rutherford, 2013). With the remote-sensing initiative, Beijing is one step closer to a comprehensive in-use vehicle emission management system.

## 5.2. REDUCING EMISSIONS FROM GROSS-EMITTING VEHICLES

### 5.2.1. Identification of gross-emitting vehicles

Beijing established its environmental labeling system in 1999, when the Beijing 1 (China 1) emission standards came into effect. The same practice was introduced nationwide when national emission standards came into force. The labels were certified by local environmental protection bureaus and distributed to vehicle owners after annual emission inspections. Vehicles without labels are illegal to drive. There are three types of labels issued by the BEPB, covering vehicles with different emission standards (Figure 11). The yellow label is issued for LDVs unqualified for China 1 emission standards and HDVs unqualified for China III emission standards. The blue label, current only available in Beijing, is issued for vehicles meeting China 5/V emission standards. The green label is issued for all vehicles that fall between the other two. Within each label type, the shades of the label are used to differentiate the various technologies and standards.

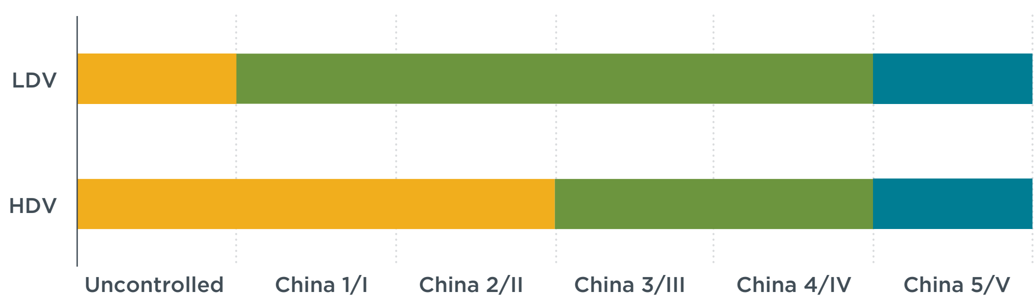



**Figure 11** Label colors for vehicles in Beijing

Yellow-label vehicles (YLVs) and aging China 1/2 vehicles are the main contributors to on-road vehicle pollution. With modern emission control systems on vehicles to meet various emission standards, green-label vehicles emit 25-90 percent less $PM_{2.5}$ than light-duty

YLVs and 80-99 percent less $PM_{2.5}$ than heavy-duty YLVs (Shao, Wagner, and Yang, 2014). Before the latest scrappage and replacement programs got under way in 2009, there were 350,000 YLVs on the streets and highways of Beijing. According to the ICCT model, those YLVs contributed around 70 percent of on-road PM and $NO_X$ emissions. Therefore, reducing emissions from gross-emitting vehicles is a "low-hanging fruit" policy and one of the most efficient ways to slash emissions from in-use vehicles immediately.

### 5.2.2. Scrappage and replacement

The practice of scrapping and replacing high-emitting vehicles in Beijing started in the 1990s. From 1996 to 2001, Beijing scrapped 120,000 pre-China 1 vehicles, including all of the 22,000 minivan (also known as "bread bun") taxis (Xinhua, 2002). Since 2005, more than 7,000 gasoline-powered buses have been phased out or replaced (Wu et al., 2011).

As new vehicles on the road became ever cleaner, Beijing started to speed up the scrappage of YLVs from September 2008 onward by compensating vehicle owners who retire them early or transfer them outside of Beijing. According to the "Management of Encouraging Early Scrappage of Yellow-label Vehicles," vehicle owners who scrapped their YLVs between September 27, 2008, and June 30, 2009, were eligible for 800 RMB to 25,000 RMB (about $131 to $4,086) compensation. Lesser compensation was awarded for vehicles scrapped during the rest of 2009. The program was extended throughout the year 2010, offering slightly higher subsidies.

When the State Council announced a national aging vehicle and YLV scrappage program on June 1, 2009, car owners in Beijing were able to participate in either the national or the local program during the overlap period. China is currently implementing one of the world's most far-reaching voluntary scrappage programs (Wagner and Rutherford, 2013). Beijing once again led the charge. Its two-year YLV scrappage program retired about 150,000 vehicles, representing 85 percent of total YLVs (BEPB, 2011).

In 2011, the Beijing government expanded its scrappage program to 1.8 million older vehicles (those in service for 6 years or more). The policy was targeted at eliminating China 1/I and 2/II vehicles purchased in or before 2005. From August 2011 to the end of 2012, owners of aging vehicles were encouraged to retire them or transfer them out of the city, with compensation ranging from 3,000 RMB to 10,500 RMB (about $484 to 1,694) (Beijing Government, 2011). This program continued in 2013 and 2014 with revised compensation rates, increasing compensation for scrapping by 2,000 RMB (about $323) for most type of vehicles and easing the criteria for eligible vehicles (Beijing Government, 2012).

To ensure the actual disposal of vehicles, owners who apply for subsidies must provide scrappage certification from a Beijing Traffic Administration Bureau (BTAB) designated vehicle scrappage station to apply for the subsidy. Since the BTAB is responsible for vehicle scrappage management, the BEPB is working with it to ensure that the handling of scrapped vehicles is in accordance with the regulations (BTAB, 2014).

In 2014, the Energy Saving and Emission Reduction Action (2014-15) issued by the State Council assigned an ambitious target for Beijing to scrap 391,000 YLVs and older vehicles, much more than the 200,000 specified in the Beijing Clean Air Action Plan (2013-17). Beijing met the 2014 scrappage target one month early (Table 5). In the longer term, Beijing has set a goal to scrap all YLVs by the end of 2015 and to retire 1 million aging vehicles from 2013 to 2017.

**Table 5.** Yellow-label and aging-vehicle scrappage results (and targets) from 2009 to 2014

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|
| **YLV** | 106,000 | 50,372 | | | | |
| **Aged vehicle*** | | | 220,400 | 370,700 (150,000)** | 324,500 (180,000) | 476,000 (391,000) |

* Vehicles older than 6 years.
** Scrappage target for the year is shown in parentheses

### 5.2.3. Retrofitting

Instead of eliminating older vehicles, retrofitting programs can upgrade vehicles so that they can continue to be driven, but with fewer emissions. Based on international experience, most retrofitting programs are small in scale, largely conducted by local authorities (Wagner and Rutherford, 2013). Whenever local agencies are developing a retrofitting program, smaller-scale pilot projects are necessary to build capacity and to find solutions that are compatible with local conditions. The cost-effectiveness of the retrofitting program is usually ambiguous because of the uncertainty of the cost of the appropriate technology and its resultant real-world emission reductions. Such programs must be well designed and implemented in order to be effective. Beijing has implemented a few pilot projects to retrofit the in-use fleet.

#### *Three-way catalytic converter retrofits*

As early as 1999, when Beijing adopted its first emission standards, the government started to retrofit LDVs purchased after 1995 by adding electronic controls and three-way catalytic converters, which could reduce $NO_x$, HC, and CO by more than 90 percent. By 2001, 154,000 vehicles had been retrofitted (Xinhua, 2007). Complemented by restrictions barring pre-China 1 vehicles from entering the area circumscribed by the Second Ring Road from late 2003 forward, some vehicle owners chose to install a TWC to switch from the yellow to the green label.

Even though some progress was achieved, there was controversy regarding whether the consumer should bear the entire cost of the TWC retrofit to comply with regulations. The impact of the installment of a TWC on vehicle performance raised a lot of concerns. Additional skepticism was voiced over the duration of TWC retrofits; they sometimes last just a couple of years owing to deterioration. Furthermore, retrofitted vehicles will become high-emitting vehicles after a short period of time if the after-treatment equipment is not well maintained and breaks down (Wu et al., 2011).

#### *Clean fuel retrofitting program for the taxi fleet*

Since 1999, taxi operators started retrofitting their vehicles to accept cleaner fuels as part of a municipal drive to convert old gasoline-powered taxis into flexible-fuel vehicles (FFVs) that can use either gasoline or liquefied petroleum gas (LPG). By 2003, there were about 45,000 LPG flexible-fuel taxis in Beijing, most of which were retrofits (Wu et al., 2011). However, not only did the retrofits result in limited emission reductions, but they also had a negative impact on engine power. The cost saved by using LPG was also offset by the limited access to LPG fueling stations. The program ultimately failed to achieve the expected results.

*Bus diesel particulate filter retrofitting*

Prior to the 2008 Olympics, Beijing considered reducing air pollution (especially PM) by adding diesel particulate filters (DPFs) to buses. A joint study on 25 buses by the BEPB, the U.S. Environmental Protection Agency, the MEP, and the Southwest Research Institute showed that passive DPFs did not work well since the catalyst is inactive at the relatively low temperature that prevailed during operation (EPA, 2008). As a result, electrically assisted (active) DPFs were chosen for China I/II buses.

However, a DPF requires a secondary means of burning off accumulated particulate matter periodically. Since the bus engines were outdated, the regeneration systems in the retrofitted buses needed to be plugged in and cleaned manually every night. The level of maintenance needed to keep the filters from being overwhelmed by soot constituted a tremendous burden for the operators. The program was cancelled eventually.

Beijing has also launched many smaller retrofitting programs that this report does not have the space to elaborate on. It is always technically challenging to guarantee satisfactory performance of retrofitted engines or after-treatment equipment without deeper cooperation and support from manufacturers. Therefore, every pilot program, successful or failed, provides valuable experience for the future consideration of retrofitting programs.

## 5.3. REDUCING VEHICLE EMISSIONS IN URBAN AREAS THROUGH TRAFFIC MANAGEMENT

Alongside technology-based emission reduction regulations and programs, traffic management is a complementary measure to reduce in-use vehicle emissions. Congestion reduces vehicle speed in the city. On one front, traffic management in Beijing reduces urban vehicle emissions by restricting high-emitting vehicle traveling in the city. On the other, Beijing reduces on-road vehicle numbers to reduce emission levels and relieve congestion.

### 5.3.1. Traffic restriction

Figure 12 summarizes the expansion of traffic restrictions to YLVs and nonlocal vehicles. Because of their massive emissions, the squeeze on YLVs began in 2003. YLVs were first forbidden from driving inside the Second Ring Road, and the restricted area was expanded to the Fifth Ring Road starting from January 1, 2009, and further to the Sixth Ring Road from October 1, 2009. As of 2015, YLVs registered outside Beijing will be forbidden in the entire Beijing metropolitan area. YLV drivers who violate the restriction face a 100 RMB ($16) penalty and are assessed points on their licenses.[16]

Additionally, Beijing strictly controls vehicles registered outside the city. On December 16, 2010, the Beijing Municipal Public Security Bureau issued a Notice on the Nonlocal Passenger Vehicle Traffic Management Measures to limit the entrance of vehicles registered outside the city for emission reduction purposes (BPSB, 2010). Passenger vehicles registered outside Beijing are required to apply for a Beijing City Pass (effective for seven days) to proceed beyond the Fifth Ring Road. During peak hours, moreover, only local passenger vehicles are allowed within the circuit of the Fifth Ring Road. Starting from April 11, 2014, the area requiring the City Pass for passenger vehicles was

16 Points are accumulated on an annual basis. Drivers who receive 12 points in any one year will have their license temporarily revoked and will be required to study traffic laws.

expanded to the Sixth Ring Road, according to a new notice on traffic management (BPSB, 2014). Nonlocal trucks are only allowed to pass beyond the Sixth Ring Road from midnight to 6 am. Since YLVs are no longer eligible for the City Pass and will be forbidden from driving in the entire metropolitan area by the end of 2014, they will completely disappear from Beijing's streets.

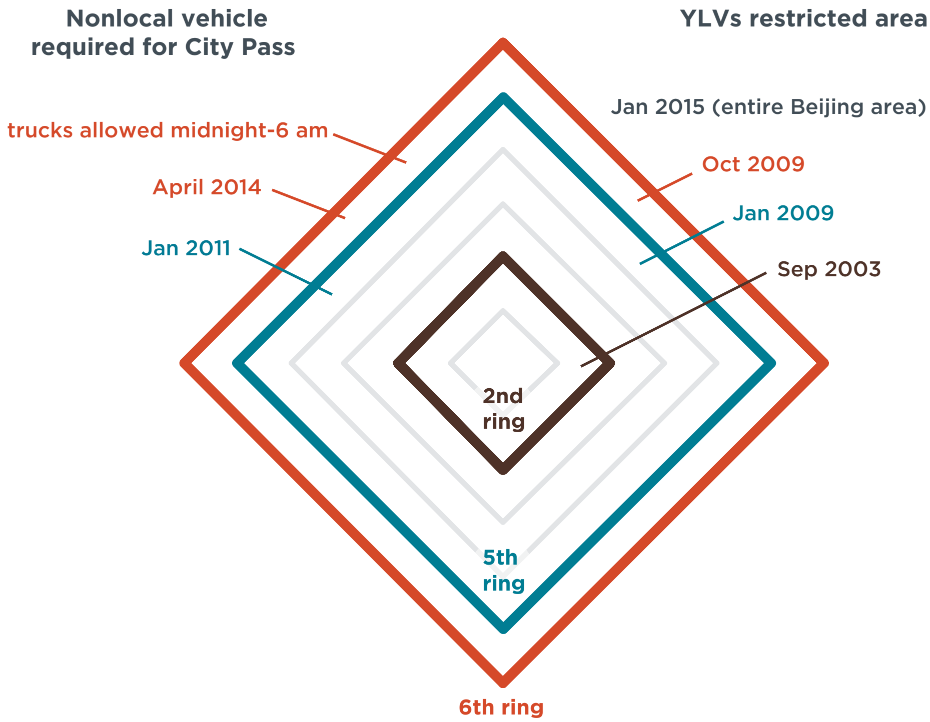



**Figure 12** Traffic restrictions on yellow-label vehicles and nonlocal vehicles in Beijing

Beijing is planning to carry out a more comprehensive low emission zone (LEZ) program in 2016 to buttress the current driving restrictions. This program constrains road access not only for YLVs but also for some green-label vehicles, such as China 1 LDGVs.

### 5.3.2. Vehicle usage restrictions

Beijing is the first city in China to order temporal limits on vehicle use according to license plate numbers in an effort to stem traffic congestion and cut down on emissions. In 2008, when the city was preparing to hold the Olympics, the municipal government temporarily implemented alternate driving days for cars with even- and odd-numbered license plates, over the course of two months, to relieve traffic congestion and reduce ambient pollution. The dramatic emission reduction the city experienced at the time showed the effectiveness of the program, which was consequently extended after the Olympics with a less aggressive regime—vehicles were not allowed on the roads one day per week from 7 am to 8 pm within the Fifth Ring Road, with the day based on the last digit of their license plate numbers. Both local and nonlocal vehicles must comply with the rules.

This approach is seen as a short-term solution to alleviate the problem of emissions. On October 21, 2013, the Beijing government issued an Emergency Plan for Extreme Air Pollution (Beijing government, 2013c), announcing that the alternate driving days rule will be in effect whenever the local forecast predicts at least three consecutive days of severe air pollution.[17]

## 5.4. GASOLINE VAPOR RECOVERY

Volatile organic compounds (VOCs), commonly released in gasoline vapor, not only contribute greatly to ozone formation when reacting with $NO_X$ but also generate direct toxic emissions such as benzene, toluene, and xylene, jeopardizing human health (Fung and Maxwell, 2011). In 2000, the BEPB issued a regulation for gas station fuel vapor recovery to curtail the emissions of VOC vapor at storage tanks as tanker trucks unload gasoline products ("Stage I recovery" in the United States) and at the nozzle when car owners refill their fuel tank ("Stage II recovery"). Three years later, the nationwide Emission Controls and Limits for Fuel Vapors from Filling Station (DB11/208-2003) was released and came into effect in October 2003. For Stage I recovery, the vapor recovery equipment usually collects vapor from the underground storage tanks and transfers it back to the empty tanks on tanker trucks. For Stage II recovery, filling stations are required to install vacuum-assist nozzles that recover vapor escaping from the fuel tank and circulate it back to the underground oil storage tank.

The fuel recovery process was not successful initially because excess vapors escaping from underground storage tanks were not sufficiently contained. Beijing started to address this problem in April 2007 by launching a retrofit program for equipment to recover fuel at gas stations. With the aid of a financial subsidy from the local government, all gas stations, fuel storage tanks, and tanker trucks were equipped with fuel recovery and recycling capabilities. The program retrofitted more than 37 storage tanks, 1,400 gas stations, and 1,243 tanker trucks before the Beijing Olympics, with an estimated reduction of about 20,000 metric tons of VOCs per year (BEPB, 2014a).

In 2007, the MEP released the first national Emission Standard of Air Pollutant for Gasoline Filling Stations (GB20952-2007). In 2010, Beijing updated its standards (DB11/208-2010), adding requirements for online monitoring, vapor emission processing equipment, and some other supplementary provisions for testing and equipment. Prior experience demonstrated that fuel recovery inspection at gas stations is integral to the enforcement of standards. The BEPB began increasing the frequency of inspections to ensure the effectiveness of vapor recovery from refueling at gas stations (BEPB, 2014c). In 2013, the pass rate for inspections at fuel recovery facilities had reached 85 percent (Xie, 2014).

To better capture fuel vapors at the pump during refueling, the United States has introduced onboard refueling vapor recovery (ORVR) in addition to the vapor recovery system at the pump (Stage II). ORVR and Stage II recovery are types of emission control systems that capture fuel vapors from vehicle gas tanks during refueling (see Box 2). Since Stage II requires a big investment in equipment maintenance and inspection to ensure high recovery efficiency, ORVR appears to be a better option to limit different instances of vapor release (e.g., from parking, running loss, gas tank permeation and refueling) with built-in equipment in cars. In the Beijing Clean Air Action Plan 2013-17, the BEPB aims to incorporate ORVR standards and to implement a strategy to control refueling emissions at the pump by 2015.

17 Severe air pollution is defined as conditions with the air quality index (AQI) above 300 on a scale that goes up to 500, according to Technical Regulation on Ambient Air Quality Index (HJ633-2012) http://kjs.mep.gov.cn/hjbhbz/bzwb/dqhjbh/jcgfffbz/201203/t20120302_224166.htm

### BOX 2: VAPOR RECOVERY SYSTEM (STAGE II) VS. ORVR (FUNG AND MAXWELL, 2011)

Stage II vapor recovery systems operate at gasoline retail facilities by collecting gasoline vapors from a vehicle's fuel tank while customers dispense gasoline products into the tank. The Stage II regulation can be implemented quickly. There is no requirement for a full turnover of the vehicle fleet, and equipment can be retrofitted. However, it requires high capital investment, and the system is subject to deterioration from heavy use. Thus, monitoring and maintenance are necessary to ensure the efficiency of fuel recovery control. Some small-volume filling stations cannot afford the installment and maintenance of vapor recovery units.

ORVR captures fuel vapor from the vehicle gas tank during refueling. The ORVR system is highly efficient and requires little maintenance. The cost of adopting ORVR is minimal per vehicle. It is more cost-effective than converting all gas stations nationwide. However, since the devices cannot be retrofitted onto previous models, the fleet turnover rate will determine the fleet-wide efficiency of vapor recapture at any given time, which means that the approach requires a long implementation period.

# 6. OTHER STRATEGIES

## 6.1. ALTERNATIVE FUEL VEHICLES

Alternative fuel vehicles run on a fuel other than traditional gasoline or diesel, such as electricity or natural gas. To reduce air pollution and alleviate dependence on foreign oil, the Chinese government instituted a plan to boost the market penetration of new energy vehicles (NEVs), including battery-powered vehicles, plug-in hybrid electric vehicles, and fuel-cell vehicles. The plan aims at improving the competitiveness of domestic automakers and surpassing foreign automakers in producing NEVs. Beijing's first milestone was the operation of 600 battery-electric and plug-in hybrid buses during the 2008 Olympics. Since then, Beijing, along with some other cities, has been exploring ways to promote NEVs publicly, amid tremendous hopes and challenges. Meanwhile, Beijing has also been a world leader with its extensive natural-gas-fueled buses on the road.

### 6.1.1. New energy vehicle pilot city program

The first large-scale attempt to pitch NEVs to the wider public was Beijing's participation in the Energy-saving and New Energy Vehicle Promotion Pilot Program ("NEV Pilot Program") in 2009. The program was jointly administered by the Ministry of Finance, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, and the NDRC. To spur early adoption, the government lavished generous subsidies on the purchase of NEVs. As one of the 13 cities initially selected for the pilot program, Beijing stood to benefit from financial support from the national government for the purchase of public and private NEVs and the installment of charging stations. The pilot program expanded to a total of 25 cities in 2010.

The initial NEV targets for selected cities are illustrated in Figure 13. Beijing set an ambitious target of 5,000 public and 30,000 private NEVs by the end of 2012. Despite the generous subsidies and the high hopes of policymakers, the NEV program did not take off as fast as expected. By the end of the program, Beijing had added only 3,388 NEVs, all of them in public service.

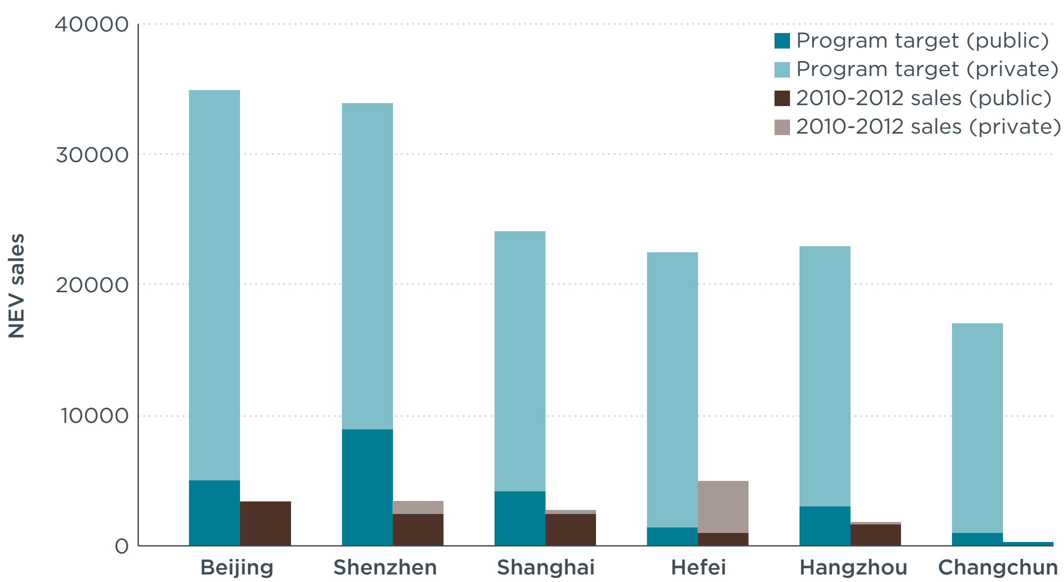



**Figure 13** New energy vehicle targets in selective cities *(Source: CATARC & Nissan China, 2013)*

### 6.1.2. Revised new energy vehicle promotion program

In 2013, the national government continued to refine its NEV push with revised subsidy provisions. A notice was issued extending the NEV subsidy policy for pilot cities to 2015. Learning from the past experience, the new program set minimum NEV sales targets for participating cities. Participating cities in the more developed eastern regions of the country were required to sell no fewer than 10,000 NEV units by the end of 2015, while assignments for the rest were set at 5,000 units. The policy limited locally manufactured vehicles to below 70 percent of total sales to discourage local industry protectionism and required participating cities to have NEVs make up at least 30 percent of new public vehicles (He, 2013b). Beijing, along with Shenzhen, has set a target of 35,000 units per year under the revised NEV promotion program, topping both other cities and the central government's requirements.

Subsidies for NEVs ranged from 35,000 to 500,000 RMB ($5,737 to $81,967) in 2013 and were cut by 5 percent in 2014 and by 10 percent in 2015. The adjusted NEV subsidy is tied to the all-electric driving range of the vehicle. This mechanism moves away from the complicated and little understood former method linking the subsidy with a combination of type of technology, fuel-saving potential, and an artificial utility parameter determined by power output (Ministry of Finance, 2013). Table 6 summarizes the new incentives for NEVs provided by the national government (He, 2013b).

**Table 6.** The 2013-15 subsidies for various types of vehicles, based upon specific improvements for each vehicle type (He, 2013b)

| Type and technology | | Criteria | Amount in 1,000 *RMB* 1,000 *US$ in parentheses* | | |
|---|---|---|---|---|---|
| | | | **2013** | **2014** | **2015** |
| **Passenger cars** | **PHEV** | R>50 km | 35 (5.7) | 31.5 (5.2) | 28 (4.6) |
| | **BEV** | 80≤R<150km | 35 (5.7) | 31.5 (5.2) | 28 (4.6) |
| | | 150≤R<250km | 50 (8.2) | 45 (7.4) | 40 (6.6) |
| | | R≥250km | 60 (9.8) | 54 (8.9) | 48 (7.9) |
| | **FCV** | / | 200 (33) | 180 (30) | 160 (26) |
| **Buses** | **PHEV** | L≥10 | 250 (41) | 250 (41) | 250 (41) |
| | **BEV** | 6≤L<8 | 300 (49) | 300 (49) | 300 (49) |
| | | 8≤L<10 | 400 (66) | 400 (66) | 400 (66) |
| | | L≥10 | 500 (82) | 500 (82) | 500 (82) |
| | **Supercapacitor/ lithium titanate** | / | 150 (25) | 150 (25) | 150 (25) |
| **Civil BEVs (postal, civil logistics, sanitation, etc.)** | | / | 2/kWh capped 150 (25) | 1.8/kWh, capped 135 (22) | 1.6/kWh capped 120 (20) |
| **HD commercial FCV** | | / | 500 (82) | 450 (74) | 400 (66) |

R= all-electric range for battery-electric vehicles or plug-ins, measured in km
L= length of buses, measured in meters
PHEV = plug-in hybrid electric vehicle; BEV = battery-electric vehicle; FCV = fuel-cell vehicle

To complement the national subsidies, Beijing is as of 2014 providing additional subsidies that match the national subsidies per electric vehicle to encourage NEV sales. Currently, Beijing is offering subsidies to buyers of seven new energy vehicle models registered in the Beijing NEV catalog (see Box 3), including the BAIC E150EV and the

C70GB, the JAC Heyue iEV, the BYD E6, the BYD-Daimler Denza EV, the BMW Brilliance Zinoro 1E, and the SAIC Roewe E50 (Beijing Government, 2014b, 2014c).

### BOX 3: LOCAL NEW ENERGY VEHICLE CATALOGS

The practice of publishing catalogs that list NEVs eligible for municipal subsidies has stirred controversy in China as a form of local protectionism. Beijing, for instance, effectively excludes other electric vehicles from its subsidy scheme by publishing a catalog that only includes a limited number of vehicle models. Other cities have charted a similar course either by publishing an exclusive catalog or by formulating criteria that only some manufacturers (often local ones) can meet. This type of localized protectionism has long hindered the development of the national economy, and the NEV policy is no exception. Without a national market established in practice, the benefits of economy of scale and efficiency remain unrealized. As a result, the national government changed the rules of the NEV promotion initiative to require a certain number of vehicles to be made outside of any city participating in the pilot program. A more sweeping move would be for the national government to eliminate local catalogs entirely and to sponsor a nationwide list of preapproved models that every city must adopt.

In addition to direct subsidies, China has exempted NEVs from "vehicle and vessel tax"[18] since 2012. The exemption from the new vehicle acquisition tax between September 2014 and the end of 2017 provides a large tax break (representing 10 percent of vehicle price) that further reduces the cost of NEVs across the country (China State Council, 2014).

Beijing also is integrating NEV promotion with its license plate lottery. There are 20,000 NEV license plate slots set independently from conventional vehicles and evenly distributed over 12 months in 2014, and the quota is set to expand to 30,000 in 2015. Owing to the competitiveness of Beijing's license plate lottery, this approach effectively spurs customer interest in NEVs, which can be seen by a steady increase in the application rate (see Table 7). However, many distributed quotas expired prior to being used[19], which means a number of selected applicants gave up purchasing NEVs after being selected. This reflects issues such as the lack of readiness of charging facilities and the limited selection of NEV models.

18 "Vehicle and vessel tax" is a tax that vehicle and vessel owners are required to pay annually.

19 Applicant must purchase the vehicle within 6 months of being selected, otherwise the quota is seen as expired and rolled to the next round of lottery quota.

**Table 7.** Beijing 2014 NEV quotas and application numbers (every two months)

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| **Private car** | | | | | | |
| **Quota** | 1,666 | 1,904* | 1,666 | 1,812 | 2724 | 4157 |
| **Application** | 1,428 | 2,420 | 1,520 | 1,734 | 2108 | / |
| **Final Selected** | 1,428 | 1,904 | 1,520 | 1,734 | 2108 | / |
| **Expired**** | 980 | 1,618 | 1,193 | / | / | / |
| **Company car** | | | | | | |
| **Quota** | 1,666 | 1,666 | 1,666 | 2134 | 3005 | 4316 |
| **Application** | 2,537 | 2,557 | 1,198 | 795 | 468 | / |
| **Final Selected** | 1,666 | 1,666 | 1,198 | 795 | 468 | / |

* Any quota slots that go unfilled will automatically be rolled over into the quota of the next round. The grey marks indicate whether the application exceed the quota of each around. If yes, the quota number is marked as grey; if no, the application number is marked as grey.

*Source*: ESCN, 2014; people.cn, 2014, BJHJYD (http://www.bjhjyd.gov.cn/jggb/index.html)

** Selected applicant must purchase the NEVs within 6 months of being selected or is seen as giving up the quota.

To facilitate local sales of NEVs, Beijing plans to complete the construction of 1,000 public fast-charging electric carports in 2014, covering the downtown and outlying areas. These NEV charging devices, estimated at 5 million RMB ($817,000) each, are categorized according to two types: (1) individual use for private and business purposes and (2) public use (Beijing Review, 2014). As a long-term plan, Beijing plans to build a charging circle with an average radius of 5 kilometers within the Fifth Ring Road, gradually forming a service system of public charging devices with 10,000 public fast-charging electric carports by 2017. The individual-use ports will work through the alternating current slow-charging mode, while the public ones will employ the direct current fast-charging mode, which enables an ordinary vehicle to travel 100 km after half an hour's charging (Beijing Review, 2014). Nevertheless, the pace of charging infrastructure development in Beijing is still slow compared with leading cities in other countries, such as San Francisco in California, US (Lutsey et al., 2015).

As part of the 2013-17 Beijing Clean Air Action Plan, the city has introduced clean energy vehicles into the government's fleet. The promotion of NEVs extends to public transportation (buses and taxis). Beijing incorporated almost 2,000 NEVs into its public fleet in 2013 and has set a target of 8,507 for 2014-15.[20] Even though it is hard to evaluate its success by extrapolating from NEV sales, Beijing continues making efforts to promote NEVs to consumers as well. With a combination of more far-reaching government targets, generous subsidies, big tax breaks, increasing prevalence of charging stations, and better chances to obtain license plates, Beijing is going well beyond the introduction of NEVs for public service activities to encourage private purchases in the mass market. The long-term objective is for new energy and clean energy cars to reach 200,000 in total by 2017.

20 For more details, see http://www.gov.cn/xinwen/2014-10/22/content_2769115.htm.

### 6.1.3. Natural gas vehicles

In addition to electric vehicles, Beijing is also actively expanding the fleet powered by natural gas, especially the bus network. In 1999, 300 compressed natural gas (CNG) buses were brought into service in the area bounded by the Second Ring Road. In 2001, Beijing became the city with the largest natural-gas-powered bus fleet in the world, with 1,300 CNG buses accounting for 17 percent of the total (BJbus, 2014). The CNG bus fleet was expanded further to 4,000 in 2007 as part of the effort to improve air quality during the 2008 Olympic Games (Xinhua, 2007).

Since the buses have limited downtime for refueling, the scale of the CNG bus fleet is restricted by the capacity of existing fueling stations. This puts a significant constraint on the CNG fleet but at the same time encouraged Beijing to find more efficient alternatives. Since liquefied natural gas (LNG) has a higher energy density and therefore affords a longer range for a similar size fuel tank, the city introduced LNG buses in 2012 to meet the growing demand for clean transport. By early 2013, there were 640 LNG buses running in Beijing (BJWB, 2013), and that number will expand as LNG buses start to replace retiring diesel buses. Overall, by the end of 2013, there were 4,551 natural gas buses operating on the road, accounting for 20 percent of the bus fleet (BJbus, 2013).

The adoption of alternative fuel vehicles by the public transportation system is seen as an important measure to reduce urban HDDV emissions. Beijing is seeking to have alternative fuel vehicles constitute 65 percent of the public transportation fleet by 2017. Figure 14 diagrams the recent history of energy sources for public transportation in Beijing, with future projections included. The municipal government is poised to expand natural-gas-fueled buses to 50 percent of the fleet by 2020. For taxis, natural gas will also make inroads by 2020, powering 7 percent of the fleet.

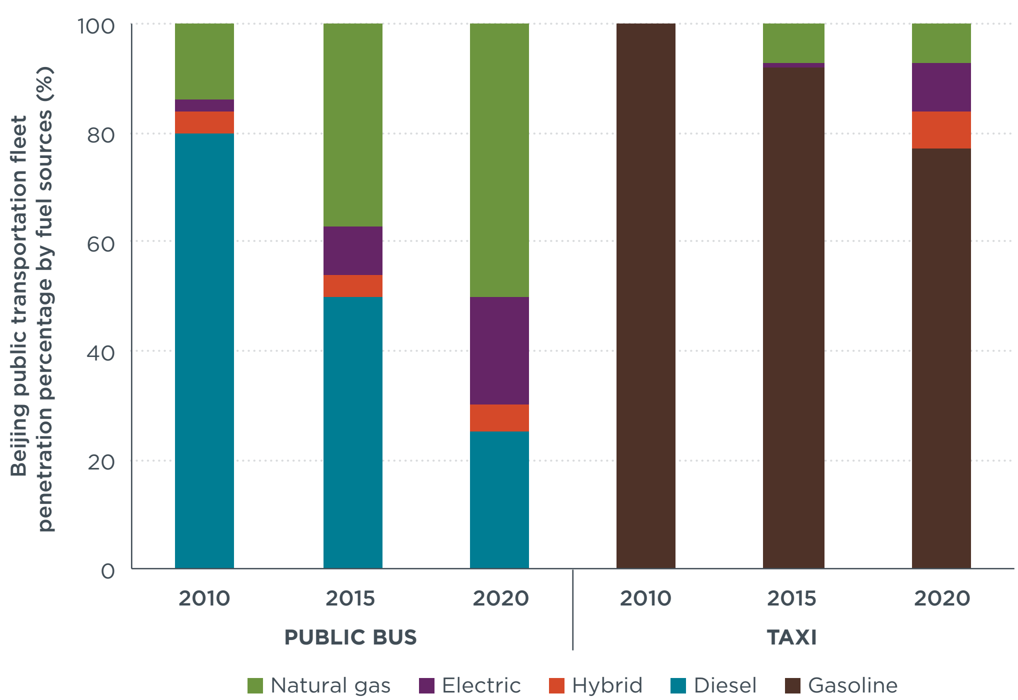



**Figure 14** Proportions of various power sources used in the Beijing public transportation fleet *(Source: Zhang et al., 2014)*

Different engine technologies can have significant consequences for natural gas vehicle emissions. Natural gas engines can be either stoichiometric, spark ignited; lean-burn, compression-ignited, high-pressure direct injection; or lean-burn spark ignited. The engine technology used on natural gas vehicles in China is lean-burn spark ignited operation with oxidation catalyst (CATARC, 2014). The lean-burn spark ignited natural gas engine produces much less engine-out $PM_{2.5}$, but may emit comparable $NO_X$ to its counterpart diesel engine, which may not meet Beijing's increasingly stringent emission standards (Ligterink, Patuleia, and Koornneef, 2013). The use of stoichiometric spark ignited natural gas engines would enable a straightforward pathway to reducing both $NO_X$ and $PM_{2.5}$ by using a standard TWC (Einewall, Tunestal, and Johansson, 2005).

## 6.2. VEHICLE POPULATION CONTROL

To control the growth in vehicle stock, mitigate worsening traffic, and reduce emissions from on-road transportation, the Beijing government, in late 2010, made public its Tentative Provisions on the Quantity Control of Small Passenger Vehicles (Beijing Government, 2010), together with their implementing rules (BMCT, 2010). These provisions, which came into effect immediately upon their announcement, required, as mentioned in Subsection 6.1, a license plate restriction to be imposed to limit new passenger car sales beginning in 2011. The Beijing Municipal Commission of Transport is the entity determining the numerical cap and the allocation of plate numbers. The implementing rules specify the plate quota allocation to vehicles for private and commercial use, the necessary qualifications for applicants, and the application procedures and rules.

The implementing rules were revised twice, in 2011 and 2013. Among other changes, the agency set a special cap for new energy vehicles, independent of conventional vehicles. For conventional vehicles, the lottery rules were also adjusted to increase the chance of winning for applicants who had been in the application pool for a longer time. In addition, there are complementary policies that prevent people from getting around the system, such as registering vehicles outside Beijing but driving in the city nonetheless. Beijing has vigilant enforcement toward temporary permits for vehicles from other provinces.

The overall cap for new passenger car registrations in Beijing was 240,000 annually from 2011 to 2013, equivalent to a quarter of the new passenger vehicles registered in 2010. The number has since been lowered to 150,000 annually from 2014 to 2017 in order to keep the vehicle population lower than 6 million by 2017.

# 7. BEIJING VEHICLE EMISSION REDUCTION — MODELING RESULTS

## 7.1. MODELED SCENARIOS FOR BEIJING

Beijing has adopted comprehensive vehicle emission regulations and is dedicated to keeping this momentum going. To quantify Beijing's efforts in cutting on-road vehicle emissions, ICCT's China model (Façanha, Blumberg, and Miller, 2012; Wagner and Shao, 2015) helps offer perspective on Beijing's achievements in the areas of both the environment and human health. Limited by the data availability, the category of the vehicles is adjusted to best fit the model structure. The environmental improvements are gauged mostly by the declining trend of conventional pollutants such as $NO_X$, $PM_{2.5}$, and BC. The emission factors adopted in this analysis are from COPERT, which are generated based on real world testing in Europe (EMISIA S.A. 2009). The emission factors from COPERT are reprehensive for those vehicles following European certification test procedures. Though we find the absolute value of the emission factors can vary from source to source, the emission factor trends vary consistently based on applicable emission standards. The health effects are estimated through calculations of premature mortality (early deaths from lung cancer, cardiopulmonary disease, and acute respiratory infection) attributable to primary $PM_{2.5}$ emissions exposure (Chambliss et al., 2013).

The modeling results mainly reflect the environmental and health impacts resulting from the adoption of vehicle tailpipe emission standards, low-sulfur fuel standards, and scrappage programs. There is a lot of nuance in Beijing's strategy to reduce vehicle emissions that the model cannot reflect. For example, Beijing has implemented numerous in-use vehicle emission control programs, including inspection and maintenance programs, remote sensing, and retrofitting, aging vehicle restriction, vapor recovery, low-emission zones, and vehicle usage restriction, as described in detail earlier. Because of the limitations of the modeling, not all of these initiatives can be captured or assessed in the results. Similarly, the methodology used to evaluate health benefits only examines the impacts from primary on-road $PM_{2.5}$. Thus, the results for both environmental and health improvements should be regarded as conservative.

Three scenarios (Table 8) have been devised to show what benefits Beijing has achieved and will achieve from implementing stringent standards, extrapolating from recent experience. Emission standards, fuel standards, and scrappage programs are the three primary policy yardsticks used to quantify the emission reductions and health improvements. The Beijing BAU (business as usual) scenario assumes that there will be no further actions taken beyond today, which means that Beijing stops at China 5/V and 10 ppm fuel sulfur content. In the China BAU scenario, Beijing is assumed to have followed national steps from China 1/I forward and remain at China 4/IV, as does the rest of the country. This scenario is used to shed some light on the achievements of early adoption of stricter regimes.

Finally, the Beijing 6/VI scenario serves to address the potential benefits from the next phase of emission standards, which is planned to be implemented around 2016.

**Table 8.** The three scenarios and relevant assumptions used in modeling for this analysis

| Scenarios | Emission Standards | Fuel Standards | Scrappage |
|---|---|---|---|
| **Beijing BAU** | China 5/V in 2013 | 10 ppm fuel sulfur in 2012 | Voluntary YLVs scrapped by 2010 |
| **China BAU** | Follows national steps: LDGV China 4 in 2011; HDDV China IV in 2013 | 350 ppm sulfur diesel in 2011 50 ppm sulfur gasoline in 2014 | N/A |
| **Beijing 6/VI** | Beijing 6/VI in 2016 | 10 ppm fuel sulfur in 2012 | Based on voluntary scrappage, 1 million older vehicles retired by 2018 |

## 7.2. TRENDS IN VEHICLE EMISSIONS

Beijing has successfully reduced airborne emissions by adopting all the strategies described above. In Figure 15, the Beijing BAU scenario shows a steady reduction in on-road vehicle $NO_x$ emissions starting in 2000. Further, the voluntary scrappage program results in an immediate drop in emissions around 2010, which reaffirms the story of Beijing successfully reining in high-emitter vehicles. Compared with the China BAU scenario, Beijing BAU shows the clear benefit of early adoption, which helped Beijing lower $NO_x$ levels from the very beginning. The gap between these two scenarios peaks when the scrappage program is introduced, with more than 40 percent of the $NO_x$ emissions in China BAU avoided in the Beijing BAU scenario. On average, early adoption (Beijing BAU) manages to avoid a quarter of the emissions otherwise produced each year. However, even with license restrictions, emissions will soon start to increase again if no more stringent standards are pursued. Beijing 6/VI could offer a sharp emissions decrease immediately after implementation. The scrappage program—with 1 million older vehicles retired—would help speed up turnover and accelerate the benefits from Beijing 6/VI as well. Thus, $NO_x$ emissions would keep declining all the way out to 2030 (the far edge of the model's projections). This suggests powerfully that only by adopting the Beijing 6/VI standards could the city attain its long-term $NO_x$ emission reduction goals.

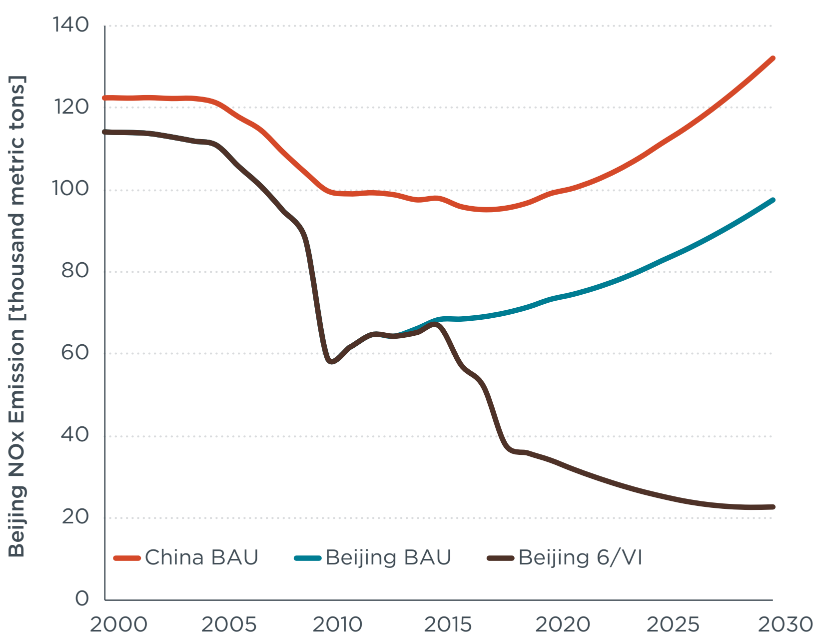



**Figure 15** Beijing $NO_x$ vehicle emissions trends under three scenarios, 2000–2030

For $PM_{2.5}$, the emission reduction patterns are similar. Beijing BAU has successfully stemmed the emissions. Figure 16 starkly lays out the gains Beijing has reaped from early standards adoption. The extent to which $PM_{2.5}$ has dropped is impressively significant in recent years. Even taking into account the rapid growth of the vehicle market, compared with the 2000 level, PM emissions were still more than 80 percent lower in 2013. It is also apparent from the chart that early adoption has helped Beijing lower PM emissions by 40 percent on average compared with the China BAU case. However, with vehicle demand growing inexorably, progress has already been halted, and emissions will soon start to tick up again in the BAU scenario. Only in the Beijing 6/VI scenario could $PM_{2.5}$ be effectively prevented from increasing. With the scrappage program, emissions would decline more quickly. The modeling results again indicate the potential effectiveness of Beijing 6/VI in controlling vehicle tailpipe emissions.

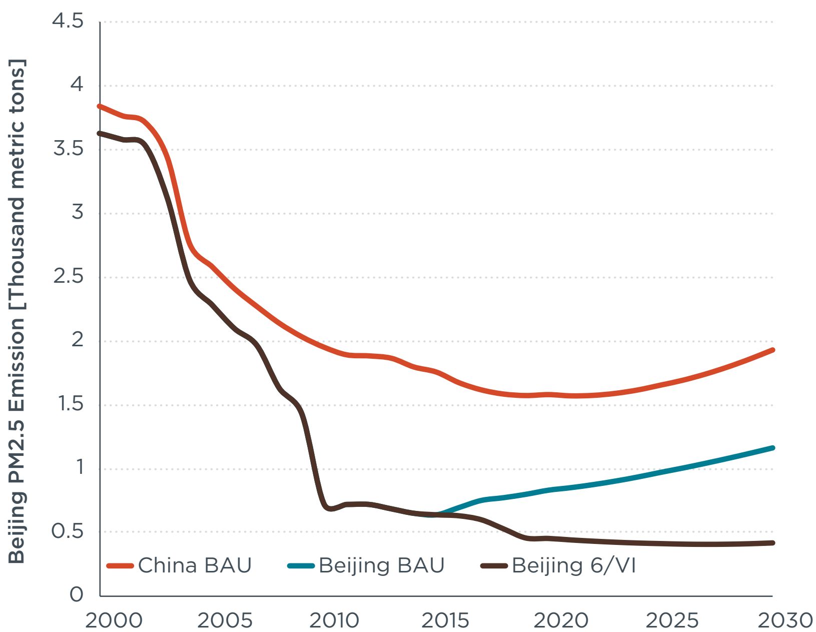



**Figure 16** Beijing $PM_{2.5}$ vehicle emissions trends under three scenarios, 2000–2030

Black carbon has been well controlled in Beijing historically but will continue declining only if Beijing 6/VI is adopted on time. As shown in Figure 17, the BC in the Beijing BAU scenario has kept decreasing over the past decade. There has been a 70 percent decrease in BC from the level of 2000. However, the emissions will now increase steadily all the way to 2030 in the BAU scenarios. The absence of further policy changes would eventually eliminate all the benefits Beijing has garnered through early adoption, as the lines from Beijing BAU and China BAU conjoin around 2027. The reason is that China 5/V fails to take any new measures to lower BC emission limits, while the vehicle market continues to burgeon. With Beijing 6/VI, a further 80 percent of existing BC emissions could be avoided in 2030. Thus, moving quickly to Beijing 6/VI is well justified as a policy priority.

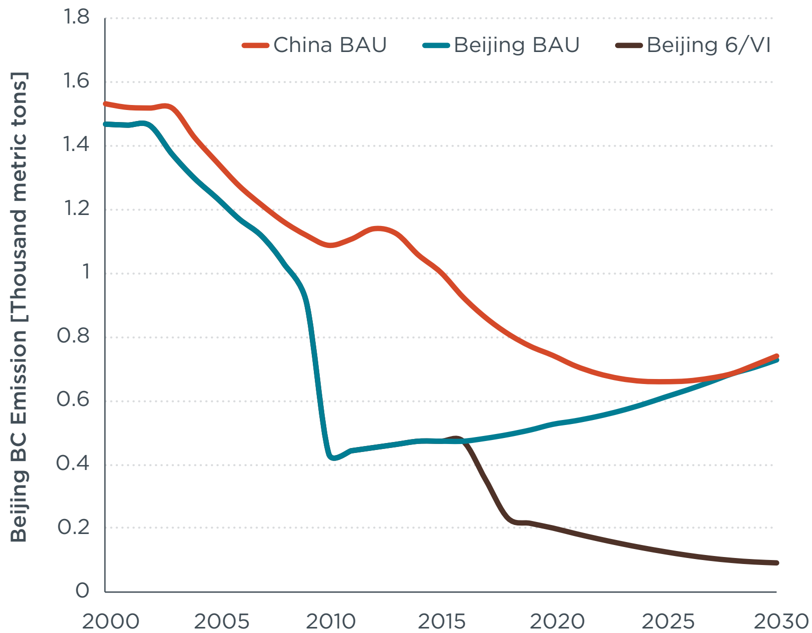



**Figure 17** Beijing BC emissions trends under three scenarios, 2000–2030

Beijing 6/VI promises tremendous emission reductions for all types of conventional pollutants. Table 9 illustrates the emission savings for five major pollutants in 2010 (Beijing BAU versus China BAU) as well as 2030 (Beijing 6/VI versus Beijing BAU). Scrappage with early adoption of stringent standards in 2010 has already yielded tons of emission cuts, with as much as a 77 percent reduction in one case. This reinforces the premise that this program offers instant returns. The table also shows the benefits from Beijing 6/VI in the long term. With emission reductions as high as 88 percent from on-road vehicles, the modeling offers strong support for the prompt adoption of Beijing 6/VI by Beijing policymakers.

**Table 9.** Emission reduction comparisons for $NO_x$, $PM_{2.5}$, BC, HC, and CO

| Pollutant | Annual emission reductions in 2010 of Beijing BAU vs. China BAU | Annual emission reductions in 2030 of Beijing 6/VI vs. Beijing BAU |
|---|---|---|
| **$NO_x$** | 40,795 tons (-41%) | 74,833 tons (-77%) |
| **$PM_{2.5}$** | 1,334 tons (-68%) | 745 tons (-64%) |
| **BC** | 686 tons (-63%) | 649 tons (-88%) |
| **HC** | 26,494 tons (-77%) | 1,066 tons (-18%) |
| **CO** | 277,322 tons (-59%) | 15,476 tons (-8%) |

Despite growing capabilities in emission reduction technology and management, cross-boundary vehicle management poses a challenge to Beijing and may hamper efforts to trim the city's growing emissions. As a matter of fact, there are a fair number of vehicles used in Beijing that are registered and refueled in other regions, mostly in neighboring

Tianjin and in the surrounding Hebei province. Vehicle and fuel standards in those areas still follow the national schedule, trailing behind Beijing. Though enforcement of the temporary entry pass system could prevent certain kinds of dirty vehicles, especially heavy-duty diesel trucks, from moving inside the Sixth Ring Road, there is still a chance that older vehicles with low emission standards are being driven inside Beijing. Also, vehicles registered in Beijing may be refueled outside the city, where sulfur content in the fuel is higher. This geographic mismatch between vehicles and fuel will increase tailpipe pollutants (Zhang et al., 2014) directly as well as raise the risk of deactivating the after-treatment catalysts, which will result in still higher emissions. Those loopholes, with a potential to inflate real-world emissions that is not reflected in the charts presented above, need to be closed expeditiously. In order to achieve the full benefits from stringent emission standards and the scrappage program, it is vital to ensure that vehicle and fuel standards are consistent in surrounding regions. In other words, Beijing should push the Jing-Jin-Ji (Beijing-Tianjin-Hebei) conurbation to leapfrog to Beijing 6/VI as well in order for the entire capital region to enjoy the benefits of better air quality.

As a mega-city with a high population density, Beijing suffers from severe urban air pollution. Neighborhoods bordering busy roads are particularly at risk for health problems associated with emissions. Though actions taken by the municipality have already yielded health improvements, they are not enough. Figure 18 reveals that Beijing had already achieved 60 percent reduction in the incidence of premature deaths compared with the China BAU scenario by 2013. However, the premature mortality rate will soon shoot up again thanks to the rapid growth of the vehicle market and the urban population. Aware of the threat, Beijing keeps pushing stringent standards: In ICCT's model, Beijing 6/VI could prevent premature mortality from increasing even given the current projections for population and vehicle fleet expansion. Again, note that the premature mortality estimate is derived solely from exposure to primary on-road PM emissions. The figure would be substantially increased if secondary emissions were also considered.

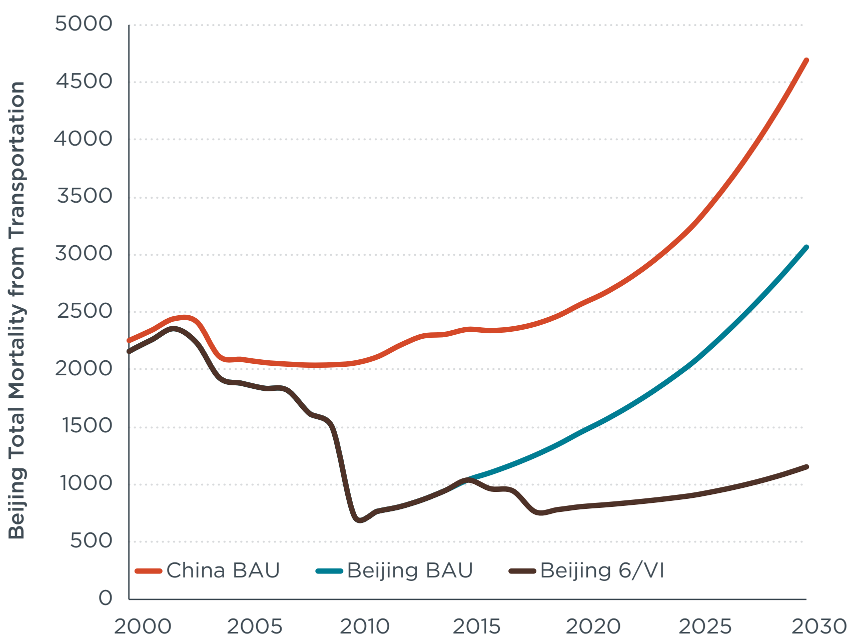



**Figure 18** Beijing premature mortality trends, 2000–2030

Beijing's success might be challenging for many regions to replicate because they lack sufficient resources. However, the cost-benefit analysis—a widely accepted way to evaluate the long-term impacts of certain policies—yields results implying that the rules and standards used by the capital's municipal government are cost-effective (Figure 19). The analysis specifically examines the potential costs and benefits of implementing Beijing 6/VI. Since Beijing has already adopted 10 ppm fuel requirement, the focus is directed toward the cost of vehicle technology improvements and the forecast benefits from both climate and health improvements in 2040.[21] Figure 19 shows that the benefit-cost ratio of implementing Beijing 6/VI could reach as high as 4:1, with most of the benefit coming from sounder public health. Because this finding is based on very conservative measures of public health improvement, the actual degree to which benefits surpass costs is bound to be even higher. If evaluated for even later years, beyond 2030, the ratio would grow still more pronounced.

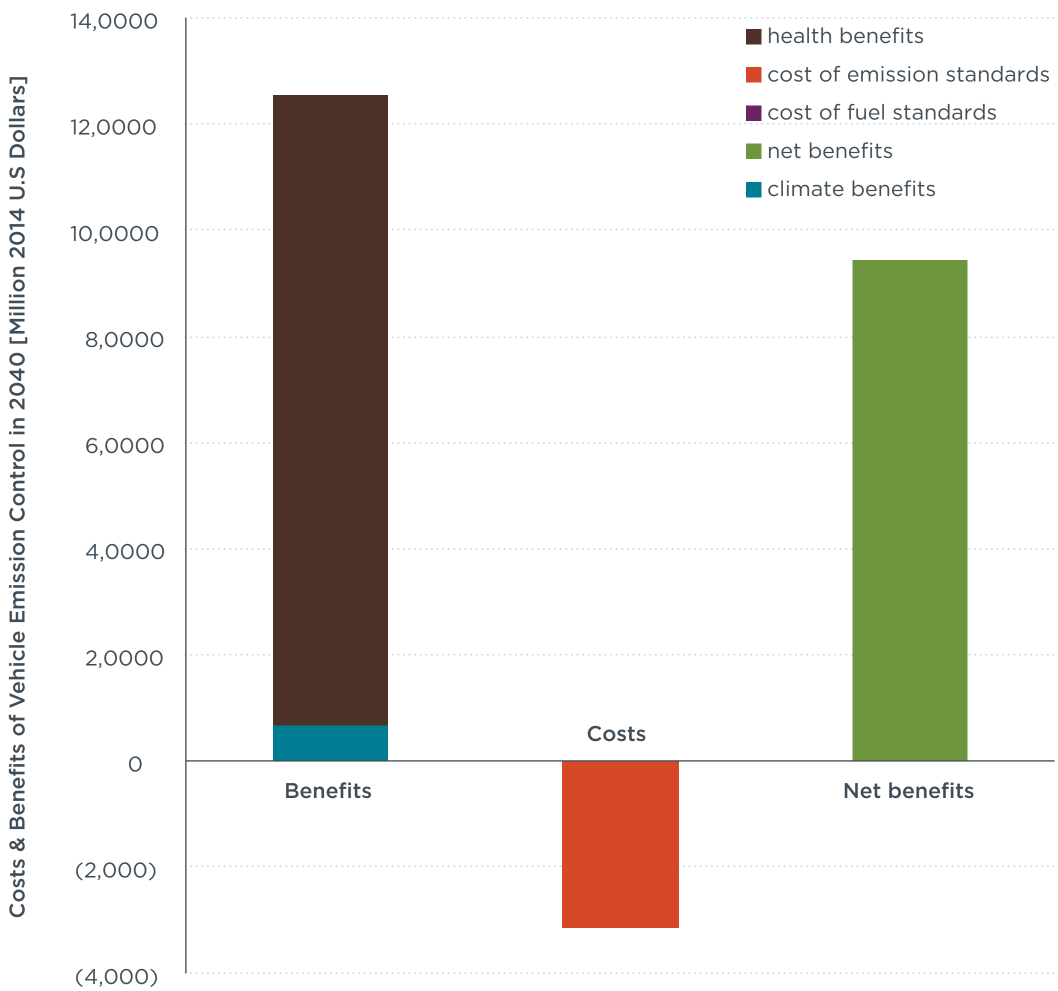



**Figure 19** Annual cost and benefit analysis of Beijing 6/VI in 2040

21 In this analysis, we consider the benefits and costs of the Beijing 6/VI from 2016 to 2040, 24 years after the planned implementation date. The selected time period can capture the benefits from the regulation, though conservatively, as the benefits are expected to grow after 2040, but also reduce the uncertainty of long-term projection on sales, population and growth rate. This time frame is consistent with EPA's recommendation on mortality-avoided distribution, which is 20 years.

# 8. CONCLUSIONS

Based on a comprehensive review of vehicle emission control policies in Beijing, the city's Environmental Protection Bureau has demonstrated its position as an environmental leader within China. In order to think about how Beijing can maintain its leading position, maximize the environmental and health benefits, and, through its experience, inspire other cities to achieve their goal, below are a few conclusions drawn from the analysis above.

***Conclusion 1: Beijing's vehicle emission control regime has delivered significant environmental and health benefits, but only Beijing 6/VI (or potentially China 6/VI) can help Beijing prevent long-term emissions growth.***

On-road vehicles and nonroad engines and equipment are large and growing contributors to air pollution, especially in cities. Fully recognizing the importance of transportation sector emission management, Beijing has made tremendous progress in developing and implementing comprehensive motor vehicle emission reduction programs. By taking proactive regulatory action in issuing new vehicle emission and fuel quality standards and in conducting scrappage programs, 50,000 metric tons of $NO_x$ and 3,000 tons of PM emissions were avoided in 2013 compared with the 2000 baseline level. The $NO_x$ and PM emissions in 2013 were 35 percent and 65 percent below the emission levels that would have been sustained if Beijing had followed the national implementation timeline. Moreover, since the ICCT model results do not take into consideration any in-use vehicle emission controls except for scrappage, the real-world benefit is likely more significant than the estimate presented in this paper.

Although Beijing has had great success with emission reductions, current standards cannot prevent a long-term increase in vehicle emissions that will result from the growing vehicle population. Only implementing Beijing 6/VI, as scheduled, can help maintain or even reduce emissions from transportation in the long term. In addition, the adoption of Beijing 6/VI is extremely cost-effective, with the benefit-cost ratio of its implementation reaching as high as 10:1.

***Conclusion 2: Accelerating the pace of emission control in the areas surrounding Beijing will maximize the regional environmental impact.***

Notwithstanding Beijing's leadership of local-level vehicle emission reduction policy, it cannot solve the problem alone, as air quality is a regional issue. The inconsistency in the degree and speed of implementation between Beijing and the surrounding cities and counties will attenuate the expected real-world environmental and health benefits of more stringent standards. For example, the fuel quality gap between Beijing and surrounding cities not only increases vehicle emissions, but also contributes to engine wear, particularly catalytic converters and other soot filters and traps. Regulatory gaps will certainly dilute the effects of Beijing's early adoption of Beijing 6/VI.

Furthermore, because high-emitting vehicles frequently are transferred out of Beijing instead of being retired, they will likely continue polluting. Traffic restrictions on yellow-label and nonlocal vehicles, though significantly reducing on-road vehicle emission in Beijing itself, may result in the shifting of tailpipe emissions to nearby Tianjin or adjacent Heibei province, which is bound to influence Beijing's air quality in the long term. Thus, the city should focus on cooperating with the surrounding Jing-Jin-Ji (Beijing-Tianjin-Hebei) capital region to push for lower-sulfur fuel and to encourage neighboring jurisdictions to leapfrog to China 6/VI as well as to set up in-use vehicle programs in the service of regional air quality.

***Conclusion 3: Beijing's vehicle emission control experience can be an inspiration for other cities.***

Given its unique concentration of resources and power, Beijing's aggressive approach in vehicle emission reduction will be challenging for other cities to emulate. Nevertheless, other cities have the legal power to carry out most of the same actions as Beijing, such as early adoption of national vehicle emission standards, securing early supplies of low-sulfur fuel, and instituting a variety of in-use vehicle emission control programs.

Amid the steady progress Beijing has made since the dawn of the new century, there have been twists and turns in the search for the optimal path to clearing the air of the nation's capital. One point of emphasis is governmental capacity building that enables local authorities to adopt far-reaching emission control initiatives with confidence. Local agencies should consistently make efforts to enhance their competencies and expertise and should always be prepared to push policy regulations forward whenever the window of opportunity permits.

To be fair, environmental regulations are often influenced, and in some cases watered down, by various stakeholders. This is demonstrated by the controversy over lowered octane ratings and the restrictive catalogs of locally approved new energy vehicles. However strong the will to reduce emissions is, political pressure and economic considerations may override environmental objectives. The Beijing municipal government has had to recalibrate its strategy to mitigate the effects of compromises that are in many ways unavoidable. From another perspective, other cities in China can draw lessons from not just the success stories but also the hard choices and tradeoffs made as they seek out the routes most appropriate to their own situation to realize emission reductions.

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