JUNE 2021

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

A RETROSPECTIVE REVIEW OF CHINA'S CLEAN DIESEL PROGRAM

LIUHANZI YANG, HUI HE, ZHENYING SHAO, HONGYANG CUI, AND XIAOLI MAO

ACKNOWLEDGMENTS

The authors acknowledge Michael Walsh, Dr. Ding Yan (Vehicle Emission Control Center), Dr. Wu Ye (Tsinghua University), and Dr. Zhang Shaojun (Tsinghua University) for their guidance and constructive comments. This study was funded through the generous support of the Pisces Foundation and the Sequoia Climate Fund Foundation.

International Council on Clean Transportation
1500 K Street NW, Suite 650
Washington, DC 20005

communications@theicct.org | www.theicct.org | @TheICCT

TABLE OF CONTENTS

LIST OF ACRONYMS

Administration of Quality Supervision, Inspection and Quarantine (AQSIQ)
Battery electric vehicle (BEV)
Bureau of Environment and Ecology (BEE)
Carbon dioxide (CO_2)
Carbon monoxide (CO)
China Green Freight Initiative (CGFI)
Clean Air Asia (CAA)
Compressed natural gas (CNG)
Conformity of production (COP)
Diesel particulate filter (DPF)
Domestic emission control area (DECA)
Emission Control Zone (ECZ)
Environmental Protection Bureau (EPB)
Fuel cell electric vehicle (FCV)
Greenhouse gases (GHGs)
Hydrocarbons (HC)
Inspection and maintenance (I/M)
International Maritime Organization (IMO)
Kilometers (km)
Liquefied natural gas (LNG)
Ministry of Ecology and Environment (MEE)
Ministry of Environmental Protection (MEP)
Ministry of Industry and Information Technology (MIIT)
Ministry of Science and Technology (MoST)
Ministry of Transport (MOT)
National Development and Reform Commission (NDRC)
National Energy Administration (NEA)
National Environmental Protection Agency (NEPA)
New energy vehicle (NEV)
Nitric oxide (NO)
Nitrogen oxides (NO_x)
Onboard diagnostics (OBD)
Particulate matter (PM)
Particulate number (PN)
Parts per million (ppm)
Plug-in hybrid electric vehicle (PHEV)
Portable emission measurement system (PEMS)
Selective Catalytic Reduction (SCR)
Standardization Administration of China (SAC)
State Administration for Market Regulation (SAMR)
State Environmental Protection Administration (SEPA)
Sulfur dioxide (SO_2)
Sulfur oxides (SO_x)
Vehicle Emission Control Center (VECC)

1. INTRODUCTION

Diesel vehicles are only 9.1% of the on-road fleet in China but are estimated to be the country's largest on-road source of nitrogen oxides (NO_x) and particulate matter (PM) emissions. In 2019, diesel vehicles were responsible for 88.9% and 99% of vehicle NO_x and PM emissions in China (Ministry of Ecology and Environment [MEE], 2020). Since the 1980s, China has implemented a series of policies and regulations to address harmful diesel emissions, and this paper aims to review the diesel emissions control programs and measures that have been adopted. The programs covered focus on diesel mobile sources, including on-road diesel vehicles, off-road machinery, and shipping vessels, and also on diesel fuel quality.

The report is organized as follows: Section 2 gives an overview of the historical evolution of China's Clean Diesel Program; Section 3 describes each of the policies and measures that make up the program; and Section 4 summarizes findings. This paper provides a foundation for understanding potential areas where China could further reduce diesel engine pollution and is an overview of the best practices emerging from the implementation of China's Clean Diesel Program that could be useful in other parts of the world that are facing similar challenges. A future companion paper will introduce California's Clean Diesel Program, compare China's program with California's experiences, and offer policy recommendations for China's next phase of clean diesel actions.

2. HISTORICAL EVOLUTION OF CHINA'S CLEAN DIESEL ACTIONS

Figure 1 presents an overview of the historical evolution of China's clean diesel actions since 1983.

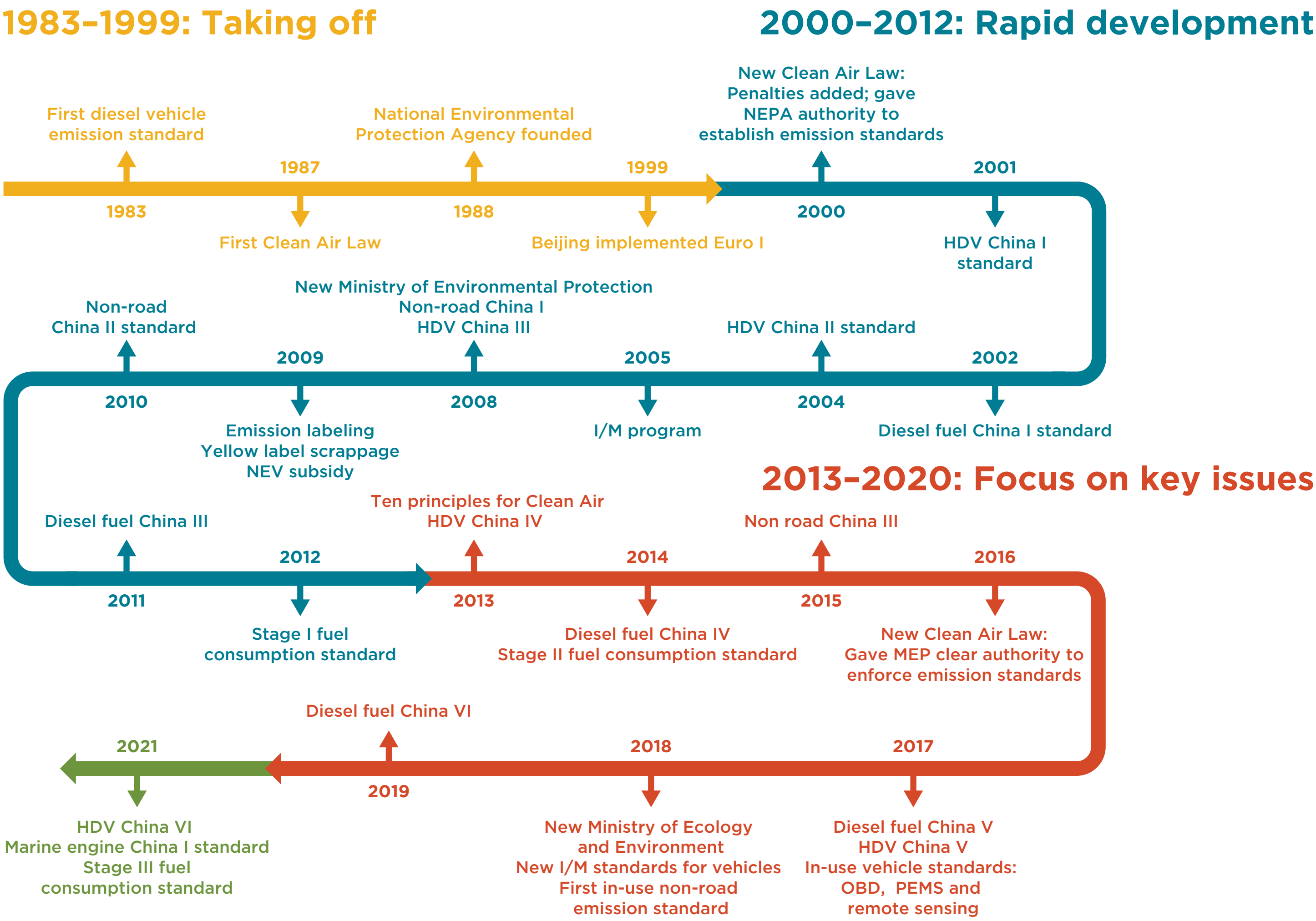

Figure 1. Historical evolution of China's actions to address pollution from diesel vehicles. The four colors represent four different stages.

1983–1999: TAKING OFF

In 1983, China issued its first national diesel vehicle and diesel engine emission standard and test methodology standard. The emission standard set limits for smoke intensity using the free-acceleration method and it applied to both new and in-use vehicles. This was the official start of China's control of diesel emissions. In 1987, the first Air Pollution Prevention and Control Law (hereafter, "the Clean Air Law") was issued by the National People's Congress. The Clean Air Law stipulated that the air pollutants emitted by motor vehicles and ships should not exceed the emission standards, and this provided the legal basis for controlling diesel emissions. In 1988, China's first environmental protection agency, the National Environmental Protection Agency (NEPA), was founded and was given authority over the prevention and control of vehicle pollution. In 1990, six government departments jointly issued Measures for the Supervision and Management of Vehicle Exhaust Pollution, which clarified the authority and responsibilities of different departments concerning diesel vehicle emissions. In 1993, three more diesel vehicle emission standards, following Europe's ECE R15 regulations, were issued, and via these, China's emission limits were further tightened.

Funded by the World Bank, NEPA carried out China's Motor Vehicle Emission Pollution Control Strategy Research Project (B-9-3) in 1997. This was the first report that assessed the status of China's motor vehicle emissions pollution and control policies. It also set a path for vehicle emission control policies in China and required that China would follow the EU emission standard system, starting from Euro I, for the next 10–15 years.

In 1998, after serious air pollution occurred in Beijing, the Beijing Municipal Government took emergency measures and implemented the Euro 1 emission standard for light-duty vehicles earlier than the national schedule. That same year, NEPA, which was at the vice-ministerial level, was upgraded and renamed the State Environmental Protection Administration (SEPA). In 1999, SEPA, the Ministry of Science and Technology (MoST), and the National Machinery and Industry Bureau jointly issued the Technical Policy for the Prevention and Control of Motor Vehicle Emission Pollution and determined the implementation timeline for China I to China III heavy-duty vehicle (HDV) emission standards (SEPA, 1999).

2000–2012: RAPID DEVELOPMENT

In this period, China's efforts mainly focused on new vehicle emissions control by developing and strengthening vehicle testing protocols and mandatory emissions limits. The revised Clean Air Law, adopted in 2000, set penalties for violations of motor vehicle emission regulations but was very vague about which regulatory authorities should develop and implement the emission standards. In 2001, China implemented China stage I (China I) HDV emission standards using China I diesel fuel with a 2,000 parts per million (ppm) sulfur limit; this followed the European pathway. In 2004, the China II standard containing tightened carbon monoxide (CO), NO_x, and PM limits was implemented. In 2008, the China III HDV emission standard was implemented. However, China's diesel fuel quality standards and the availability of the required fuel supply lagged vehicle emission standards (Yue et al., 2015). Due to poor diesel fuel quality, the implementation of the China IV emission standard was delayed twice. The China IV standard finally took effect in July 2013, two years later than the initially set date of July 2011. Even then, the diesel fuel available on the market was still at China III levels, with a maximum sulfur content of 350 ppm.

As the emission standards gradually tightened, China started to pay more attention to in-use diesel fleets. The 12th Environmental Protection Five-Year Plan, published in 2011, set a target for total NO_x emissions reduction and described in detail the requirements of vehicle NO_x emission control (China State Council, 2011). The emission standard for in-use diesel vehicles was revised in 2005 and required that smoke density be tested using the lug-down method in heavily polluted cities. Vehicles that failed to meet emission limits for in-use vehicles in annual vehicle inspection were banned from driving on the road. In July 2008, the Ministry of Environmental Protection initiated an emissions labeling program for motor vehicles; this was also known as the yellow-green label policy. Pre-China III diesel vehicles were defined as yellow-label vehicles. In 2009, China initiated a nationwide consumer incentive program to accelerate scrappage of yellow-label vehicles. Vehicle owners who replaced and scrapped their yellow-label vehicles with new purchases were eligible for cash rebates. In some big cities facing severe air pollution problems, yellow-label vehicles were restricted from operating in the main urban area of the city.

At the same time, China started to promote new energy vehicles.[1] This was mainly to support the broader mission for a more energy independent future. In 2009, China launched the Ten Cities, Thousand Vehicles program and a national subsidy program

1 In China, new energy vehicles include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs).

to support the development of electric vehicles. In 2012, the Stage 1 fuel consumption standard for HDVs took effect. Subsequent phases were to be designed to reduce energy consumption of vehicles, and therefore carbon dioxide (CO_2) emissions from new HDVs. For in-use trucks, China launched the China Green Freight Initiative in 2012. This is a national, voluntary program and a collaborative effort that aims to promote the adoption of fuel-saving technologies for trucks, increase driving efficiency through driver training, and promote advanced transportation modes such as drop-and-hook.

During this period, China also started to look at emissions from non-road diesel engines. The first emission standard for non-road machinery, China I, was implemented in 2008, and was strengthened in 2010.

2013–2020: FOCUS ON KEY ISSUES

In winter 2013, an outbreak of smoggy haze swept through China and triggered widespread attention on the air pollution issue. In response, the China State Council issued the Air Pollution Prevention and Control Action Plan. This policy, also known as Ten Principles for Clean Air, was the first national-level plan to focus on air pollution control. The plan set the roadmap for air pollution control for 2013–2017, with a focus on three key regions: Jing-Jin-Ji, the Yangtze River Delta, and the Pearl River Delta. This was because those regions have significant economic activity and suffered from heavily polluted air.

In addition, the central government passed a new amended Clean Air Law (hereafter, "the new Clean Air Law"), and it took effect on January 1, 2016. The biggest change of the new Clean Air Law was that it gave the Ministry of Environmental Protection (MEP, formerly the State Environmental Protection Administration) clear authority to enforce emission standards, including the authority to recall noncompliant vehicles and impose large fines on violating companies. These changes paved the way for building a strong and robust vehicle emission compliance program, which is the key to ensuring that pollutant emission standards hold their promise and lead to reduced emissions during real-world use.

Because the China V diesel fuel quality standard was not fully implemented until 2017, the implementation of the China V HDV emission standard, originally scheduled for 2012/2013, was delayed until July 2017. To prevent excess NO_x emissions from China V HDVs, MEP issued a supplemental portable emission measurement system (PEMS) testing standard in October 2017; it required additional on-road PEMS testing for all new and in-use China V HDVs. The Stage 2 HDV fuel consumption standard took effect in 2014 and included fuel consumption limits that were 10%–15% lower than Stage 1.

For in-use vehicles, because more than 97% of the yellow-label vehicles were scrapped by 2018, China III and China IV vehicles started to be the major source of diesel vehicle emissions (see Figure 2). At this time, China started to use a new technology—remote sensing—for high-emitting vehicle emissions control. In 2017, China created the first national-level remote-sensing regulation. It sets a limit for PM emissions, through limits on opacity and Ringelmann blackness, and a NO_x limit.

There were also actions with respect to emissions from non-road equipment and marine vessels. The China III non-road mobile machinery emission standard, which is equivalent to Stage IIIA of the EU standard, has been in force since 2015. Also in 2015, the Ministry of Transport (MOT) released an action plan for implementing Ship Emission Control Zones (ECZs) in three key coastal regions; it required the use of marine fuel with maximum sulfur content of 5,000 ppm within the ECZ boundary. Pilot programs on low-emission zones for non-road machinery were implemented in big cities in China starting in 2017.

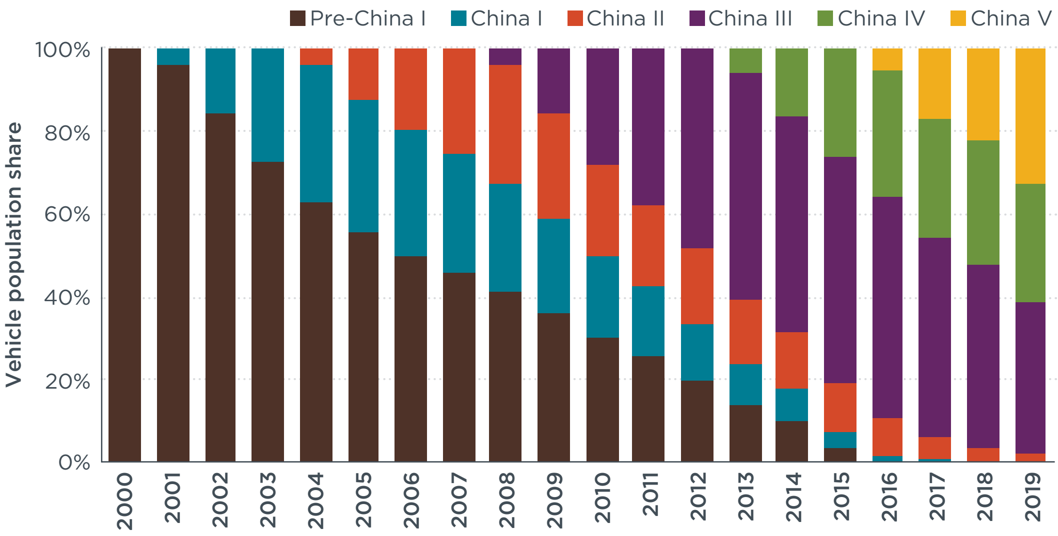

Figure 2. Historical market share of diesel heavy-duty vehicles by emission standard in China (2000–2019). Source: (MEE, 2020a).

After five years of effort, China fully achieved the targets set in the Ten Principles for Clean Air. By the end of 2017, the average PM_{10} concentration was reduced by 22.7% compared with the 2013 level.[2] The $PM_{2.5}$ concentration in Jing-Jin-Ji, Yangtze River Delta, and Pearl River Delta was reduced by 39.6%, 34.3%, and 27.7%, respectively. The change was especially evident in Beijing, where the average $PM_{2.5}$ concentration was reduced to 58 µm/m³ in 2017 (MEE, 2018a).

In 2018, the China State Council released a three-year National Plan of Blue-Sky Defense. This policy was considered as the second phase of the Ten Principles for Clean Air. The goal was to further reduce emissions of air pollutants and greenhouse gases (GHGs) and improve the air quality by 2020. The plan required implementation of the China VI fuel quality standard, early implementation of China VI emission standards in key regions, scrappage of 1 million pre-China IV diesel trucks by 2020, promotion of electric urban vehicles, and transport modal shift from truck to rail.

As a follow-up policy, MEE and 10 other government bodies in January 2019 published an Action Plan for Battle Against Diesel Truck Pollution. The plan sought to reduce emissions from on-road diesel vehicles, non-road machinery, and marine vessels. Detailed tasks are specified for four programs: Clean Diesel Vehicles, Clean Engines, Clean Transportation, and Clean Fuels. With respect to a modal shift from truck to rail, the China State Council issued a Three-year Action Plan on Promoting Shipping Structure Adjustment in a bid to efficiently tackle pollution, raise the efficiency of transportation, and reduce logistics costs (China State Council, 2018c).

A big institutional change happened in April 2018. The Ministry of Ecology and Environment (MEE) was established and assumed responsibility for all duties previously handled by the Ministry of Environmental Protection. The MEE was also given additional responsibilities with respect to climate change, marine pollution control, underground water pollution regulation, and agricultural pollution control that were formerly under the purview of six other ministries.

2 $PM_{2.5}$ refers to atmospheric particulate matter that has a diameter of less than 2.5 micrometers. PM_{10} refers to the particles with a diameter of less than 10 micrometers. Both $PM_{2.5}$ and PM_{10} can be inhaled, and some can be deposited throughout the airways, although the locations where particles deposit in the lungs depend on particle size. $PM_{2.5}$ is more likely to travel into and land on the surface of the deeper parts of the lung, whereas PM_{10} is more likely to land on the surfaces of the larger airways of the upper region of the lung. Particles that reach the lung surface can induce tissue damage and lung inflammation (California Air Resources Board, n.d.).

Under the guidance of the three-year National Plan of Blue-Sky Defense and the Action Plan for Battle Against Diesel Truck Pollution, specific actions were taken. The China VI diesel fuel quality standard, with a sulfur content limit of 10 ppm, has been fully implemented since January 1, 2019. Meanwhile, the general diesel standard for non-road diesel fuel was abolished and now only diesel fuels that are compliant with the China VI fuel quality standard are allowed to be sold in China. The China VI HDV emission standard, which combines best practices from Euro VI and U.S. regulations, is scheduled to take effect on July 1, 2021, for all new HDV sales in China. The China IV non-road emission standard has been updated and will be implemented on December 1, 2022. For new marine vessel engines, the Phase I emission standard went into effect in 2018 and Phase II is to be implemented in 2021.

For in-use fleets, revised inspection and maintenance (I/M) testing requirements and opacity limits went into effect in 2019. Additionally, a new I/M regulation for non-road machinery was developed and implemented. At the local level, pilot diesel particulate filter (DPF) retrofit programs were launched in Beijing, Tianjin, Shenzhen, and Nanjing. These programs provide subsidies to vehicle owners who retrofit their trucks.

Table 1 summarizes the key issue/goal, legislation and plans, authority, and regulations in different phases of China's clean diesel program.

Table 1. Overview of China's clean diesel actions in different phases

Phase	Key issue and/or goal	Legislation and plans	Authority	Regulations
1983–1999 (Taking off)	• First vehicle emission standards	• First Clean Air Law	• Unclear	• First diesel vehicle emission standard • Beijing implemented Euro I
2000–2012 (Rapid development)	• New vehicle emissions limits • Key trigger: Beijing pollution episode 1998	• 2nd Amendment to Clean Air Law • Enforcement measures • Failed to obtain authority over fuel quality	• Ministry of Environmental Protection (MEP) established	• China I–III HDV emission standards • Non-road China I and II emission standards • China IV emission standard was delayed twice due to poor diesel fuel quality
2013–2020 (Focused on key issues)	• 12th Five-Year Plan focused on total pollution control • 13th Five-Year Plan focused on diesel emissions control • Key trigger: pollution episode in China in winter 2013	• 3rd amendment to Clean Air Law • Ten Principles for Clean Air • Three-year National Plan of Blue-Sky Defense	• Ministry of Ecology and Environment (MEE) established and given clear authority to enforce emission standards and new responsibilities on GHG emissions control	• China IV and V HDV emission standards • Non-road China III • China VI HDV emission standard • Diesel fuel China VI standard • Marine engine China I emission standard • In-use vehicle standards

3. CHINA'S CLEAN DIESEL PROGRAM COMPONENTS

There are eight key components in China's diesel pollution strategies: laws and legislation, new vehicle and engine standards, vehicle emission compliance and enforcement, in-use vehicle and engine programs, diesel fuel programs, advanced technology programs, GHG regulations, and incentive programs (see Figure 3). This section describes each component and its progress in greater detail.

Figure 3. Program components of China's clean diesel strategies.

3.1 LEGISLATION AND PLANS

The Clean Air Law is the legal basis for the implementation of diesel vehicle pollution control regulations. The focus of the legislation has been changed from compliance with emission standards to total emissions control, and then to air quality improvement. It covers the whole chain of emissions, including source control, in-use compliance, end-of-pipe treatment, and scrappage management. Penalties for noncompliance are also becoming tougher. However, China's legislation only provides rules as principles and lacks operational rules. For example, the authorities responsible for new vehicle management and fuel quality management were not clear for many years, and as a result, some provisions were not implemented sufficiently. The new Clean Air Law, amended in 2015 and in effect from January 1, 2016, onward, for the first time gave the environmental regulatory body (at the time MEP and now known as MEE) the clear authority to enforce emission standards.

The central government implements five-year plans for social and economic development, and environmental protection plans have been part of the five-year plans since the 1990s. The national Environmental Protection Five-Year Plan is published by the China State Council and is the highest level of policy plan that directs environmental protection work during those five years. In general, the five-year plans set overall targets for environmental protection and provide guidance on measures that should be taken to achieve the targets. The corresponding government budgets also account for the need to accomplish the tasks.

Following up on the five-year plans, MEE launches detailed policies and action plans, establishes management mechanisms, develops emission standards and technical regulations, and supervises and implements these policies, all with the aim of achieving the goal set by the five-year plan. The legislation and plans related to vehicle emission control in China since 2000 are shown in Figure 4.

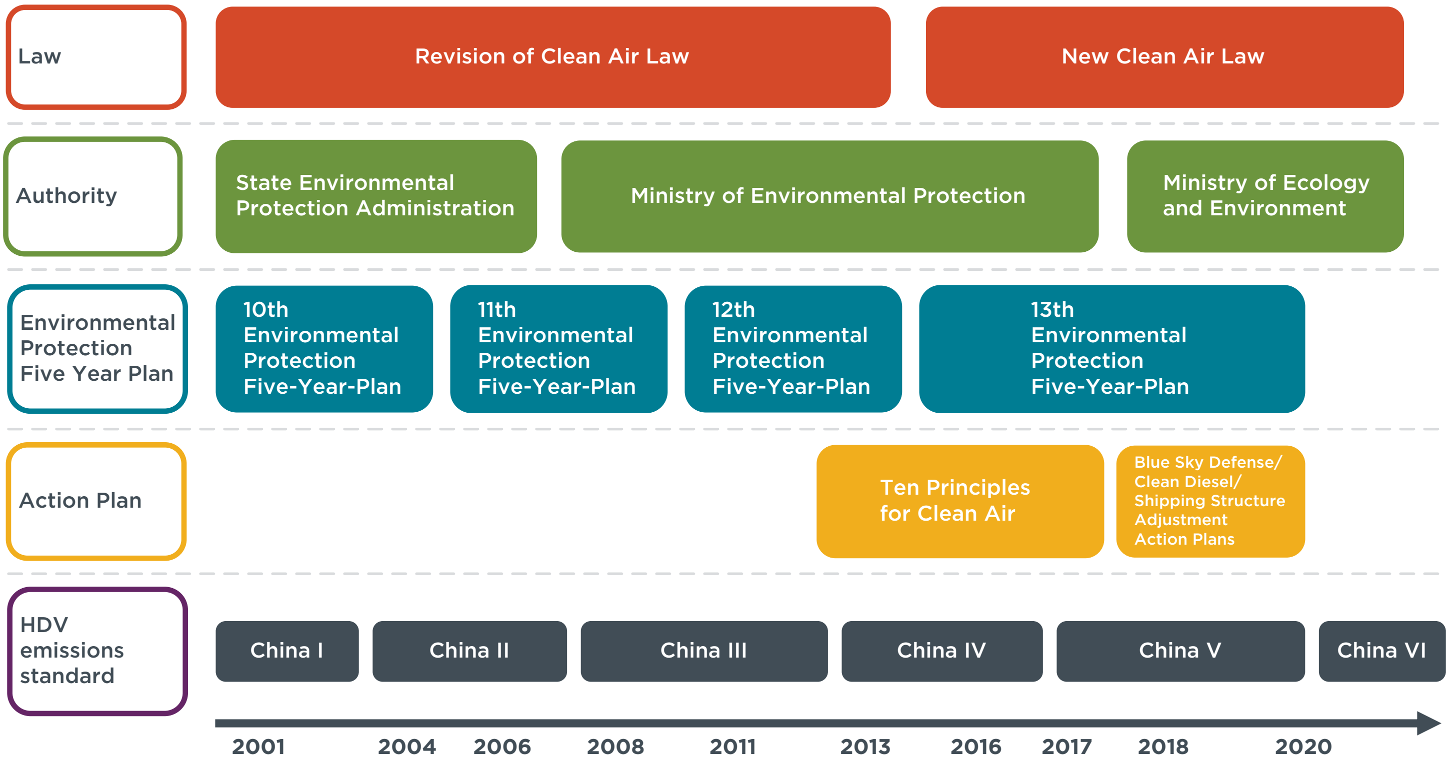

Figure 4. Legislation and plans related to vehicle emission control in China.

CLEAN AIR LAW

Over the several revisions to the Clean Air Law, regulatory bodies were given stronger, clearer, and better-defined authority to ensure compliance with various vehicle-related regulations. When noncompliance was identified before 2016, MEP did not have clear authority to enforce and penalize. The new Air Pollution Prevention and Control Law, which took effect January 1, 2016, gave MEP (now MEE) clear authority to enforce emission standards, including the authority to recall noncompliant vehicles and impose large fines on violating companies. Companies that produce, import, or sell noncompliant vehicles and non-road machinery are subject to a fine of more than one time but not more than three times the value of the goods (National People's Congress of China, 2018). These changes paved the way for building a strong and robust vehicle emission compliance program.

The new Clean Air Law also shifted focus from preproduction to in-use emission control of vehicles and formalized MEP's authority to conduct production conformity testing, a provision that originally appeared only in vehicle emission standards. This is important because in the Chinese context, emission standards are considered technical standards and are not regulations with enforcement power. Moreover, the new Clean Air Law clarified certain vague areas of authority in the old law with regard to implementation of emission standards. For example, the old law prohibited the production and sale of vehicles and engines not in compliance with emission standards but did not specify which agency had the authority to implement that prohibition. According to the new law, the MEE and local bureaus of environment and ecology (BEEs) have the authority and leading role in conducting conformity tests, and play a supportive role for industrial and commercial administrations and other agencies. Other important enhancements include provisions to secure the credibility of in-use inspection tests (I/M tests) and testing facilities, and an increased compliance burden on manufacturers/industry and vehicle owners. These provisions were created in response to recent evidence of cheating on in-use emissions testing by both industry and vehicle owners.

After the implementation of the new Clean Air Law, MEP established a new environmental information disclosure system. Also, the regulatory agency no longer type-approves new vehicle models. It now establishes the test protocols and emission limits for all required type tests, but focuses its limited resources on performing verification tests, including conformity of production, new vehicle inspection, and in-service compliance inspection. Vehicle manufacturers are required to self-test and self-certify their new vehicle models. The manufacturer must report test results and emissions-related information to the MEE and make this information available to the public.

In 2018, MEP imposed penalties on Shandong Kaima Automobile Manufacturing Co. Ltd. and Shandong Tangjun Ouling Automobile Manufacturing Co. Ltd. for failure to comply with the diesel vehicle emission standard; these were the first national-level administrative penalties of this kind and the total fines reached ¥38 million (MEE, 2018b; 2018c). In 2018, the Environmental Protection Department of Shandong Province imposed penalties on Dezhou Degong Machinery Co. Ltd. for producing and selling non-road mobile machinery that was not compliant and on Qingdao Aowei Junshan Trading Co. Ltd. for failure to disclose environmental information in accordance with the regulations. These were the first penalties imposed on non-road machinery manufacturers and automobile import companies (Shandong Environmental Protection Bureau [EPB], 2018a; 2018b). In 2019, the Beijing Ecology and Environment Bureau imposed a penalty on Jianghuai Automobile Group Corp. Ltd. for selling noncompliant diesel trucks in Beijing; the total fine was 170 million RMB, the largest fine ever imposed on a car manufacturer in China (Beijing Ecology and Environment Bureau, 2019).

AUTHORITY

The Clean Air Law stipulates that people's governments at or above the county level should incorporate air pollution prevention and control efforts into local economic and social development plans and increase financial investment in air pollution prevention and control. Local people's governments at all levels are responsible for the quality of the atmospheric environment in their respective administrative areas, and for formulating plans and adopting measures to gradually reduce levels of atmospheric pollutants. This requires local governments at all levels to assume responsibility for diesel vehicle pollution control, and various government departments need to coordinate with each other and carry out the work according to the government's plan.

The MEE is in charge of implementing environmental policies and enforcing environmental laws and regulations; the current MEE was established in 2018 (China State Council, 2018a). For diesel fuel quality management, the National Energy Administration is in charge of formulating fuel quality standards and the State Administration for Market Regulation (SAMR) is responsible for implementation of the standards and compliance. According to the new Clean Air Law, SAMR has the authority to enforce fuel quality standards. Refineries that produce noncompliant fuels and fuel stations that sell noncompliant fuels are subject to a fine of more than one time but not more than three times the value of the goods.

National and provincial ecological and environmental authorities are in charge of supervision and inspection of the air pollutant emissions of newly produced and in-use motor vehicles and non-road mobile machinery. This is done through on-site inspections and sampling tests.

The environmental protection recall system is implemented by the SAMR in conjunction with the MEE. The MOT is responsible for the supervision of vehicle maintenance stations, marine vessel and port emissions management, modal shift from truck to rail, and the promotion of green freight. Vehicle CO_2 emissions are managed via fuel consumption regulations, which are formulated and implemented by the Ministry of Industry and Information Technology (MIIT).

ENVIRONMENTAL PROTECTION FIVE-YEAR PLAN

Over time, China's five-year plans have included an increasing number of provisions related to vehicular emissions control. These have reflected a shift from goals related to total emission control to air quality goals that are better aligned with the public health impact of the emissions.

The 10th and 11th Five-Year Plans focused on industrial pollution prevention and control. The 12th Five-Year Plan required that total NO_x emissions in 2015 be reduced by 10% compared with 2010. The 13th Five-Year Plan, issued in 2016, focused on control of the emissions from heavy-duty diesel vehicles and high-emitting vehicles (China State Council, 2016). The plan called for the development and implementation of China 6/VI emission standards, the non-road China IV standard, new in-use vehicle standards, upgraded fuel quality standards, a strengthened fuel quality compliance program, the promotion of new energy urban buses, and the implementation of a marine domestic emission control area (DECA) in key regions.

As a follow-up policy, MEE issued a 13th Five-Year Plan for the Development of National Environmental Protection Standards in 2017 (MEE, 2017a). The plan listed environmental standards that were planned to be published or revised from 2016 to 2020 (see Table 2). MEE is in charge of developing the new and revised standards. By March 2021, some of the key standards had been published, such as the China VI HDV, PEMS, remote sensing, and I/M standards. Other standards are still being developed.

Table 2. Environmental standards to be published or revised by 2020.

Type	Standard	Status by March 2021
New vehicle/engine and associated standard	China VI HDV emission standard	Published
	PEMS standard for heavy-duty vehicles and engines	Published
	LDV real-world driving emissions testing technical standard	In progress
	HDV remote onboard diagnostics (OBD) technical standard	In progress
	Vehicle/non-road environmental information disclosure technical standards	In progress
In-use vehicle standard	I/M testing regulation for vehicles	Published
	Remote sensing standard	Published
	Environmental aftertreatment system retrofit technical standard	In progress
	OBD regulation for in-use vehicles	In progress
In-use non-road machinery standard	I/M testing regulation for non-road machinery	Published
Emission inventory standard	Technical standard on atmospheric pollutants emissions inventory	Published

AIR POLLUTION PREVENTION AND CONTROL ACTION PLAN

In January 2013, eastern China experienced a severe smoggy haze outbreak. Subsequently, in September 2013, the China State Council issued the Air Pollution Prevention and Control Action Plan (China State Council, 2013). This policy, also known as Ten Principles for Clean Air, was the first and the most powerful national-level plan that focuses on air pollution control. The plan set the roadmap for air pollution control for 2013–2017, with a focus on three key regions, Jing-Jin-Ji, the Yangtze River Delta, and the Pearl River Delta. The objective of the plan was to improve air quality and reduce heavy polluted days by 2017. It stated that the average PM_{10} concentration nationwide should be reduced by 10% by 2017, whereas the average $PM_{2.5}$ concentration in Jing-Jin-Ji, the Yangtze River Delta, and the Pearl River Delta should be reduced by 25%, 20%, 15%, respectively, also by 2017. In Beijing, the average concentration of $PM_{2.5}$ was to be brought below 60 $\mu m/m^3$ by 2017. The plan also set targets to strengthen mobile source pollution control, improve fuel quality, and promote new energy vehicles.

THREE-YEAR NATIONAL PLAN OF BLUE-SKY DEFENSE

In 2018, the China State Council released a three-year National Plan of Blue-Sky Defense (China State Council, 2018b). This policy was considered to be the second phase of Ten Principles for Clean Air. The plan aimed to reduce emissions of air pollutants and GHGs and improve air quality by 2020. It set specific targets and timelines: By 2020, emissions of sulfur dioxide (SO_2) and NO_x should decline at least 15% compared with 2015 levels. Cities with poor air quality should see ambient $PM_{2.5}$ concentration fall at least 18%. The number of days with good air quality should reach 80% by 2020, and the percentage of heavy polluted days should decrease at least 25% compared with 2015. Specific targets and measures are listed in Table 3.

Table 3. Key targets and measures in three-year National Plan of Blue Sky Defense

Modal shift	Compared with 2017, a 30% increase in railway freight nationwide, and a 40%, 10%, and 25% increase in Jing-Jin-Ji, Yangtze River Delta, and Fen-Wei Plain, respectively
	10% annual increase in water-rail combined transport
	At key ports, bulk cargo such as coal, ore, and hard coke shall be transported by rail and water instead of diesel truck
Electric vehicle (EV) promotion	Annual EV sales shall reach 2 million by 2020
	In key regions, 80% of new urban vehicles (buses, postal vehicles, sanitation vehicles, taxis, light drayage trucks) shall be EVs by 2020
New vehicle standards	Early implementation of China VI emission standards in key regions starting from July 1, 2019
	Full implementation of China VI fuel quality standard starting from January 1, 2019, and early adoption in key regions
In-use vehicles and non-road program	Scrappage program for pre-China IV diesel trucks, and lean-burn and retrofitted compressed natural gas (CNG) trucks
	Scrappage of 1 million pre-China IV diesel trucks in Jing-Jin-Ji and Fen-Wei Plain by 2020
	In key regions, retrofit diesel trucks with aftertreatment systems and a remote emissions management system
	In key regions, develop low-emission zones for non-road machinery
	In key regions, expand domestic emission control area
	Develop a national remote sensing monitoring platform by the end of 2019

ACTION PLAN FOR BATTLE AGAINST DIESEL TRUCK POLLUTION

In January 2019, MEE, the National Development and Reform Commission (NDRC), and nine other government bodies published an Action Plan for Battle Against Diesel Truck Pollution (MEE, 2019a). This policy supports the three-year National Plan of Blue-Sky Defense. Despite the name, the vehicle itself is not the only target. The policy is also aimed at reducing emissions from non-road machinery and marine vessels. Detailed tasks are classified in four programs: Clean Diesel Vehicles, Clean Engines, Clean Transportation, and Clean Fuels. According to the plan, the compliance rate of in-use diesel vehicles should reach 90% nationwide and 95% in key regions. On diesel and urea quality, the target is to reach a compliance rate of 95% nationwide and 98% in key regions in 2020. Key measures include early adoption of China VI/6 standards in key regions, strengthening in-use supervision, phasing out 1 million pre-China IV trucks, increasing the freight volume of railways and waterways, promoting green freight, promoting new energy vehicles, and improving diesel fuel quality and supervision.

THREE-YEAR ACTION PLAN ON PROMOTING SHIPPING STRUCTURE ADJUSTMENT

On-road freight is a major energy consumer and emissions producer in China. The National Plan of Blue-Sky Defense targeted a 30% increase in the national volume of railway freight by 2020, compared to the 2017 level. In some key ports, raw materials such as coal, ore, and coke were to be transported by rail or waterway, instead of truck, by 2020. In September 2018, China's State Council issued a supportive policy, a Three-year Action Plan on Promoting Shipping Structure Adjustment (China State Council, 2018c). This action plan set out detailed tasks, quantitative indicators, and deadlines for accomplishing the goals. For example, 80% of new logistics parks and large industrial and mining enterprises with a total freight volume of more than 1.5 million tonnes were to be connected to industrial railways by 2020. Main ports along the Yangtze River were to be integrated into railway. The plan requested the promotion of multimodal transportation demonstration projects, container railway-waterway combined transportation, and urban green freight distribution demonstration projects. According to the plan, around 100 urban green freight distribution demonstration projects would be implemented by 2020, and concentrated transportation modes such as drop and hook, joint distribution, centralized distribution, and night delivery are encouraged. Currently, transportation agencies and local governments are providing financial support and policy support such as road access privileges to these demonstration projects.

At the regional level, MEE issued a work plan for air pollution prevention and control in Jing-Jin-Ji and surrounding areas in 2017 (MEE, 2017b). The plan banned the use of diesel trucks for coal transport from ports in Tianjin by the end of July 2017, and from all ports around the Bohai Rim by the end of September 2017. In September 2018, MEE issued a work plan for comprehensive air pollution prevention in Jing-Jin-Ji and surrounding areas for the autumn and winter of 2018 and 2019. The plan required that only trains be allowed to transport coal to the ports in Tianjin Port, Tangshan Port, Huanghua Port and all ports around Bohai Rim by the end of December 2018. According to the Action Plan for the Battle Against Diesel Truck Pollution, the ban was expanded to all key ports by 2018. In addition, ore and coke were no longer to be transported by truck at key ports by 2020.

3.2 NEW VEHICLE AND ENGINE STANDARDS

HEAVY-DUTY DIESEL ENGINES AND VEHICLES EMISSIONS STANDARD

China has implemented standards equivalent to those in effect in the European Union, with implementation dates of the China HDV standards generally lagging the equivalent EU standard by 8–10 years (see Figure 5). In June 2018, MEE released the final rule for the China VI emission standard for HDVs (MEE, 2018d). Unlike the previous phases, though, the China VI standard combines best practices from both European and U.S. regulations and also creates its own.

China VIa is largely equivalent to Euro VI, and China VIb introduces slightly more stringent testing requirements and a remote emissions monitoring system. In China VI, NO_x and PM emission limits are reduced by around 70% from the current China V standard; particulate number (PN) limits are included; and full vehicle PEMS testing and requirements and in-service conformity testing are adopted (see PEMS emission limits in Table 4). In addition, China VIb requires new vehicles to be equipped with a remote emission monitoring on-board terminal, and this is the first in-vehicle regulation anywhere in the world. In short, China VI is one of the most stringent emission standards to date. For all new HDVs, China VIa will be implemented starting from July 2021, and China VIb will be implemented starting from July 2023. More than a dozen provinces and cities in key regions have implemented the China VI standard ahead of the national schedule, mostly starting from July 1, 2019.

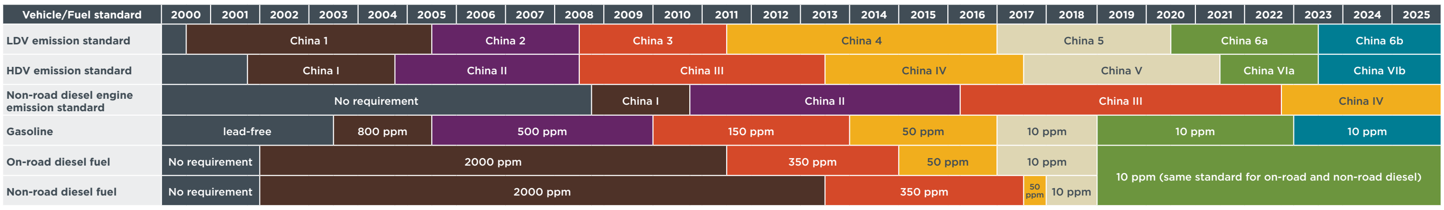

Figure 5. Implementation timeline of China LDV and HDV emissions standards and gasoline and diesel fuel standards.

Table 4. PEMS emission limits in China VI HDV emission standard

Stage	Pollutant	CO	NO_x	PN	
China VI	Break-specific emission limits[a]	≤6 g/kilowatt hours (kWh) (CF=1.5)	≤0.69 g/kWh (CF=2.0)	No limit for China VI-a 1.2x10^{12} #/kWh for China VI-b (CF=2.0)	
	Instantaneous emission limits[b]	—	500 ppm	—	—
	[a] 90% of all valid windows shall meet the limit. [b] 95% of the instantaneous NO_x emission rates shall meet the limit.				

Improved OBD requirements

An OBD system is designed to help ensure proper operation of vehicle emission control devices (Posada & Bandivadekar, 2015). When the OBD detects a malfunction related to emission performance, the malfunction indicator light illuminates to alert the vehicle driver. In China, OBD standards follow the European OBD standards. The OBD standard was designed to apply nationally beginning on July 1, 2008, but this was delayed until 2013 to harmonize with the adoption of China IV and V regulations. Starting with the China IV HDV emission standard, OBDs were required to be installed on HDVs. However, fake China III/IV HDVs without selective catalytic reduction (SCR) systems were reportedly widespread in the market in 2014 (Ding & Wang, 2014). In addition, a so-called "urea controller," which can reduce or stop urea injection, was sold by online shops in China before 2017 (Gao, 2017). In response to this problem, the new China VI emission standard includes improved requirements for OBD systems based on EU OBD requirements and anti-tampering provisions based on U.S. OBD requirements.

Remote OBD system

For the first time in any HDV regulation, the China VI standard requires HDVs to be equipped with an on-board remote emissions monitoring system or remote OBD. Data items that are required to be reported through the remote OBD system are listed in Table 5.

Table 5. Required data items for remote emission management on-board terminal

Required data type	Required data item
Time	Year, month, date, hour, minute, second
GPS	Position status, longitude, latitude, velocity, direction, distance
ECU	Velocity
	Barometric pressure
	Engine reference torque
	Engine percent torque
	Friction torque
	Engine speed
	Calculated engine load
	Engine fuel rate
	Accelerator pedal position
	NO_x sensor
	DPF outlet temperature
	DPF differential pressure
	MAF air flow rate
	Driver's demand engine percent torque
	Actual engine percent torque
	Max engine reference torque (as a function of engine speed)
Malfunction code	ECU malfunction code
	Other malfunction number
	Other malfunction code

Remote OBD provisions are valuable for improving in-use compliance and improving the effectiveness of future inspection and maintenance programs. MEE is currently developing a technical specification for the remote OBD system, which will be hopefully published by 2021. Local governments such as Beijing and Nanjing are conducting remote OBD pilot programs on heavy-duty buses.

NON-ROAD MACHINERY DIESEL ENGINE EMISSION STANDARD

China has established emission standards for multiple categories of non-highway vehicles and engines. These include standards for three-wheeled and low-speed vehicles as well as non-road mobile machinery. Chinese emission standards for non-road mobile machinery are generally based on the European emission standards. However, the Chinese standards also include small diesel engines that are not included in the European standards. Emissions limits for the smallest engines are consistent with the U.S. Tier 1/2 non-road standards.

Currently, China is implementing the China III non-road mobile machinery emission standard, which is equivalent to Stage IIIA of the EU standard. In December 2020, MEE released Emission Control Technical Requirements of Non-road Mobile Machinery and Diesel Engine (MEE, 2020b), and this is considered as an updated China IV non-road mobile machinery emission standard. The standard follows the path of the latest Stage V regulations in Europe and further tightens the emission requirements for gaseous pollutants and particulate matter from non-road diesel engines. On the basis of the old China IV non-road emission standard, the technical requirements policy includes stricter requirements in the following aspects:

» Test procedure is changed to transient test cycle

- Non-road mobile machinery equipped with a diesel engine (37 kW to 560 kW) is required to be equipped with wall-flow DPF, the PN emitted shall be less than 5×10^{12}#/kWh, and no smoke shall be detected during DPF regeneration
- PEMS test requirement
- Stricter targets for manufacturers based on EU Stage V emission limits
- Positioning requirement for machinery above 37 kW
- Modified adopting of the requirements of EU2016/1628 on the part of control area
- Requirements on aftertreatment system control
- More stringent warranty period requirements

The China IV non-road emission standard will be implemented on December 1, 2022. The standard is the first non-road mobile machinery emission standard in the world that requires mandatory installation of a DPF and China will be among the countries with the most stringent non-road emission standards.

MARINE ENGINE EMISSIONS STANDARD

On August 30, 2016, MEE and Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) jointly released the first-ever national emission standards for marine engines used in domestic shipping in China. Phase I standards took effect on July 1, 2018, and stricter Phase II standards will take effect on July 1, 2021. Affected vessel types include ships navigating in inland waterways and coastal waters; those used for emergency and rescue purposes are exempt.

The marine engine standards cover both compression ignition engines and spark ignition engines, including dual-fuel engines. The standards apply to Category 1 and 2 marine engines installed on river vessels, coastal vessels, river-sea ships, channel ships, and fishing vessels with net power at or above 37 kW and with no more than 30 liters per cylinder of displacement. Smaller engines, with net power less than 37 kW, are subject to a separate engine regulation for non-road machinery. Marine engines greater than 130 kW are already subject to NO_x regulations set by the International Maritime Organization (IMO).

3.3 VEHICLE EMISSIONS COMPLIANCE AND ENFORCEMENT

SUPPLEMENTAL PEMS STANDARD

Studies in China have shown that real-world emissions can be significantly higher than the corresponding certification levels as tested in the laboratory (Wu et al., 2012; Zhang et al., 2014; Yang, 2017). To help prevent excess NO_x emissions, the MEE issued the first national standard for PEMS testing of HDVs in September 2017 (MEE, 2017c). The regulation is a supplement to all existing requirements under the China V standard and requires additional on-road PEMS testing for new and in-use China V HDVs. The PEMS testing standard took effect on October 1, 2017. Type approvals of new China V heavy-duty diesel and gas fueled models after that date must comply with the standard. For China V models type-approved before October 1, 2017, the standard requires in-use compliance testing and reporting of results to the regulatory agency. Table 6 presents the emission limits in the China V PEMS standard. The China VI PEMS emissions limits are more stringent and are specified in the China VI emission standard (see Table 4).

Table 6. Emission limits in China V PEMS standard.

Stage	Pollutant	CO	NO_x	THC	PM
China V	Break-specific emission limits[a]	≤6 g/kWh (CF=1.5)	≤4 g/kWh (CF=2.0)	Optional	Optional
	Instantaneous emission limits[b]	—	900 ppm	—	—
	[a] 90% of all valid windows shall meet the limit. [b] 95% of the instantaneous NO_x emission rates shall meet the limit.				

CONFORMITY OF PRODUCTION

Starting from China III, the MEP (and now the MEE) has carried out inspections of conformity of production (COP) every year. In the type-approval stage, manufacturers must submit a COP guarantee plan and a self-inspection report every year. According to the company's self-inspection plan, the Vehicle Emission Control Center (VECC) formulates annual inspection plans at the beginning of the year and implements the inspection plan upon approval by the MEP. Light-duty diesel vehicles and heavy-duty diesel vehicles and engines are all within the scope of COP inspection. According to the regulation, four prototype vehicles shall be selected from the production line of the manufacturer, the product warehouse, or the seller and tested at a third-party testing agency. Diesel vehicles or engines from 10 to 20 companies are sampled annually depending on VECC's budget. For vehicles that do not meet the standards, manufacturers shall rectify as appropriate. In 2018, penalties were imposed on two diesel vehicle manufacturers, Kama and Tang Jun Ouling, for producing diesel vehicles that were not compliant with the emission standard.

IN-USE COMPLIANCE TESTING

Starting from China IV, diesel vehicle manufacturers are required to submit an in-use compliance assurance plan and then submit a self-inspection report every year. However, due to an inadequate supply of qualified diesel fuel on the market in the past, there was a time when MEE did not effectively carry out in-use compliance inspections. PEMS tests results from third parties have shown that some China IV and China V in-use diesel vehicles exceeded the emission limits during this time.

Compared with previous standards in China, one of the major changes of China VI is that type approval is replaced with a type test. In addition, the China VI regulation requires a number of agency- and manufacturer-run regulatory tests that apply to vehicle prototypes and throughout a vehicle's useful life (see Figure 6). Manufacturer-performed tests mandated by the China VI standards include four stages of testing: type test, COP test, new vehicle test, and in-use conformity test. For all four, MEE has the authority to conduct verification tests of the manufacturer tests. For in-service testing, PEMS testing is required to be performed on in-use vehicles by both engine and vehicle manufacturers. Test results are required to be reported to the agency and published by manufacturers. For in-service vehicles with mileage exceeding 10,000 kilometers (km), the agency has the authority to randomly select three vehicles from each vehicle family and perform an in-use surveillance test. The in-use test may include a PEMS test plus an OBD and NO_x control strategy check.

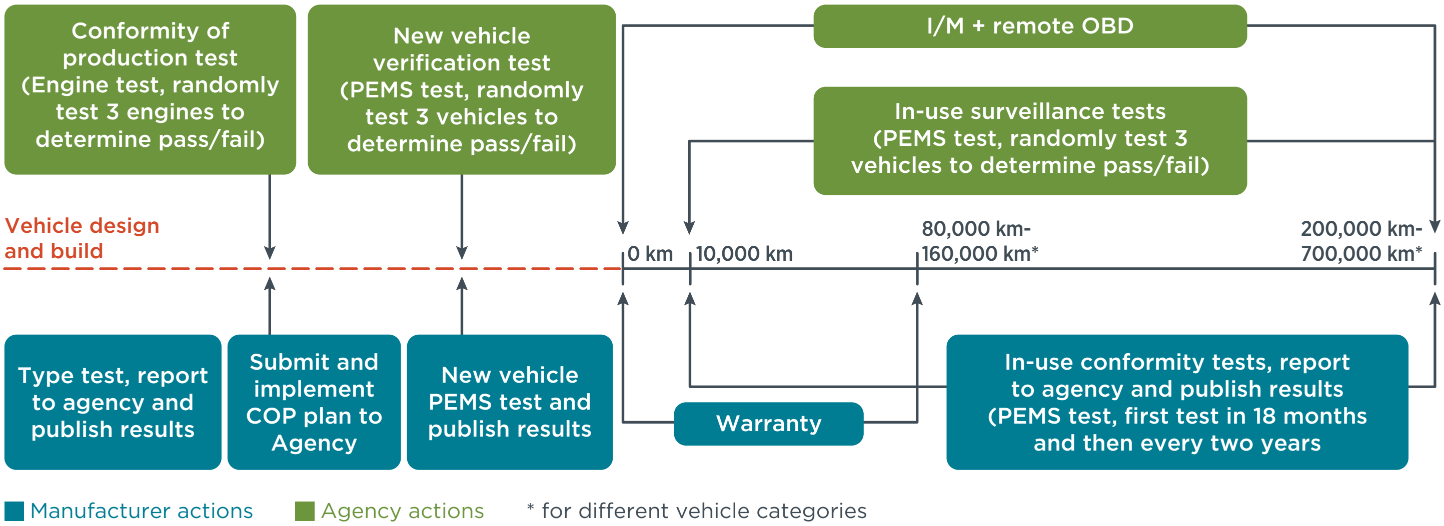

Figure 6. China VI compliance program

EMISSION WARRANTY

Manufacturers are required to guarantee a number of emission control components in their new vehicles for a minimum distance or time. If the emission control equipment and related components malfunction while still under warranty, manufacturers are responsible for repairing the part and paying the relevant expenses. In addition, manufacturers are required to publish a list of the emission control equipment and related components that they make and their corresponding warranty parameters. The minimum warranty parameters in the China VI standard are shown in Table 7.

Table 7. Minimum warranty parameters in China VI HDV emission standard

Vehicle category	Minimum warranty[a]	
	Distance traveled (km)	Service time (years)
M1, M2, N1	80,000	5
M3, N2, N3	160,000	5

[a] Distance traveled or service time, whichever is sooner

RECALL AND ENFORCEMENT

Vehicle manufacturers and importers that produce or sell noncompliant vehicles or machinery must recall them voluntarily. If noncompliant vehicles are not recalled, SAMR and MEE shall order the recall. In April 2021, SAMR and MEE jointly released a regulation on the management of vehicle emission recall (SAMR & MEE, 2021). According to the regulation, SAMR and MEE will jointly establish a vehicle environmental information management and warranty data reporting program. Manufacturers should report the emission-control components that have warranties and their warranty parameters to the authorities. If the cumulative number of claims made on an emissions-related component reaches a certain number,[3] the manufacturer must file an emission warranty information report. If there is a significant share or number of warranty claims subject to a specific emissions issue, or a possible emissions issue identified from other data sources, SAMR and MEE will investigate. If an emission defect is determined, SAMR and MEE will require that the manufacturer recall and fix the affected vehicles and engines. When such a recall occurs, the manufacturer must release the recall information to the public and notify vehicle owners within 30 days. The manufacturer must repair, replace, or refund the vehicles with an emission defect.

3 The proposal did not specify what the number is.

In August 2020, Zhejiang Feidie Automobile Manufacturing Co. Ltd. voluntarily recalled 458 diesel vehicles due to OBD system calibration problems (MEE, 2020c).

3.4 IN-USE VEHICLE AND ENGINE PROGRAMS

IN-USE DIESEL FLEET REGULATIONS

Emissions labeling

In July 2009, MEP announced a nationwide labeling system that required all provincial and municipal EPBs with established emission label programs to verify and issue vehicle emissions stickers. Pursuant to this system, which is still in place today, all gasoline vehicles that meet the China 1 standard and above and diesel vehicles that meet China III and above receive green labels. Vehicles that do not meet these minimum requirements but still meet their corresponding emission standards receive yellow labels. Vehicles that fail to meet their corresponding emission standards cannot be granted a label. For regulatory simplicity, many local governments combine their I/M program with their yellow/green sticker program. Vehicles can only be registered if they have a yellow/green emission sticker.

The labeling program was introduced mainly to support in-use vehicle programs. Emission labels have been used for two types of programs: local traffic restrictions and the national scrappage incentive program. Vehicles with yellow labels are banned from traveling into inner-city areas. For example, since 2010, yellow-label vehicles have been restricted from entering the Sixth Ring Road in Beijing, and the restricted area was expanded to the whole city in December 2015. Since 2017, pre-China IV diesel trucks have been banned from entering the Sixth Ring Road (United Nations Environment Programme, 2019). Many other cities are implementing local traffic restrictions, as well.

Under the yellow-label scrappage subsidy program, owners of old or yellow-label vehicles who scrap them and replace them with new vehicles are eligible for a cash rebate. By the end of 2019, almost all yellow-label vehicles were scrapped. The scrappage incentive program is discussed in detail in Section 3.8.

DPF retrofit program

After yellow-label vehicles were essentially eliminated, China III to China IV diesel trucks became the most common vehicle types in the fleet. These vehicles were not typically equipped with a DPF when they were sold so they have become the major contributors of particulate matter emissions from on-road vehicles. The main strategy to reduce the emissions from these older vehicles is to eliminate them. For old vehicle and non-road machines that have a high salvage value, though, a DPF retrofit program is a recommended measure to reduce the emissions from them. Some local BEEs are conducting DPF retrofit programs on diesel trucks and non-road machinery. In such programs, the local government usually provides a financial subsidy.

In 2017, the Shenzhen EPB published a technical regulation on DPF retrofits on diesel vehicles and non-road machinery (Shenzhen AMR, 2017). The regulation provides principles and methods for selecting qualified DPFs and vehicles, matching DPFs with vehicles, on-road demonstration measurement, installation, and maintenance and monitoring. Targeted vehicles included China III and newer diesel vehicles and China I and newer non-road machinery.

According to the regulation, retrofitted vehicles are required to be tested on the Worldwide Harmonized Transient Cycle, and during the non-regeneration period, the filter efficiency is required to be above 97%. NO_x, CO, and hydrocarbon (HC) emissions must not increase after the retrofit. Any CO_2 emissions increase must be kept below 3%. In addition, the regulation requires that each retrofitted vehicle and non-road machine be connected with a real-time remote monitoring system. Through this, key information including geographical location, temperature, pressure at the inlet/outlet of the DPF, and alert information is reported to Shenzhen EBB. The DPF supplier is responsible for ensuring the in-use compliance of the DPF systems within their useful life (200,000 kilometers or 4 years).

In 2008, Beijing launched a DPF retrofit program for diesel HDVs and 10,000 diesel vehicles were retrofitted. In 2015, approximately 8,800 China IV/V diesel buses were retrofitted to reduce NO_x emissions. From January 2016 to December 2017, approximately 17,000 heavy-duty public service vehicles were retrofitted with DPFs (UN Environment, 2019). During 2008–2014, subsidies equivalent to half (but no more than ¥15,000) of the total retrofitting costs were granted for retrofitting heavy-duty diesel vehicles in Beijing (UN Environment, 2019).

In 2013, Nanjing launched a DPF retrofit program for China II yellow-label diesel vehicles. PM emissions from the retrofitted vehicles met the China III standard and the vehicles were issued a China III green label (VECC, 2017b). In a 2017 pilot program, 240 diesel vehicles and non-road machines were retrofitted with DPFs.

The 2018 "Shenzhen Blue" Action plan set a target to retrofit or scrap 1,000 diesel sanitation trucks and 1,360 diesel construction trucks in 2018 (Shenzhen Municipal Government, 2018a). Owners of truck and non-road machinery who retrofitted were eligible for a subsidy of up to ¥10,000 per vehicle or machine (Shenzhen Bureau of Environment and Ecology, 2018).

In 2017, the Tianjin Municipal Transportation Commission banned China III medium- and heavy-duty trucks without DPFs from entering the city. Tianjin encouraged China III trucks to be retrofitted with DPFs and provided a subsidy of up to ¥15,000 for truck owners who did so before the end of 2017 (Tianjin Municipal Transportation Commission, 2017).

IN-USE EMISSION INSPECTION

In-use vehicle emission standards

Over the years, the in-use vehicle emission standard has gone through several iterations. The most important upgrade was the change from idle and simple testing to more sophisticated cycle-based and loaded testing. This was done to more closely reflect realistic driving conditions.

The current standards, published in 2018, are free-acceleration and lug-down tests for diesel vehicles and two-speed idle conditions and short driving mode conditions tests for gasoline vehicles (MEE, 2018e; MEE, 2018f). The lug-down test and short driving mode are the preferred testing approaches for diesel and gasoline vehicles, respectively, and when they are not applicable, the free-acceleration test and two-speed idle test can be used. Updated in-use emission limits went into effect on May 1, 2019. The standard for in-use diesel vehicles created two sets of limits (see Table 8). Limit a applies to all vehicles, and the more stringent limit b applies to vehicles registered in cities with a vehicle population of more than 5 million or cities where mobile sources are the major contributor of air pollution.

The standards for in-use vehicle emissions testing discussed above are to be used for periodic inspection in I/M programs.

Table 8. In-use vehicle inspection test items and limits

Vehicle type	Diesel vehicles		Gasoline vehicles		
Test	Lug-down		Short driving mode		
Test items	Opacity (%)	NO_x (ppm)	CO (g/km)	HC (g/km)	NO_x (g/km)
Limit a	40	1,500	8	1.6	1.3
Limit b	26	900	5	1	0.7

Note: NOx limits took effect on November 1, 2020. For regions that adopt limit b, a transition limit of 1,200 ppm was applied before July 1, 2020.

Inspection/maintenance program

The purpose of an I/M program is to identify and mitigate emissions from high-emitting vehicles. Obligatory periodic emission inspections have been carried out in China for decades. However, some vehicles that fail the test have not been effectively repaired. In some cases, vehicles pass the emissions test by replacing emission control devices temporarily or falsifying emissions test results. To solve this problem, MEE, MOT, and SAMR jointly released a notice on establishing and implementing a vehicle emissions inspection and maintenance program in June 2020 (MEE, MOT, and SAMR, 2020). The major improvement of the new I/M program was the establishment of a closed-loop information sharing platform.

According to the notice, in-use vehicle periodic emission inspection programs are supervised by local EEBs and local AMRs, which entrust accredited vehicle test centers to conduct inspections. The inspection stations are to connect to MEE's national platform and the real-time test data is to be uploaded to the platform. Maintenance and repair stations are supervised by local transportation management bureaus.

Figure 7 presents a flow chart of the closed-loop management of the I/M program. For vehicles that fail the emission test, the inspection station will inform the vehicle owner in writing that they must repair the vehicle at a maintenance station. After maintenance, the maintenance station will share relevant repair information with a data-sharing platform available to inspection stations or issue a maintenance certification to the vehicle owner. Then, the vehicle must be re-tested at the inspection station. Vehicles that pass the emissions test will be issued an emission certification or emission label. If a vehicle fails the emissions test again, it is not allowed to be operated on the road until it passes the emissions test. If a non-compliant vehicle operates on the road without an emission certification, the vehicle owner will be subject to a penalty according to the new Clean Air Law.

If an inspection station is found to be conducting fraudulent testing or issuing a false report, the authorities will suspend its network connection with EEB and AMR and its report printing ability and levy a fine. If a maintenance station is found to be using counterfeit components, temporarily replacing the emission control systems, or exaggerating the performance of the maintenance, the transportation bureau will issue a fine according to regulations. In the case of serious violation, the certificate for conducting inspection and maintenance can be revoked.

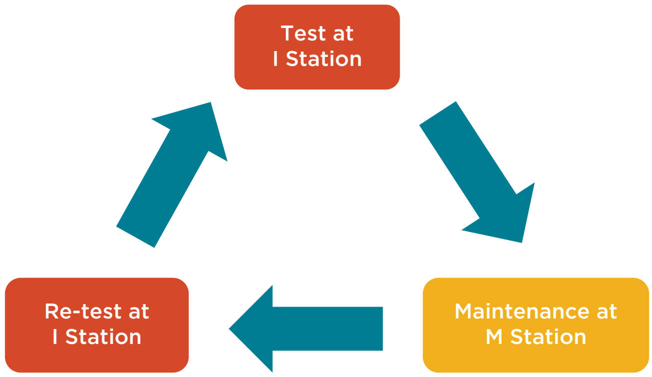

Figure 7. Closed-loop management of I/M program.

Currently, all 31 provinces in China have established periodic inspection programs. By the end of 2019, there were 9,768 inspection stations throughout the country. Most of them are connected to a three-level (nation-province-city) monitoring platform. By the end of 2019, 247.8 million vehicles had been tested in the periodic inspection program, and this accounted for 98.1% of the total vehicle population in China. In addition, MEE carried out 14,993 instances of supervision and inspection on I/M stations in 2019. Eight hundred and fifty-nine I/M stations were found to be violating the regulation and were fined. In addition, MEE and local departments of ecology and environment carried out 371 million instances of random inspections of in-use vehicles by remote sensing, roadside inspection, and door-to-door inspections. Eleven million vehicles were found to be not compliant with the emission standards (MEE, 2020d). According to an internal report of VECC, the pass rate of the diesel vehicle I/M program has been improving for all emission standards since 2017. The overall pass rate of diesel vehicles reached 90% in 2020 (see Figure 8). In addition, the average smoke intensity for all diesel vehicles tested in I/M programs fell from 2018 to 2020.

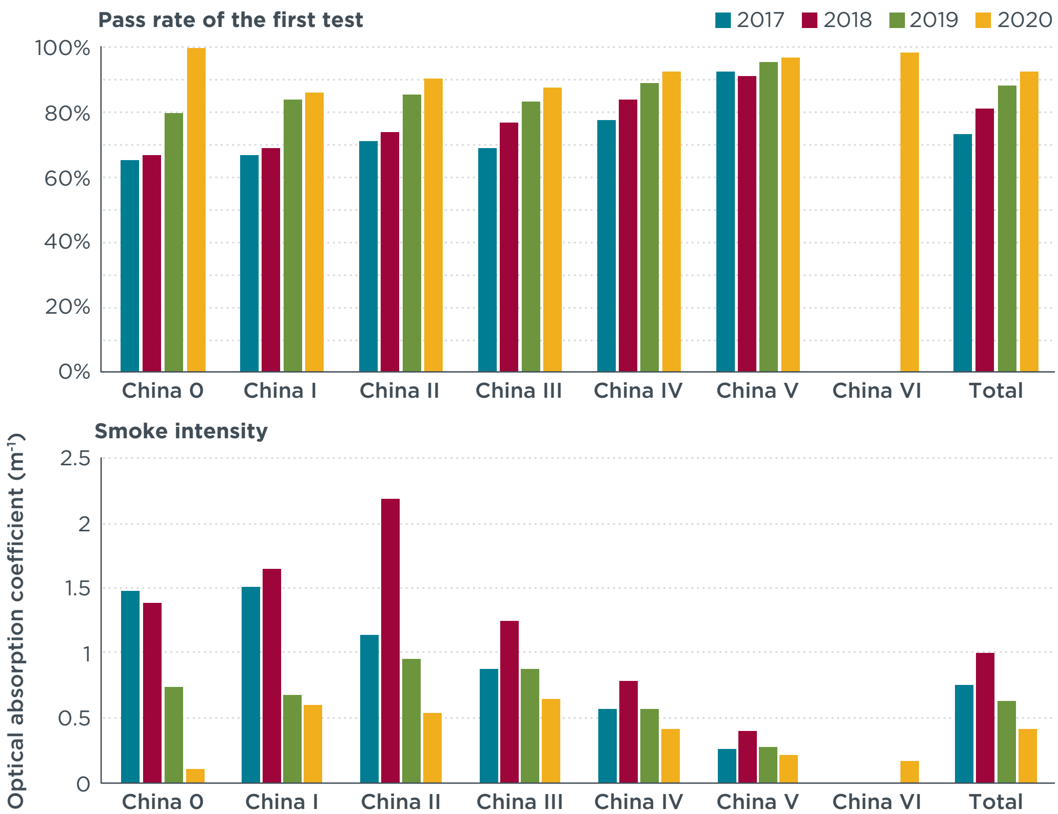

Figure 8. The pass rate of I/M program and the average smoke intensity for China 0 to China VI diesel vehicles, 2017 to 2020 (VECC, 2021).

Roadside emission inspection and remote sensing program

Currently, the MEE and local departments of ecology and environment are carrying out roadside inspection of diesel vehicles in accordance with the new in-use vehicle emission standard and checking emissions via the free-acceleration method, the OBD status, the pollution control device status, and the environmental protection information list. In addition, the MEE is formulating standards and methods for the rapid testing of fuel quality. For diesel vehicles that fail the roadside inspection, enforcement officers will impose penalties on the owners of the vehicles and upload the information to the national platform for information sharing. For diesel vehicles that exceed the standard on more than one occasion, the local authorities will urge the owner to carry out maintenance as soon as possible. The China VIb standard requires that HDVs be equipped with a remote OBD. With the implementation of China VIb, it is expected that regular inspections of diesel vehicles will be phased out in the future.

Remote sensing is a promising technology that measures exhaust emissions from on-road vehicles without interrupting traffic. Compared with PEMS, remote sensing can measure a large sample of vehicles in a short period of time at a far lower cost per vehicle. Further, it is difficult for vehicles to detect when they are being tested by remote sensing.

In 2017, China created a national regulation for measuring emissions from diesel vehicles using remote sensing (MEE, 2017d). It was the first national-level remote-sensing regulation in the world. The standard replaced all local standards related to the monitoring of diesel exhaust emissions using remote sensing, and it applies to all diesel vehicles, including light-duty and heavy-duty. The regulation is a technical standard for test protocols with recommended limits for local agencies to follow if they currently have or decide to implement a remote-sensing program. This standard sets a limit for PM emissions through opacity and Ringelmann blackness (see Table 9). For nitric oxide (NO), the limit is only used for screening high-emitting vehicles that are then subject to further inspection. A vehicle is determined to be noncompliant if it exceeds the remote-sensing emission limits in Table 9 for the same pollutant in two or more consecutive remote-sensing tests in 6 months. A high-emitting vehicle typically refers to a vehicle that is forbidden from entering a city or a low-emission zone set by the local government. In cities that are implementing remote-sensing programs, vehicles that are found to be noncompliant with the opacity or Ringelmann blackness limits can be subject to a penalty and will be required to be repaired. The specifics depend on the region.

Table 9. Remote-sensing emission limits for diesel vehicles in China

Pollutant	Limits
Opacity	30%
Ringelmann blackness	Level I (20%)
NO	1,500 ppm

Note. The NO limit is only used for screening high-emitting vehicles.

In Beijing, 10% of the vehicle population is responsible for more than 50% of the total on-road vehicle emissions. By a conservative estimate, 5% of the current vehicle fleet in China is contributing 25% of total vehicle emissions (VECC, 2017a). Therefore, the remote sensing regulation set a goal to eliminate the top 5% of emitters in the fleet in China.

The China Clean Diesel Action Plan requires accelerated deployment of both remote sensing and the data reporting system that connects the city level to the provincial level, and ultimately to the central platform (aka three-tier reporting); in key regions, this was to have happened by the end of 2018, and the requirement was 2020 for the rest of the nation. By the end of 2019, 2,671 remote-sensing stations had been established throughout the country and connected to the central monitoring platform. Another 960 stations are planned (MEE, 2020d).

Two hundred and seventy-three million measurements were taken in 2018 via remote sensing and black smoke capture testing and 2.1 million vehicles were found to be not compliant. In addition, local authorities tested 5 million in-use vehicles randomly on the roadside and 55,200 of them were found to be not compliant with the standard (MEE, 2019b).

IN-USE DIESEL ENGINE PROGRAMS

In-use non-road emission standard

In 2018, MEE released the first mandatory national standard for exhaust smoke emissions from non-road machines with diesel engines below 560 kW (MEE, 2018g). The standard combined the existing standards that had been implemented in various regions and standardized the testing protocols of the smoke measurements on free-load conditions. If an engine fails to meet the Ringelmann smoke limit (see Table 10), it is considered a noncompliant engine. For engines that pass the Ringelmann smoke test, the authority can still further measure the light absorption coefficient, with the results of the light absorption coefficient measurement prevailing in determining compliance.

Table 10. Limits set by the in-use non-road emission standard

Type	Rated net power (kW)	Light absorption coefficient (m^{-1})	Ringelmann blackness
I	$P_{max}<19$	3.00	1
	$19 \le P_{max}<37$	2.00	
	$37 \le P_{max}<560$	1.61	
II	$P_{max}<19$	2.00	1
	$19 \le P_{max}<37$	1.00	1 (no visible smoke)
	$P_{max} \ge 37$	0.80	
III	$P_{max} \ge 37$	0.50	1 (no visible smoke)
	$P_{max}<37$	0.80	

The standard set three levels of limits for free-load emissions measurement. Phase I limits apply to China II and pre-China II non-road diesel machines, Phase II limits apply to China III and post-China III non-road diesel machines, and the most stringent Phase III limits give local authorities reference when they implement low-emission zone policies for non-road machines.

Non-road low-emission zone program

The Clean Diesel Action Plan requires that local authorities carry out a registration and labeling program for non-road machinery and create low-emission zones that apply to non-road mobile machinery. A registration and labeling program is an important measure for non-road machinery emissions control and management at the city level. Some cities, including Shanghai, Chengdu, and Hangzhou, have implemented a non-road mobile machinery labeling program. All new and in-use non-road mobile machines shall be registered and issued an emission label after registration. The information that needs to be submitted to the agency includes a photo of the machinery, environmental information, engine nameplate information, and the business license of the operating company or the identification information of the owner.

By the end of 2019, approximately 730,000 non-road machines had been registered and 178 cities and municipalities across China had issued notices on banning the use of high-emission non-road mobile machines in low-emission zones (MEE, 2020d). In these cities, non-road machines that do not meet certain emission standards are banned from entering low-emission zones. For example, since December 1, 2017, pre-China III non-road machinery has been banned from entering the Fifth Ring of Beijing. In Shenzhen, pre-China I non-road machinery was banned from Type I districts (Futian, Luohu, Yantian, and Nanshan) and Type II low-emission zones (the other four districts) starting from November 1, 2018. Pre-China II non-road machinery was banned from Type I low-emission zones starting from September 1, 2020 (Shenzhen Municipal Government, 2018b). In Chengdu, pre-China II non-road machinery was banned from entering the Fourth Ring of the city starting from February 1, 2018 (Chengdu Municipal Government, 2018). Companies and individuals who operate non-road machinery in violation of the requirements are subject to a maximum fine of ¥50,000.

Marine DECA

In December 2015, the MOT released an action plan for establishing three regional DECAs to control emissions of sulfur oxides (SO_x) and NO_x from ships (Mao, 2016; see Figure 9). The regional DECA plan established a review provision, to be completed by the end of 2019, to determine if further actions were needed. In December 2018, almost 12 months ahead of schedule, the MOT released an upgraded action plan for establishing a national DECA (MOT, 2018a).

The national DECA extends 12 nautical miles from China's entire coastal baseline. Starting January 1, 2019, all ships, regardless of nationality, were required to use fuel with sulfur content of less than 5,000 ppm within the national DECA. Additionally, Chinese ships built after 2022 will need to comply with Tier III NO_x emission standards set by the IMO. Specifically, in the DECA region around Hainan Province, the fuel sulfur limit will be tightened to 1,000 ppm starting in 2022.

Beyond SO_x and NO_x control, the national DECA framework includes a shore power mandate. Chinese ships will have to use shore power when berthing at DECA ports as much as possible and among different types of ships, cruise ships need to comply first, both new builds and the existing fleet, regardless of nationality.

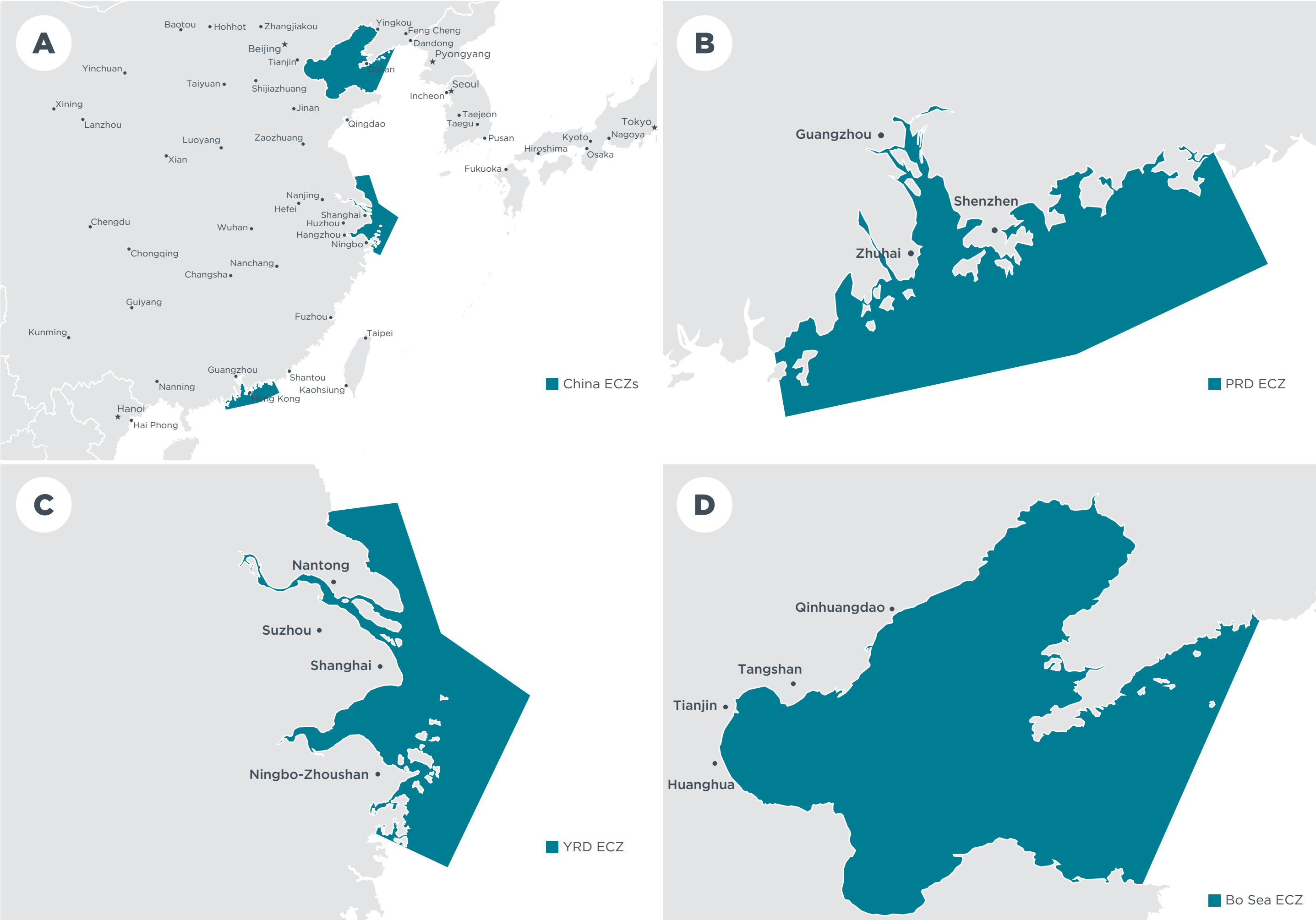

Figure 9. Definition of the (a) ECZ regions, (b) Pearl River Delta ECZ regions, (c) Yangtze River Delta ECZ regions, and (d) Bo Sea ECZ regions. Source: ICCT, based on WTI input.

3.5 DIESEL FUEL PROGRAMS

DIESEL FUEL STANDARDS

The National Energy Administration (NEA) is in charge of formulating fuel quality standards. SAMR is responsible for implementation of the standards and compliance. China's fuel quality standards follow the path created by Europe's standards and, since 2000, they have been gradually strengthened (see Figure 5). For diesel, the limit on the sulfur content of on-road fuel was lowered from 2,000 ppm in the China I standards to the current level of 10 ppm in China VI. Key properties of diesel regulated under China VI include sulfur content, polyaromatics, cetane number, density, flash point, ash content, viscosity, polycyclic aromatic hydrocarbons, and total pollutant content.

When revised in 2015, the new Clean Air Law gave the MEE clear authority to formulate and implement ambient air quality standards and vehicle emission standards for air pollutants. Additionally, the law states that "fuel quality standards shall comply with the national air pollutant control requirements and be linked to the national vehicle and non-road mobile machinery emission standards and implemented simultaneously." But the MEE does not have the authority to create or enforce fuel quality standards, and it has repeatedly failed to coordinate with the SAMR and the Standardization Administration of China (SAC) to implement fuel quality standards in concert with vehicle emission standards (Yue et al., 2015). For example, the China IV emission standard was delayed for 30 months, from January 1, 2011, to July 1, 2013, because of an inadequate supply of qualified diesel fuel on the market.

NON-ROAD DIESEL STANDARD

For diesel fuel used for off-road machinery, sulfur levels were set in a national standard separate from the one for on-road vehicles. In the past, non-road diesel fuel quality lagged significantly behind the diesel quality for on-road vehicles. The non-road diesel or general diesel has higher sulfur content, lower cetane number, and poorer lubricity than on-road diesel. When both types of diesel were available on the market at the same time, it left room for the use of non-road diesel in on-road vehicles (Yue et al., 2015). In 2018, the National Plan of Blue-Sky Defense required the abolition of the general diesel standard and the alignment of on-road and non-road diesel standards (China State Council, 2018b). Accordingly, on November 26, 2018, SAMR and SAC abolished the general diesel standard (SAMR & SAC, 2018). As of January 1, 2019, only diesel fuels that are compliant with the China VI fuel quality standard with a maximum of 10 ppm of sulfur content are allowed to be sold in China.

ALTERNATIVE DIESEL FUEL PROGRAM

In 2015, the NEA issued a biodiesel industry development policy and proposed building a sustainable raw materials supply system for biodiesel, with waste oil supplemented by non-edible wood (grass) oil. To achieve this goal, the policy proposed that provinces developing a biodiesel industry should establish a comprehensive waste oil recovery and utilization system and develop regulations for waste oil recovery. The policy also required that biodiesel production enterprises build a complete raw material supply system and construct material planting bases where oil-based energy plants are used as materials. It is required that the yield coefficient of biodiesel products should reach at least 90%, the methanol consumption per ton of biodiesel should be less than 125 kilograms (kg), the freshwater consumption per ton of biodiesel should be less than 0.35 cubic meters, and the comprehensive energy consumption should be less than 150 kg of standard coal. In addition, the promotion of biodiesel was encouraged in key regions that are facing air pollution problems such as Jing-Jin-Ji, the Yangtze River Delta, and the Pearl River Delta. Vehicle and vessel manufacturers are encouraged to research and develop optimized engines that are suitable for biodiesel (National Energy Administration, 2015).

The current national standard on biodiesel, B5 Biodiesel GB 21599-2017, took effect in September 2017. The standard merges and upgrades the two previous national standards of Biodiesel Blend Fuel B5 and Diesel Fuel Blend Biodiesel BD100 and is upgraded from a recommended standard to a mandatory standard. Also, the technical requirements and test protocols for vehicle biodiesel (China VI) are consistent with the national standard for vehicle diesel (China VI) and the Euro VI standard.

Previously there were hundreds of biodiesel manufacturers in China, but the number has declined sharply in recent years. Pilot projects in Hainan, Anhui, and Yunnan provinces have failed. Shanghai has promoted the application of biodiesel in the public transport system since 2017. Shanghai is the first and currently the only region in China that successfully applies biodiesel, but even there, biodiesel has not been widely used (Tong, 2018).

MARINE DIESEL

For oceangoing vessels in China, the marine fuel standards follow the global standard, which is ISO 8217, except for sulfur content. Sulfur content is required by IMO separately in MARPOL Annex VI, not as a fuel specification, but as an emission standard. ISO 8217 includes multiple marine fuel types. A ship can use blended fuels in order to achieve a specific sulfur content requirement. Standards for blended fuels are missing right now.

For larger river vessels and river-sea vessels, the current GB/T17411-2015 marine fuel standards apply and are equivalent to the current ISO 8217 fuel standard. This standard is expected to be updated soon. Similarly, sulfur content is limited by MEE/MOT separately under the DECA framework, not as a fuel specification, but as an emission standard.

For other smaller river vessels, the China VI automobile diesel fuel standards apply, and these require ultralow-sulfur diesel fuel of less than 10 ppm.

FUEL QUALITY COMPLIANCE PROGRAM

The fuel quality compliance program in China is part of the product quality supervision and inspection program run by SAMR. The central and local AMR agencies that carry out annual fuel quality inspections typically do so as part of product quality inspection programs. Fuel samples are collected from refineries and fuel stations, and compliance rates and the names and locations of fuel stations that supply noncompliant fuels are published in a summary report available to the public. However, detailed test results such as sulfur content levels are not revealed.[4] In the past, refineries that were found to have produced noncompliant fuels and fuel stations that were found to have sold noncompliant fuels were not heavily penalized because China lacked fuel quality compliance legislation. Violating refineries and fuel stations were simply ordered to stop producing and selling the noncompliant fuels.

National testing protocols for diesel and gasoline fuel are available for regional AMR agencies to follow when they conduct supervision and inspection (SAMR, 2015). The test protocols specify the sampling method, handling method, items to be tested, whether testing of these items is mandatory or voluntary, testing method, rules regarding how results are determined, rules regarding how to handle contested results, and retest method.

A random check conducted by the MEE in 2017 showed that the diesel compliance rate of private fuel stations in Jing-Jin-Ji and surrounding areas was less than 50%, and the compliance rate of diesel extracted from truck tanks was even less than 10% (Green Focus, 2018). Independent investigations by third parties and research organizations also showed that diesel quality was a serious problem, especially in private fuel stations (Yue et al., 2015).

The Clean Diesel Fuel Program, as one of the four programs in the Clean Diesel Action Plan, calls for strengthening the supervision of fuel quality throughout the supply chain, including during refining, storage, distribution, retail, and usage. The Clean Diesel Fuel Program targets a compliance rate of 95% nationwide for diesel fuel quality and 98% for diesel emission fluid (urea) in key regions by 2020. To achieve this goal, China plans to establish a supply chain supervision program for diesel fuel and urea, strengthen random checks at retail stations and from the fuel tanks of vehicles, and carry out special campaigns against violating fuel stations. This work is led by SAMR, the NDRC, the Ministry of Commerce, the MOT, and the MEE.

In 2019, MEE in conjunction with relevant departments, carried out a special diesel fuel inspection in Jing-Jin-Ji. In all, 11,769 fuel stations were randomly inspected and 19,552 diesel samples were collected. It was found that sulfur content from 873 diesel samples exceeded the limits. The noncompliant samples were 4.5% of the total number of samples collected. The sulfur content from the noncompliant diesel samples exceeded the limit by 25 times on average, and 55 samples exceeded the limit by more than 100 times. In addition, 561 illegal fuel stations were found and penalized (MEE, 2020d).

4 Compliance rate indicates the percentage of sampled products that are compliant with the standard.

3.6 GHG REGULATIONS AND PROGRAMS

In China, GHG emissions are not directly regulated in one single regulation. Vehicle CO_2 emissions are regulated via fuel consumption regulations and some short-lived climate pollutants are regulated via the China VI emission standard.

NEW VEHICLE FUEL CONSUMPTION STANDARDS

The MIIT is responsible for the management of the automotive industry, the formulation of technical standards, including fuel consumption standards, and the implementation of policies for promoting energy conservation in the automotive industry. China is one of six nations and regions worldwide that have implemented fuel consumption standards for new HDVs; the others are Japan, the United States, Canada, India, and the European Union. Three stages of standards have been issued so far. Stages 1 and 2 were implemented in 2012 and 2014. Stage 3 was finalized in February 2018 and went into effect on July 1, 2019, for new type approvals; it will go into effect for new HDVs sold in China on July 1, 2021. The Stage 3 standard reduces fuel consumption limits by around 15% for new HDVs. Tractors and straight trucks are covered by the standards, but trailers are not covered, even though trailer technology is known to have an important impact on fuel consumption. According to the China Automotive Technology and Research Center (CATARC, 2019), 25%–42% of HDVs registered after 2017 are still not compliant with the Stage 3 fuel consumption standard.[5] The next stage, Stage 4, is currently being discussed and will likely address some of the additional opportunities for further reductions. The Stage 4 standard is currently expected to be implemented for new type approvals in July 2024, and for all new vehicles produced in July 2026 (CATARC, 2019).

However, China enforces its fuel consumption standards with administrative, rather than financial, penalties. For example, the MIIT can deny type-approval applications for new vehicles that fail to meet the fuel consumption limits, but it does not have clear authority to recall vehicles that are not compliant with fuel-consumption standards (Cazzola et al., 2019; Cui, 2018). Compared with the increasing regulatory actions taken against those not compliant with vehicle emission standards, regulatory actions for noncompliance with fuel-consumption standards are falling behind.

IN-USE GHG PROGRAMS

China Green Freight Initiative

The China Green Freight Initiative (CGFI) is a voluntary program that was launched in 2012. It aims to improve energy efficiency and reduce GHGs and air pollutants from road freight in China. This is a national, voluntary program and is a collaborative effort between government, the private sector, development agencies, civil society, and other stakeholders. The China Road Transport Association, Clean Air Asia (CAA), and the Research Institute of Highway of the MOT are the leading organizations of the initiative under the guidance of MOT (globalgreenfreight.org, 2021).

The program has three components—green management, green technology, and green driving. Green management aims to improve fleet management through better loading and drop-and-hook practices. Green technologies aim to promote the adoption of fuel-saving technologies for trucks through the development of voluntary green truck standards and the issuance of a catalogue of green technologies and energy-saving products. For green driving, CGFI is seeking to promote eco-driving through the development of eco-driving training programs and guidebooks (Smart Freight Centre, 2017). CGFI has released two voluntary standards, the Green Freight Enterprise Standard and the Green Freight Vehicle Standard, which provide details on the "five-

5 Twenty-five percent of straight trucks, 42% of dump trucks, 37% of coaches, and 35% of tractors are not compliant with the stage 3 fuel consumption standard.

star" labeling program requirements for companies and trucks (China Road Transport Association, 2015a; 2015b). Table 11 and Table 12 provide summaries of the Green Freight Vehicle and Enterprise standard.

The CGFI is now in its fourth phase and is focused on engaging more shippers, launching local pilot projects, and developing quantification tools and a communication platform (globalgreenfreight.org, 2021). With support and funding from CGFI, Guangdong Province launched a green freight demonstration project from 2011 to 2015. A total of 14 carrier companies and 1,500 trucks joined this program. Fuel-saving technologies such as low rolling-resistance tires, wind deflectors, and energy-saving driving systems were installed on most of the trucks in the pilot and significant fuel savings were demonstrated. Overall, the project produced a very positive demonstration effect. After it ended, carriers continued to purchase fuel-saving technologies on their own. According to one estimation, the project reduced CO_2 emissions by 64,000 tonnes per year (Guangdong Green Freight Demonstration Project Office, 2015).

Table 11. Summary of the voluntary Green Freight Vehicle Standard

Type	Requirement
Fuel consumption	Meet stage II of MOT's fuel consumption standard
Emission standard	China IV
Fuel saving technologies (optional)	Light weighting, aerodynamics technologies, low rolling-resistance tires, low viscosity lubricants, exhaust gas turbocharging, thermal management system, high pressure common rail, on-road smart terminal.
Vehicle technology management requirements	Vehicle performance inspection and maintenance, vehicle fuel consumption quota management system, lubricant/tire/vehicle component management system
Recommended vehicle type	Drop-and-hook trucks, CNG/LNG trucks, hybrid and electric trucks

Table 12. Summary of Green Freight Enterprise Standard

Category	Assessment criteria
Green management	Vehicle utilization rate (in mileage)
	Rate of drop-and-hook
	Professional logistics and distribution
	Information management system
	Freight platform access rate
Green technology	Green vehicles
	Fuel consumption
	Fleet size and type
	Number of new energy vehicles
	Fuel saving technology utilization rate
Green driving	Reward and punishment mechanism
	Responsibility mechanism
	Energy saving driving training
	Energy consumption management system
	Ratio of driver who drives safely for 1 million kilometers

In July 2018, the MOT initiated a demonstration program on promoting green freight transportation in 22 cities (MOT, 2018c). In 2019, 24 other cities were selected as the second phase of demonstration cities (MOT, 2019). Promoting electric trucks is one of the major logistics tasks in the demonstration program. Key measures include improving the urban freight charging infrastructure, road access privileges for electric trucks, and preferential treatment on tax, financing, and insurance for demonstration projects (MOT, 2019).

3.7 ADVANCED TECHNOLOGY PROGRAMS

NATURAL GAS VEHICLES PROMOTION POLICY

In 1999, China launched a Clean Vehicle Initiative and established a national clean vehicle coordination leading group consisting of 13 ministries and commissions, including the MoST, MOT, Ministry of Construction, and the State Environmental Protection Administration. Twelve cities were identified as the first pilot cities in the Clean Vehicle Initiative, and among them were Beijing, Shanghai, Tianjin, and Chongqing (Liu, 2008). 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% of the fleet total. 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 (Li, 2008). Because liquefied natural gas (LNG) has a higher energy density and therefore affords a longer range for a similar size fuel tank, Beijing introduced LNG buses in 2012 to meet the growing demand for cleaner transport (Yang et al., 2015). Many other cities, including Hangzhou, Xiamen, Dongguan, and Baoding, have introduced CNG and LNG vehicles in their bus fleets (National Energy Administration, 2012).

In 2014, the China State Council issued the National Climate Change Adaptation Plan (2014–2020), which required the promotion of natural gas-powered vehicles and electric vehicles (China State Council, 2014a). In 2015, the Ministry of Finance (MOF), the State Taxation Administration, and the MIIT published a preferential taxation policy for natural gas-powered commercial vehicles that reduced their vehicle and vessel tax by half (MOF, 2015). The 13th Five-Year Plan for natural gas development, issued by the NDRC, promoted support for the development of natural gas vehicles and vessels, especially for buses, trucks, taxis, and commercial vessels (NDRC, 2016). The target was to promote 10 million natural gas vehicles, and establish 12,000 gas fuel stations for vehicles and 200 gas fuel stations for vessels by 2020 (NDRC, 2016). By the end of 2018, the natural-gas vehicle population reached 6.7 million (China Communications and Transportation Association, 2019).

In general, China supports and encourages the development of natural gas vehicles. But compared to new energy vehicles, China has far fewer subsidies for natural gas vehicles at the national level. Only some local governments subsidize natural gas buses and trucks, and many of the corresponding subsidy policies expired before 2018.

NEW ENERGY VEHICLES

In China, new energy vehicles (NEVs) include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles (FCVs). China started to promote NEVs in 2009 with the landmark Ten Cities, Thousand Vehicles pilot program. Over the ensuing decade, China became the world's largest electric vehicle market, accounting for half of the world's electric cars and close to 99% of electric buses. Because there are almost no diesel passenger cars in China, we focus here on new energy buses and trucks.

In 2015, MOT set a goal to have 300,000 new energy buses, taxis, and urban delivery trucks on the road by 2020 (MOT, 2015). In 2018, MOT further strengthened this target to 600,000 (MOT, 2018b). The Three-year National Plan of Blue-Sky Defense released by MEE in 2018 also required that 80% of new urban vehicles (i.e., buses, postal trucks, sanitation trucks, taxis, and drayage trucks) in key regions be NEVs by 2020. Additionally, 100% of urban buses in key regions were required to be NEVs by 2020 (China State Council, 2018b), and MIIT is considering developing a NEV mandate policy for commercial vehicles like buses and trucks that would mandate that a certain percentage of new vehicle productions be NEVs (MIIT, 2018). The NEV mandate policy for passenger cars has been implemented in China from 2019 (Cui, 2018).

By the end of 2020, China had deployed 588,000 new energy buses. Among them, 85% are BEVs and 15% are PHEVs (International Energy Agency, 2021). Leading cities like Shenzhen and Guangzhou have already achieved a nearly 100% zero-emission bus fleet, with only a few diesel-fueled buses remaining for emergency use (Shenzhen Department of Transportation, 2018; Guangzhou Municipal Government, 2018).

Besides electric vehicles, China sent a strong signal to the hydrogen FCV industry with policy moves in 2020. China set a target to get to 50,000 FCV in stock by 2025, and 1 million by 2030. Hydrogen was listed as an energy source in a national law for the first time, in the draft Energy Law of the People's Republic of China. Then, promotion policies for FCVs were separated from those of plug-in electric vehicles in the Notice on Optimizing Fiscal Subsidies for Promoting New Energy Vehicles from four central ministries. A subsequent document that contained details of how the new policies would be implemented was shared with select provinces for consultation. In addition, China will initiate pilot programs in select cities that have both hydrogen energy supply capacity and enough of an economic and policy foundation to support the development of FCVs. Instead of nationwide purchase subsidies, financial awards are given only to approved pilot cities (Jin & He, 2020).

ZERO-EMISSION NON-ROAD MACHINERY

The Three-year National Plan for Blue-Sky Defense requires that new-energy non-road machinery be given priority in port areas in the key regions. The Non-road Mobile Machinery Pollution Prevention and Control Technology Policy published by MEE in 2018 also encourages the application of new energy technologies such as pure electric power and fuel cells in non-road mobile machinery. Of all types of non-road machinery, the forklift has a relatively high electrification rate. According to the 13th Five-Year Development Plan for the Construction Machinery Industry, issued by the China Construction Machinery Industry Association in 2016, forklifts powered by lithium batteries and fuel cells are innovative products that are recommended and promoted. In 2020, more than 50% of new forklift sales were electric (China Industrial Truck Association, 2020). Also, MOT will release an action plan for the promotion of electric public vehicles and non-road machinery. The goal is that the number of electric forklifts will account for more than 55% of the total number of forklifts by 2025 (MIIT, 2020).

3.8 INCENTIVES

YELLOW-LABEL VEHICLE AND OLD VEHICLE SCRAPPAGE PROGRAM

In 2009, pre-China I vehicles were 17.1% of the total vehicle population but were responsible for 49.7% of total vehicle NO_x emissions and 55.9% of PM emissions (MEE, 2010). At the national level, the government aimed to scrap 6 million yellow-label vehicles by the end of 2014; scrap all the yellow-label vehicles registered before 2005 by the end of 2015; and scrap almost all yellow-label vehicles by the end of 2017 (China State Council, 2013; China State Council, 2014b). In 2004, the MOF and Ministry of Commerce initiated a nationwide consumer incentive program to accelerate scrappage of old vehicles. In the program, vehicle owners who scrapped their old vehicles and replaced them with new purchases were eligible for cash rebates from ¥4,000 to ¥15,000, depending on vehicle class (MOF, 2005). The upper limit of the subsidy was raised to ¥18,000 in January 2011 (MOF, 2011). Some local governments provided additional financial incentives, as well. For example, Beijing provided a fiscal subsidy of up to ¥12,000 per vehicle (Fan, 2018). Hainan provided a scrappage subsidy of up to ¥25,000 per vehicle (Zhou, 2018).

In 2010, there were 8.66 million yellow-label diesel vehicles nationwide. By the end of 2019, the yellow label (pre-China III) diesel vehicle population was only 250,000; that means that 97% of the yellow-label diesel vehicles had been scrapped (VECC, 2020). According to the Action Plan for Battle Against Diesel Truck Pollution, the next step is to eliminate 1 million pre-China IV heavy-duty trucks in key regions.

NEV SUBSIDIES

Fiscal incentives were a crucial tool that spurred NEV deployment at the early stage. China began to subsidize NEVs in 2009, both at the national and sub-national levels. The subsidy program is ongoing today but has been fine-tuned to tighten the technical requirements for qualifying vehicles. It also has been phased down as the technologies are increasingly mature for commercialization (see Figure 10).

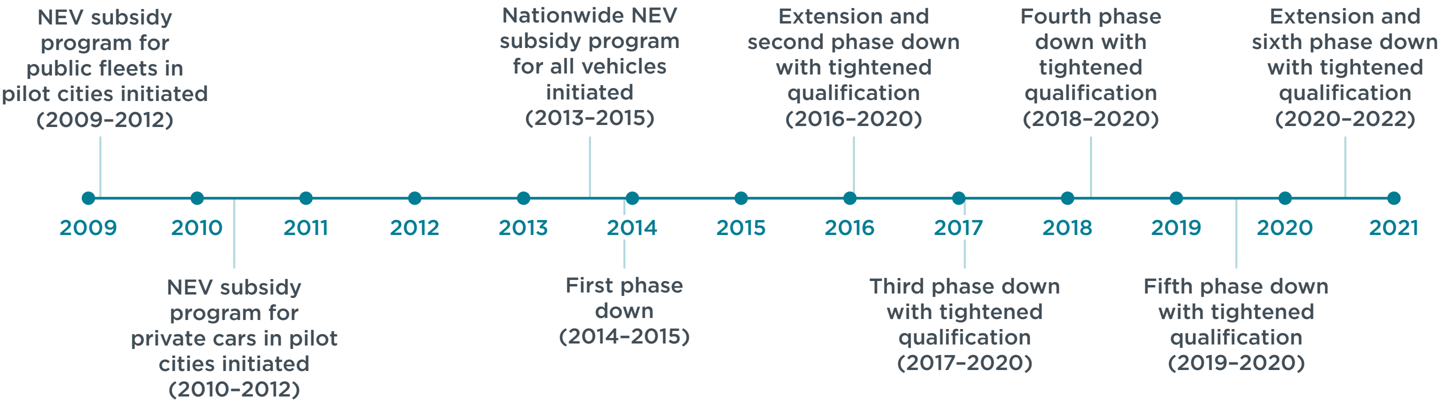

Figure 10. Timeline of China's national subsidy program for new energy vehicles

Table 13 details the national subsidies for battery electric and plug-in hybrid electric buses and coaches based on the most recently modified policies (MOF, 2020). The subsidy calculation method for battery electric and plug-in hybrid electric buses and coaches is specified in the following equation:

$$Subsidy = min\ \{Subsidy_{BC\text{-}i},\ Subsidy_{VL\text{-}i}\} \times F_i$$

Where,

$Subsidy_{BC\text{-}i}$ = base subsidy determined by battery capacity for vehicle type *i* (regular BEV, fast-charging BEV, or PHEV)

$Subsidy_{VL\text{-}i}$ = maximum subsidy allowed by vehicle length for vehicle type *i*

F_i = multiplier for vehicle type *i* (electric energy consumption for regular BEV, charging speed for fast-charging BEV, and fuel saving for PHEV). Electric buses also enjoy sub-national subsidies, which are usually half of the national amounts.

Table 13. Subsidies for battery electric and plug-in hybrid electric buses and coaches in 2020

Technology	Base subsidy (CNY/kWh)	Maximum subsidy by vehicle length (L) (1,000 CNY/vehicle)			Multiplier		
		6m<L≤8m	8m<L≤10m	L>10m	Parameter	Bin	Value
Regular BEV	500	25	55	90	Electric energy consumption (EC, Wh/km·kg)	0.17<EC≤0.18	0.8
						0.15<EC≤0.17	0.9
						EC≤0.15	1
Fast-charging BEV	900	20	40	65	Charging speed (CS, C-rate)	3C<CS≤5C	0.8
						5C<CS≤15C	0.9
						CS>15C	1
PHEV	600	10	20	38	Fuel savings (FS, %)	60%<FS≤65%	0.8
						65%<FS≤70%	0.9
						FS>70%	1

Table 14 provides the national subsidies for battery electric and plug-in hybrid electric trucks and vocational vehicles based on the newest policies (Cui & He, 2020). The subsidies are determined as a function of vehicle battery capacity and are further subject to various ceilings dependent on technology type and vehicle weight class. Starting from June 26, 2019, no sub-national subsidies are offered to electric trucks.

Table 14. Subsidies for battery electric and plug-in hybrid electric trucks and vocational vehicles in 2020

Technology	Base subsidy (CNY/kWh)	Max. subsidy by gross vehicle weight (M) (1,000 CNY/vehicle)		
		M≤3,500kg	3,500kg<M≤12,000kg	M>12,000kg
BEV	315	18	35	50
PHEV	450	—	20	31.5

The Chinese central government stopped providing purchase subsidies for FCVs on April 23, 2020. In place of the subsidies, a new four-year pilot program was initiated, and suitable cities will be selected to carry out research and development and application demonstrations of FCVs. This pilot program aims to encourage innovation and to stimulate the development of hydrogen fuel and the FCV industry in China. The Chinese central government will reward successful pilot cities and details of those benefits are to be provided in a separate policy document (Cui & He, 2020).

4. SUMMARY

Since 2013, China has achieved significant success in making air quality improvements. Average $PM_{2.5}$ concentration was reduced from 72 μg/m^3 in 2013 to 36 μg/m^3 in 2019. By 2020, almost all yellow-label vehicles had been scrapped. The limit on the sulfur content of diesel fuel for on-road vehicles and non-road machinery was reduced from 2,000 ppm in the China I standards to the current level of 10 ppm in China VI. The China 6/VI emission standards are among the most stringent in the world.

However, China still faces major challenges. The average $PM_{2.5}$ concentration remains higher than the 10 μg/m^3 specified in World Health Organization guidelines. In recent years, ozone pollution has become a concern in major cities in China, and diesel vehicles and engines are still major sources of NO_x and PM emissions. In addition, CO_2 emissions are regulated in a separate standard and thus are not controlled in parallel with criteria pollutants.

In a companion paper, we will introduce California's clean diesel program and compare the components of China's and California's clean diesel programs. We will also provide policy recommendations regarding how China's clean diesel program can further reduce emissions from diesel engines and improve air quality.

5. REFERENCES

Beijing Ecology and Environment Bureau. (2019). Administrative penalty decision (Jianghuai Automobile Group Corp., Ltd). Retrieved from http://gzcx.sthjj.beijing.gov.cn/eportalapply/downfile/8414F103052842D6AB59F57D93CA4B61/B386538B-1D5B-4D08-8C1C-51D1F2046B3F/处罚决定书.pdf

California Air Resources Board. (n.d.). Inhalable particulate matter and health ($PM_{2.5}$ and PM_{10}). Retrieved June 10, 2021, from https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health

China Automotive Technology and Research Center. (2019). 20th meeting of the heavy duty commercial vehicles fuel consumption standard working group presentation.

Cazzola, P., Scheffer, S., Paoli, L., Craglia, M., Tietge, U., & Yang, Z. (2019). *Fuel economy in major car markets: Technology and policy drivers, 2005–2017.* Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/gfei-tech-policy-drivers-2005-2017

Chengdu Municipal Government. (2018). Announcement of Chengdu Municipal People's Government on Delimiting Areas Prohibiting the Use of High-Emission Non-road Mobile Machinery. Retrieved from http://e.chengdu.cn/html/2018-01/06/content_614949.htm

China Communications and Transportation Association. (2019, May 19). China's natural gas vehicle population continues to rank first in the world. Retrieved from http://www.inengyuan.com/kuaixun/110.html

China Industrial Truck Association. (2020). Total sales of industrial vehicles in 2020 is expected to exceed 750,000. Retrieved from https://www.sohu.com/a/441464494_817053

China Road Transport Association. (2015a). Green Freight Enterprise Standards. Retrieved from http://www.cleanairasia.cn/uploads/soft/151119/1-151119131241.pdf

China Road Transport Association. (2015b). Green Freight Vehicle Standards. Retrieved from http://www.cleanairasia.cn/uploads/soft/151119/1-151119131320.pdf

China State Council. (2011). The 12th Environmental Protection Five–Year Plan. Retrieved from http://www.gov.cn/zwgk/2011-12/20/content_2024895.htm

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

China State Council. (2014a). National Climate Change Adaptation Plan (2014-2020). Retrieved from http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/35861/37265/xgzc37271/Document/1603660/1603660.htm

China State Council. (2014b). Government Work Report. Retrieved from http://www.gov.cn/guowuyuan/2014-03/14/content_2638989.htm

China State Council. (2016). The 13th Environmental Protection Five–Year Plan. Retrieved from http://www.gov.cn/zhengce/content/2016-12/05/content_5143290.htm

China State Council. (2018a). China to establish ministry of ecological environment. Retrieved from http://english.www.gov.cn/state_council/ministries/2018/03/13/content_281476076462818.htm

China State Council. (2018b). Three-year Action Plan of Blue Sky Defense. Retrieved from http://www.gov.cn/zhengce/content/2018-07/03/content_5303158.htm

China State Council. (2018c). Three-year Action Plan on Promoting Shipping Structure Adjustment. Retrieved from http://www.gov.cn/zhengce/content/2018-10/09/content_5328817.htm

Cui, H. (2018). *China's New Energy Vehicle mandate policy (final rule).* Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/china-nev-mandate-final-policy-update-20180111

Cui, H., & He, H. (2020). *China announced 2020–2022 subsidies for new energy vehicles.* Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/china-2020-22-subsidies-new-energy-vehicles-jul2020.

Ding, J., & Wang, Z. (2014, March 27). Fake China III diesel vehicles are widespread because of poor enforcement (in Chinese). *Economic Information.* Retrieved from http://dz.jjckb.cn/www/pages/webpage2009/html/2014-03/27/content_88270.htm?div=-1

Fan, X. (2018, March 9). Beijing: 1.58 billion RMB subsidies for scrappage of old vehicles in 2017. *Beijing Daily.* Retrieved from http://xinhuanet.com/auto/2018-03/09/c_1122509428.htm

Gao, F. (2017, February 16). Tampering devices are sold on Taobao. Emissions cheating of commercial vehicles is increasing (in Chinese). *Economic Observer.* Retrieved from http://www.eeo.com.cn/2017/0216/298238.shtml

Globalgreenfreight.org. (n.d.). China Green Freight Initiative (CGFI). Retrieved June 10, 2021, from http://www.globalgreenfreight.org/green-freight/china-green-freight

Green Focus: How to fight against air pollution. (2018, August 4). *People's Daily.* Retrieved from http://www.xinhuanet.com/fortune/2018-08/04/c_1123221467.htm

Guangdong Green Freight Demonstration Project Office. (2015). Guangdong Green Freight Demonstration Project. Retrieved from http://www.allaboutair.cn/a/green_transport_column/2015/1109/47.html

Guangzhou Municipal Government. (2018). Buses in Guangzhou will achieve 100% of electrification by 2020. Retrieved from http://www.gz.gov.cn/zwfw/zxfw/kjcy/content/mpost_2861125.html

International Energy Agency. (2021). Global EV data explorer. Retrieved from https://www.iea.org/articles/global-ev-data-explorer

Jin, L., & He, H. (2020). Ten cities, thousand fuel cell vehicles? China is sketching a roadmap for hydrogen vehicles [Blog post]. Retrieved from https://theicct.org/blog/staff/china-sketching-roadmap-hydrogen-vehicles-aug2020

Li, N. (2008, July 30). Beijing Public Transport goes with the "Green Olympics." *China Daily.* Retrieved from http://unn.people.com.cn/GB/7583685.html

Liu, J. (2008, March 11). Ten years of development of clean energy vehicles. *Guangming Daily.* Retrieved from https://epaper.gmw.cn/gmrb/html/2008-03/11/nw.D110000gmrb_20080311_2-07.htm

Mao, X. (2016). *Action Plan for establishing ship emission control zones in China*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/action-plan-establishing-ship-emission-control-zones-china

Ministry of Ecology and Environment. (2010). *China Vehicle Emission Control Annual Report 2010*. Retrieved from http://www.mee.gov.cn/hjzl/sthjzk/ydyhjgl/201605/P020160513584224576662.pdf

Ministry of Ecology and Environment. (2017a). Notice on Issuing the "13th Five-Year Development Plan for National Environmental Protection Standards." Retrieved from http://www.mee.gov.cn/gkml/hbb/bwj/201704/t20170414_411566.htm

Ministry of Ecology and Environment. (2017b). Work Plan for air pollution prevention and control in JJJ and surrounding areas in 2017. Retrieved from http://www.mee.gov.cn/ywdt/hjywnews/201703/t20170330_409037.shtml

Ministry of Ecology and Environment. (2017c). National standard for portable emission measurement system (PEMS) testing of heavy-duty vehicles (HDVs). Retrieved from http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/dqhjbh/dqydywrwpfbz/201709/t20170921_422035.shtml

Ministry of Ecology and Environment. (2017d.) Measurement method and specifications for exhaust pollutants from in-use diesel vehicles by remote sensing method. Retrieved from http://203.187.160.134:9011/kjs.mee.gov.cn/c3pr90ntc0td/hjbhbz/bzwb/dqhjbh/dqydywrwpfbz/201708/W020170802605590990126.pdf

Ministry of Ecology and Environment. (2018a). Announcement on the final assessment results of the implementation of the Air Pollution Prevention and Control Action Plan. Retrieved from http://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/201806/t20180601_629733.html

Ministry of Ecology and Environment. (2018b). Administrative penalty decision (Shandong Tangjun Ouling Automobile Manufacturing Co., Ltd.). Retrieved from http://www.mee.gov.cn/gkml/sthjbgw/qt/201801/t20180108_429270_wh.htm

Ministry of Ecology and Environment. (2018c). Administrative penalty decision (Shangdong Kaima Automobile Manufacturing Co., Ltd.). Retrieved from http://www.mee.gov.cn/gkml/sthjbgw/qt/201801/t20180108_429269_wh.htm

Ministry of Ecology and Environment. (2018d). China VI emission standard for heavy-duty vehicles. Retrieved from http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/dqhjbh/dqydywrwpfbz/201807/W020180703397013304274.pdf

Ministry of Ecology and Environment. (2018e). Limits and measurement methods for emissions from gasoline vehicles under two-speed idle conditions and short driving mode conditions. Retrieved from http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/dqhjbh/dqydywrwpfbz/201811/t20181113_673593.shtml

Ministry of Ecology and Environment. (2018f). Limits and measurement methods for emissions from diesel vehicles under free-acceleration and lugdown cycle. Retrieved from http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/dqhjbh/dqydywrwpfbz/201811/t20181113_673588.shtml

Ministry of Ecology and Environment. (2018g). Limits and measurement methods for exhaust smoke from non-road mobile machinery equipped with diesel engine. Retrieved from http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/dqhjbh/dqydywrwpfbz/201811/W020181113596500172888.pdf

Ministry of Ecology and Environment. (2019a). Action Plan for Battle Against Diesel Truck Pollution. Retrieved from http://www.mee.gov.cn/xxgk2018/xxgk/xxgk03/201901/t20190104_688587.html

Ministry of Ecology and Environment. (2019b). *China Mobile Source Environmental Management Annual Report 2019*. Retrieved from http://www.mee.gov.cn/hjzl/sthjzk/ydyhjgl/201909/P020190905586230826402.pdf

Ministry of Ecology and Environment. (2020a). China Vehicle Emission Control Annual Report 2001-2020. Retrieved from https://www.vecc.org.cn/jdcwfj/1871.jhtml

Ministry of Ecology and Environment. (2020b). Emission control technical requirements of non-road diesel mobile machinery. Retrieved from http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/dqhjbh/dqydywrwpfbz/202012/t20201231_815684.shtml

Ministry of Ecology and Environment. (2020c). Zhejiang Feidie Automobile Manufacturing Co., Ltd. recalls diesel trucks. Retrieved from http://www.mee.gov.cn/ywgz/dqhjbh/ydyhjgl/202008/t20200828_795687.shtml

Ministry of Ecology and Environment. (2020d). *China Mobile Source Environmental Management Annual Report 2020*. Retrieved from http://www.mee.gov.cn/hjzl/sthjzk/ydyhjgl/202008/P020200811521365906550.pdf

Ministry of Ecology and Environment, Ministry of Transport, and State Administration for Market Regulation. (2020). Notice on establishing and implementing vehicle emission inspection and maintenance system. Retrieved from http://xxgk.mot.gov.cn/jigou/ysfws/202006/t20200623_3398675.html

Ministry of Industry and Information Technology. (2018). New energy commercial vehicle dual credits policy is under study. Retrieved from http://www.360buses.cn/news/2018/0123/65510.shtml

Ministry of Industry and Information Technology. (2020). Letter on Reply to Proposal No. 1535 at the Third Session of the Thirteenth CPPCC National Committee. Retrieved from https://www.miit.gov.cn/zwgk/jytafwgk/art/2020/art_75c6d5a31df24aa58aa283cbc1e031f7.html

Ministry of Finance. (2005). Notice on the issuance of subsidy funds for scrappage of old vehicles in 2005. Retrieved from http://www.mofcom.gov.cn/aarticle/b/d/200504/20050400068889.html

Ministry of Finance. (2011). Scope and standard of subsidy funds for old vehicles scrapped in 2011. Retrieved from http://www.mofcom.gov.cn/article/b/d/201106/20110607590770.shtml

Ministry of Finance. (2015). Notice on preferential tax policies for saving energy and using new energy vehicles and vessels. Retrieved from http://www.chinatax.gov.cn/n810341/n810755/c1617349/content.html

Ministry of Finance. (2020). Notice on optimizing fiscal subsidies for promoting new energy vehicles. Retrieved from http://jjs.mof.gov.cn/zhengcefagui/202004/t20200423_3502975.htm

Ministry of Transport. (2015). Notice on promoting new energy vehicles in the transportation industry. Retrieved from http://www.gov.cn/gongbao/content/2015/content_2883248.htm

Ministry of Transport. (2018a). Action plan to establish a national emission control area for ship emission control. Retrieved from http://xxgk.mot.gov.cn/jigou/haishi/201812/t20181220_3146515.html

Ministry of Transport. (2018b). Eight key tasks to tackle pollution from transportation. Retrieved from http://www.mot.gov.cn/jiaotongyaowen/201806/t20180625_3036953.html

Ministry of Transport. (2018c). Notice on demonstration program on promoting green freight transportation. Retrieved from http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/37601/38477/xgzc38483/Document/1631715/1631715.htm

Ministry of Transport. (2019). Notice on the announcement of the second batch of urban green freight demonstration cities. Retrieved from http://xxgk.mot.gov.cn/jigou/ysfws/201912/t20191223_3311939.html

National Energy Administration. (2012). Natural gas buses are promoted rapidly. Retrieved from http://www.nea.gov.cn/2012-12/26/c_132063343.htm

National Energy Administration. (2015). Biodiesel industry development policy. Retrieved from http://www.gov.cn/xinwen/2015-01/28/content_2811080.htm

National People's Congress of China. (2018). Air Pollution Prevention and Control Law. Retrieved from http://www.npc.gov.cn/npc/sjxflfg/201906/daae57a178344d39985dcfc563cd4b9b.shtml

National Development and Reform Commission. (2016). 13th Five-Year Plan for natural gas development. Retrieved from http://www.gov.cn/xinwen/2017-01/19/5161260/files/ce9a75c963c84da2aeccca279a757fef.pdf

Posada, F., & Bandivadekar, A. (2015). *Global overview of on-board diagnostic (OBD) systems for heavy-duty vehicles*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/global-overview-board-diagnostic-obd-systems-heavy-duty-vehicles

State Environmental Protection Administration. (1999). The Technical Policy for the Prevention and Control of Motor Vehicle Emission Pollution. Retrieved from http://www.mee.gov.cn/gkml/zj/wj/200910/t20091022_171924.htm

Shandong Environmental Protection Bureau. (2018a). Administrative penalty decision (Dezhou Degong Machinery Co., Ltd.). Retrieved from http://sthj.shandong.gov.cn/hjjc/xzcf/201804/t20180413_1260652.html

Shandong Environmental Protection Bureau. (2018b). Administrative penalty decision (Aowei Junshan Trading Co., Ltd). Retrieved from http://sthj.shandong.gov.cn/hjjc/xzcf/201804/t20180402_1244906.html

Shenzhen Administration for Market Regulation. (2017). Technical regulation of retrofitting in-use diesel vehicles and non-road mobile machinery with particulate filter. Retrieved from http://meeb.sz.gov.cn/hdjl/myzj/myzj/201709/P020170928549763489867.pdf

Shenzhen Bureau of Environment and Ecology. (2018). Atmospheric Environment Quality Improvement Subsidy Plan (2018-2020). Retrieved from http://meeb.sz.gov.cn/xxgk/qt/hbyw/dqzlgl/201809/P020181011374903119629.pdf

Shenzhen Department of Transportation. (2018). Shenzhen promotes 16,359 electric buses. Retrieved from http://jtys.sz.gov.cn/zwgk/jtzx/gzdt/content/post_4317315.html

Shenzhen Municipal Government. (2018a). Announcement of the Shenzhen Municipal People's Government on Delimiting Areas Prohibiting the Use of High-Emission Non-road Mobile Machinery. Retrieved from http://meeb.sz.gov.cn/xxgk/zcfg/zcfg/hblgfxwj/content/post_2016189.html

Shenzhen Municipal Government. (2018b). "Shenzhen Blue" sustainable Action Plan. Retrieved from http://www.lg.gov.cn/attachment/0/208/208764/1673964.pdf

Smart Freight Centre. (2017). *Green freight programs worldwide*. Retrieved from https://www.smartfreightcentre.org/pdf/Green-Freight-Programs-Worldwide-SFC-Final-May2017.pdf

State Administration for Market Regulation. (2015). Code of practice for quality supervision and inspection of motor vehicle gasoline products. Retrieved from http://www.samr.gov.cn/zljds/zcfg/gfxwj/201602/P020190527317882281454.pdf

State Administration for Market Regulation & Ministry of Ecology and Environment. (2021). Regulation on vehicle emission recall. Retrieved from http://gkml.samr.gov.cn/nsjg/fgs/202105/t20210520_329719.html

State Administration for Market Regulation & Standardization Administration of China. (2018). Notice on abolition of National standard of general diesel. Retrieved from http://std.sacinfo.org.cn/gnoc/queryInfo?id=4DCF75809716B84B4FACB9128E4C51B7

Tianjin Municipal Transportation Commission. (2017). Announcement on the installation of DPF on China III medium and heavy-duty diesel trucks in Tianjin. Retrieved from http://jtys.tj.gov.cn/ZWXX2900/TZGG2982/202007/t20200721_3018050.html

Tong, X. (2018, August 15). Promotion of biodiesel is weak. *China Energy News*. Retrieved from https://huanbao.bjx.com.cn/news/20180815/920951.shtml

United Nations Environment Programme. (2019). *A review of 20 years' air pollution control in Beijing*. Retrieved from http://sthjj.beijing.gov.cn/bjhrb/resource/cms/2019/04/2019041916301550241.pdf

Vehicle Emission Control Center. (2017a). Explanation document of regulation for measuring pollutants in exhaust from in-use diesel vehicles using remote-sensing equipment. Retrieved from http://www.pharmnet.com.cn/image/upload/files/20170306101248.pdf

Vehicle Emission Control Center. (2017b). Explanation document of technical regulation of retrofitting in-use diesel vehicles and non-road mobile machinery with particulate filter. Retrieved from http://meeb.sz.gov.cn/hdjl/myzj/myzj/201709/P020170928549764062794.pdf

Vehicle Emission Control Center. (2020). Internal database: National Motor Vehicle Environmental Protection Information System.

Vehicle Emission Control Center. (2021). Internal report on I/M test results from 2017–2020.

Wu, Y., Zhang, S. J., Li, M. L., Ge, Y. S., Shu, J. W., Zhou, Y., ... Hao, J. M. (2012). The challenge to NO_x emission control for heavy-duty diesel vehicles in China, *12*(19), 9365–9379. Retrieved from https://doi.org/10.5194/acp-12-9365-2012

Yang, Z., et al. (2015). *Review of Beijing's comprehensive motor vehicle emission control programs*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/review-beijings-comprehensive-motor-vehicle-emission-control-programs.

Yue, X., Wu, Y., Hao, J., Pang, Y., Ma, Y., Li, Y., ... Bao, X. (2015). Fuel quality management versus vehicle emission control in China, status quo and future perspectives. *Energy Policy*, *79*, 87–98. https://doi.org/10.1016/j.enpol.2015.01.009

Zhang, S., Wu, Y., Hu, J., Huang, R., Zhou, Y., Bao, X., ... Hao, J. (2014). Can Euro V heavy-duty diesel engines, diesel hybrid and alternative fuel technologies mitigate NO_x emissions? New evidence from on-road tests of buses in China. *Applied Energy*, *132*(2), 118–126. Retrieved from https://doi.org/10.1016/j.apenergy.2014.07.008

Zhou, X. (2018, August 25). Hainan province introduces new policy to eliminate old diesel vehicles. *Hainan Daily*. Retrieved from http://www.gov.cn/xinwen/2018-08/25/content_5316493.htm

www.theicct.org

communications@theicct.org

twitter @theicct