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Review and Outlook of China Non-Road Diesel Mobile Machinery Emission Standards

Stricter emissions standards for better air quality in China

Cui Huanxing
State Environmental Protection Key Laboratory of Vehicle Emission Control and Simulation, Chinese Research Academy of Environmental Sciences (CRAES), 8 Dayangfang Beiyuan Road, Chaoyang District, Beijing, 100012, China; Jinan Automobile Testing Center Co, Ltd, Jinan, 250102, China

Li Gang, Yuan Ying, Ji Liang*
State Environmental Protection Key Laboratory of Vehicle Emission Control and Simulation, Chinese Research Academy of Environmental Sciences (CRAES), 8 Dayangfang Beiyuan Road, Chaoyang District, Beijing, 100012, China

Liu Shunli
Jinan Automobile Testing Center Co, Ltd, Jinan, 250102, China

***Email:** jiliang@craes.org.cn

China has continuously upgraded the emission standards for non-road diesel mobile machinery since they were first issued in 2007. This paper reviews the Chinese non-road diesel mobile machinery emission standards, analyses the change in the environmental situation and management policy and puts forward some principles and suggestions for developing emission standards for non-road mobile machinery in the future. It will have a positive effect on improving the theory and methods for developing mobile source emission standards, as well as boosting the level of environmental management and emission control in China.

1. Introduction

Non-road diesel mobile machinery includes construction machinery, agricultural machinery, tractors, generating units, inland waterway vessels and ground service equipment in airports, among which construction machinery and agricultural machinery are dominant. By 2017, the amount of construction machinery in China had increased to 7.2 million units and the total power of agricultural machinery had increased to 767.763 million kW. As shown in **Figure 1**, the total emissions of nitrogen oxides (NOx) and particulate matter (PM) from construction machinery and agricultural machinery were 3.652 million tons and 320,000 tons respectively (1), which is comparable to the amount of the pollutant emissions from diesel vehicles in the same period. Non-road diesel mobile machinery has become the main source of emissions in China.

Similar to the USA and the European Union (EU), air pollution control for non-road engines starts with non-road diesel mobile machinery in China. Based on analysis of the current standards in China and the latest progress in relevant international emission standards and regulations, this paper outlines vital issues for developing new non-road mobile machinery emission standards in future and provides some recommendations for formulating non-road mobile machinery emission standards.

2. Development of Emission Standards for Non-Road Diesel Mobile Machinery

In 2007, China issued 'Limits and measurement methods for exhaust pollutants from diesel

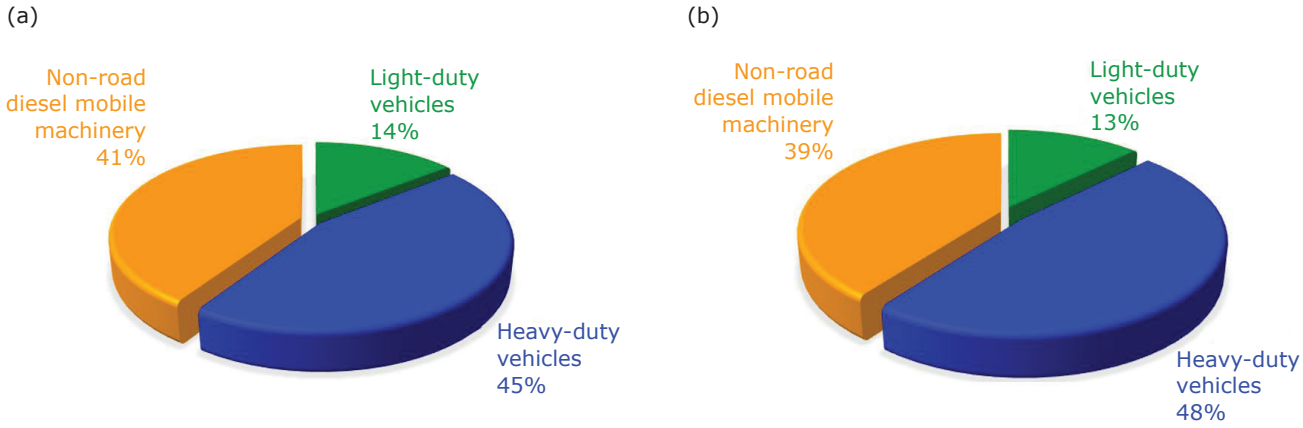

Fig. 1. Contributions of light-duty, heavy-duty vehicles and non-road diesel mobile machinery to: (a) NOx emissions; (b) PM emissions (1)

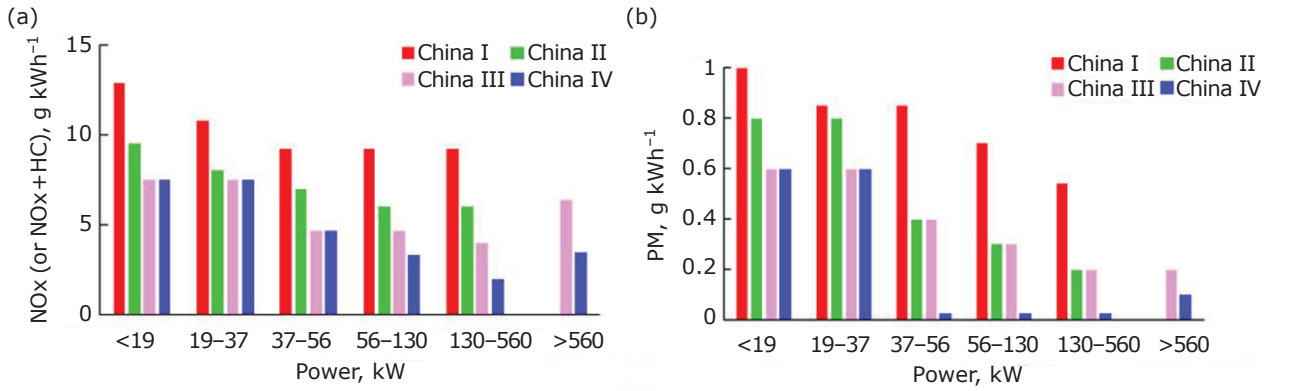

Fig. 2. Development of (a) NOx and (b) PM limits of non-road diesel engines in China (2, 3)

engines of non-road mobile machinery (I, II)' (GB20891-2007), which is applicable to diesel engines whose rated net power is less than 560 kW. The requirements of China stage I/II emissions standards were similar to those of the EU stage I/II. However, considering that a large number of non-road diesel engines under 37 kW are produced and used in China, the emission requirement on diesel engines under 37 kW has been put forward since China I. China I emission standards were implemented on 1st October 2008 (refer to production, import and sale dates below) and China II standards were implemented on 1st October 2010.

In 2014, China issued 'Limits and measurement methods for exhaust pollutants from diesel engines of non-road mobile machinery (III/IV)' (GB20891-2014) and the application scope of this standard was further extended to diesel engines with rated net power over 560 kW. The limits of these two stages were based on EU stage IIIA/IIIB and its application scope is wider, ranging from under 19 kW to over 560 kW. China III became effective from 1st October 2015 and all non-road mobile machinery manufactured, imported and sold must meet the requirements from 1st April 2016. The NOx (or NOx + HC) and PM limits from China I to China IV are shown in **Figure 2** (2, 3).

The focus of emission control for non-road mobile machinery diesel engines are NOx and PM and based on the maturity and the difficulty of control technology, as well as the increase in cost, the emission limit for diesel engines of 37–560 kW was tightened the most. Compared with China I, the NOx limit is tightened by 50–80% and the PM limit is tightened by 95–97% in China IV. For diesel engines below 37 kW, the NOx and PM limits have been tightened by 30–40% and for diesel engines over 560 kW, which have been controlled since China III, the emission limits have been tightened by about 40%.

In cycle tests, only the non-road steady-state cycle (NRSC) was used in China I to China III, including the C1 cycle for most variable speed engines, D2

cycle for constant speed engines and the G2 cycles for variable speed engines with rated power below 19 kW. These cycles are specified in ISO 8178 and each cycle contains a series of operating modes that specify the speed and torque, with different weighting factors to calculate the pollutant emissions of the whole cycle (see **Table I**).

There are different varieties of non-road mobile machinery and the actual operating conditions of different machines vary greatly, so NRSC has certain limitations in assessing the actual emissions of the machinery. Therefore, in China IV, the non-road transient cycle (NRTC, see **Figure 3**) is introduced to test variable speed diesel engines (excluding marine diesel engines) with a power range of 19–560 kW and variable-speed multi-cylinder diesel engines below 19 kW (4).

NRTC is an engine dynamometer transient driving schedule of total duration 1238 s and a composite test cycle consisting of a representative duty cycle for seven common types of non-road equipment with improved accuracy. The NRTC is

Table I NRSC Test Cycle

Mode number		1	2	3	4	5	6	7	8	9	10	11
Torque per cent, %		100	75	50	25	10	100	75	50	25	10	0
Speed		Rated speed					Intermediate speed					Low idle
Weighting factors	C1	0.15	0.15	0.15	–	0.10	0.10	0.10	0.15	–	–	0.15
	D2	0.05	0.25	0.30	0.30	0.10	–	–	–	–	–	–
	G2	0.09	0.10	0.29	0.30	0.07	–	–	–	–	–	0.05

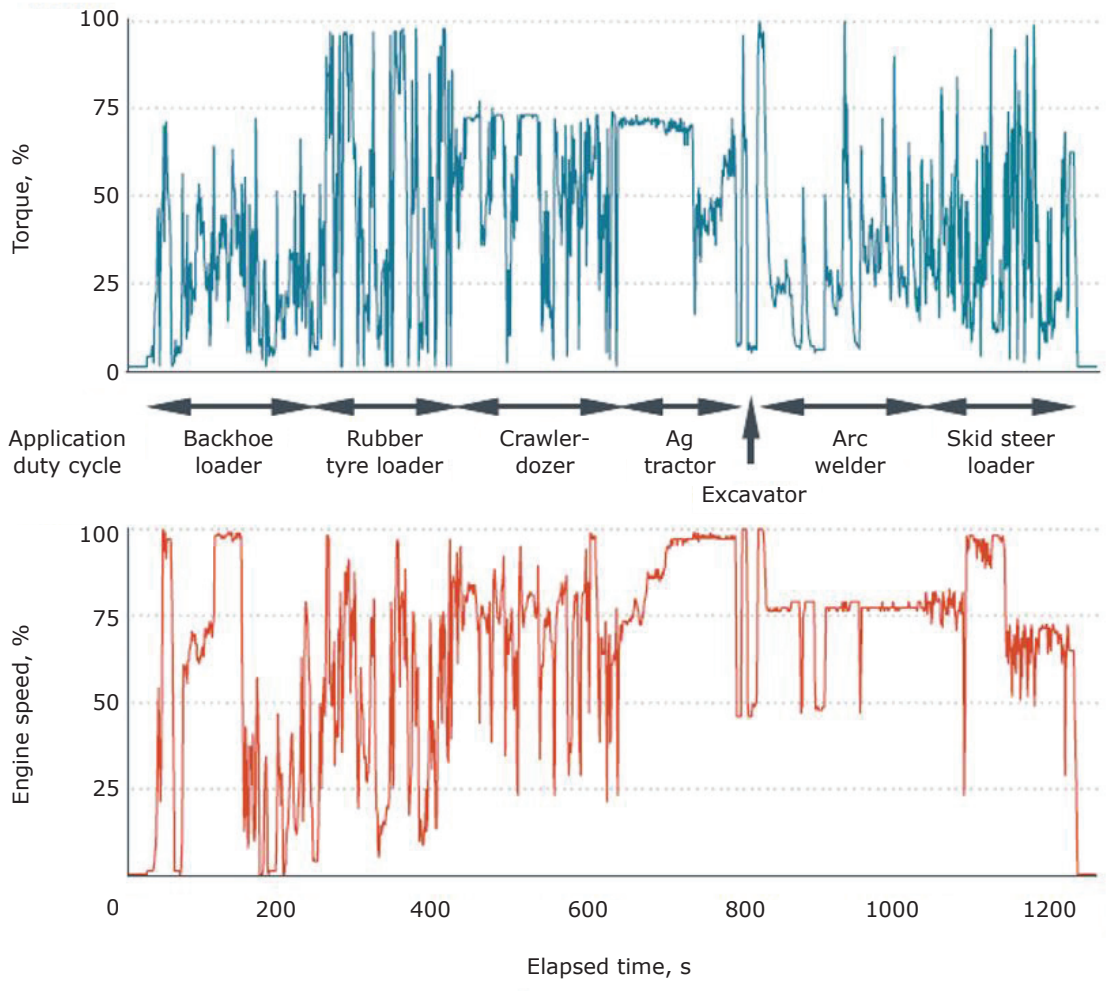

Fig. 3. NRTC normalised dynamometer schedule (4)

run twice after completion of pre-conditioning, the cold-start run and the hot-start run. Composite weighted emissions are computed by weighting the cold-start run results by 10% and the hot-start run results by 90% (5).

3. Recommendations on China's Future Non-Road Mobile Machinery Regulation

The limits and NRTC test cycle of China IV were proposed in GB 20891-2014, and the specific technical requirements will be supplemented later. Based on China's air quality improvement needs, as well as the development and progress of emission control technology and testing technology, this paper proposes the following suggestions for future emission standards of non-road mobile machinery.

3.1 Emissions can be Further Reduced by Using Advanced Emission Control Technologies

China aims to strike a balance between humans and nature to make notable achievements in reducing emissions by 2020, as well as to garner fundamental improvements in its ecology by 2035. The State Council has released the 'Three-Year Action Plan to Win the Blue Sky Defence War', in a bid to improve air quality. By 2020, emissions of sulfur dioxide (SO_2) and NOx should decline at least 15% from 2015 levels, while cities with low air quality standards should see their PM 2.5 density fall at least 18%, according to the plan (6). Diesel vehicles and non-road diesel mobile machinery are the main sources of air pollution in China, especially in cities. The action plan for diesel truck emissions control was released at the end of 2018 and includes emission control for diesel vehicles and non-road diesel engines. All these policies require stricter and more effective non-road mobile machinery emission standards to be developed and implemented in the future in China.

China III emission standards have been implemented for four years. At the present control level, engines can meet the standards without any exhaust after-treatment system. In 2018, the Ministry of Ecology and Environment of China issued the 'Technical Policy for Pollution Prevention and Control of Non-road Mobile Machinery', encouraging China IV and China V to adopt advanced emission control technologies, such as selective catalytic reduction (SCR) and diesel particulate filter (DPF) (7). It can be seen that by adopting advanced emission control technology, NOx and PM from non-road mobile machinery can be significantly reduced. The NOx and PM limits will be tighter in future regulations, and the particle number (PN) emission requirement also will be proposed.

3.2 Real World Emission Reduction Should be Focused on

Increasing studies suggest that the traditional laboratory test methods centring on a specific working cycle cannot truly reflect the level of vehicle emissions (8–10) and results may greatly differ from those obtained in actual use (11). Reducing emissions in actual use has become a major direction for the development of emission regulations in various countries and regions. The United States Environmental Protection Agency (US EPA), the EU and China have successively added measurement requirements for real road emissions to the regulations for heavy-duty and light-duty vehicles (12, 13). The same problem exists in non-road mobile machinery, so EU Stage V has added this measurement requirement when the machinery is working, but has not yet set a limit (14).

At present, emissions testing of non-road diesel mobile machinery in China is completed using the engine test bench. In our study, 16 non-road mobile machines (see **Table II**, all the engines meet

Table II Information About the Tested Mobile Machinery

Machinery number	Machinery type	Engine power		Model year
		kW	rpm	
1	Rubber tyre loader	162	2000	2017
2		260	1600	2016
3		180	1700	2016
4		129	1700	2017
5		260	1600	2017
6		273	1350	2017
7		273	1350	2015
8	Backhoe loader	120	2000	2016
9		124	2000	2016
10	Forklift	85	2200	2018
11	Tractors	95.6	2200	2017
12		110	2100	2016
13		144	1700	2017
14		150	2100	2017
15	Corn harvester	204	2000	2017
16		135	2100	2016

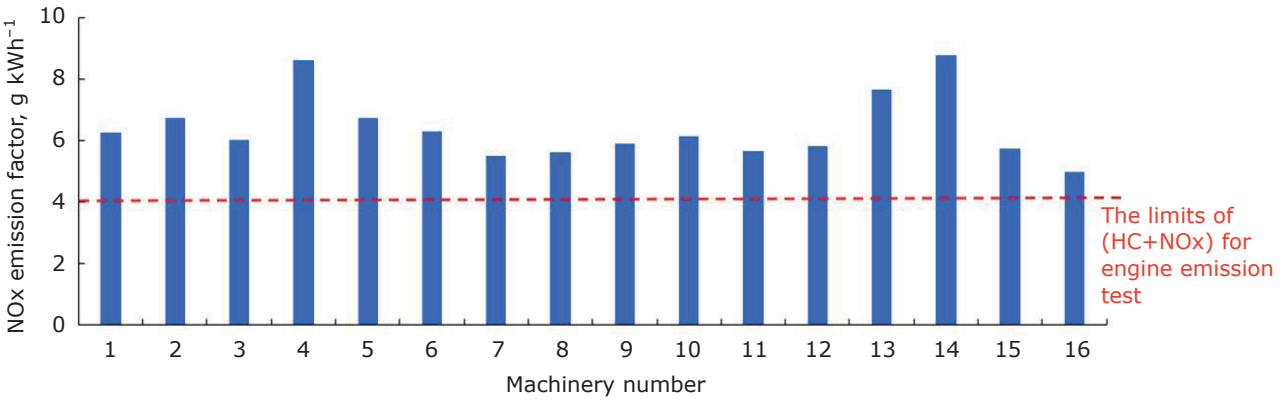

Fig. 4. NOx emission of non-road mobile machinery tested by PEMS

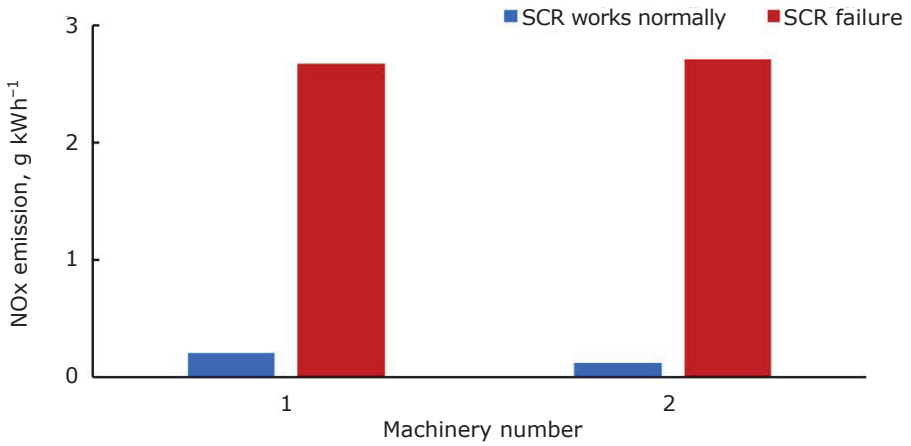

Fig. 5. Comparison of NOx emission before and after SCR failure

China III) from different OEM were tested based on the method of portable emission measurement system (PEMS). The results show that the emission of NOx is 1.5–2.25 times greater than that of the engine limit (see **Figure 4**).

The actual working conditions of machinery change frequently and the working environments vary. The engine test bench's environment conditions are relatively stable and the test conditions have been quantified, so the manufacturer can adjust the emissions characteristics of the diesel engine under the test conditions, resulting in excessive emissions in actual operation. Therefore, in order to reduce emissions during the actual operation of mobile machinery, Chinese non-road diesel mobile machinery emission standards should focus on the following issues in future: proposing a method of measuring the whole machine and reasonably setting limits according to the actual operation conditions and the working environment.

3.3 Focus on Monitoring the Actual Emissions

In order to meet the increasingly stringent emission control requirements, non-road mobile machinery has also begun to use exhaust aftertreatment systems to reduce emissions of pollutants such as NOx and PM. If the emission control device fails or performs poorly, the corresponding pollutants may multiply. In this study, two mobile machines using SCR were tested using PEMS. When urea solution is replaced by water, the emission of NOx increases nearly 20 times (see **Figure 5**). It can be concluded that whether the exhaust aftertreatment system works normally or not will directly influence the emission level of the machinery.

In order to monitor whether the key components work normally or not and to ensure the mechanical emissions meet the requirements of the regulations for the whole lifetime of the

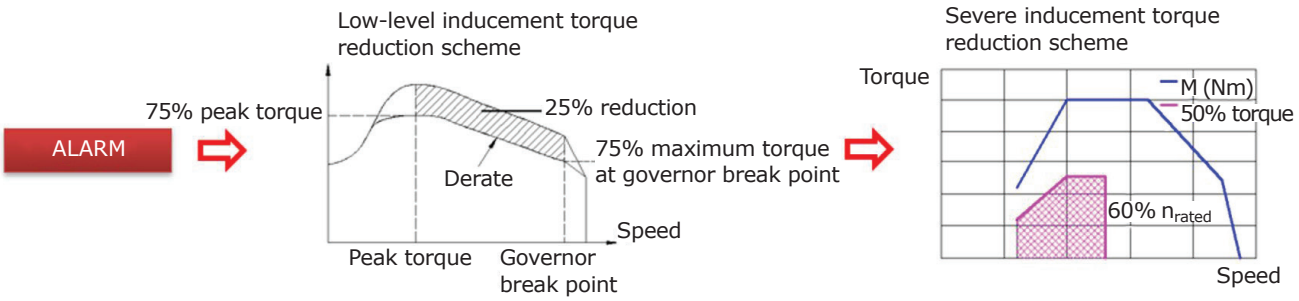

Fig. 6. Control diagnostic system of Euro V for non-road mobile machinery. Copyright European Union 2017 (15)

vehicle, many countries and regions have put forward requirements for an onboard diagnostic (OBD) system and NOx control system on the vehicle. This concept has been applied to non-road mobile machinery. In EU Stage V, the functional requirements of a NOx control diagnostic (NCD) system and particulate control diagnostic (PCD) system for NOx and PM control systems respectively are put forward. In case of failure, the warning and inducement torque reduction systems will be activated, as shown in **Figure 6** (15). Therefore, Chinese non-road diesel engine emissions regulation should include the requirements of onboard emission control and diagnostics systems in the future.

In addition, China has put forward the requirement for remote emissions monitoring in the stage VI national standard for heavy-duty vehicles ('Limits and measurement methods for emissions from diesel fuelled heavy-duty vehicles' (GB 17691-2018)), stipulating that the OBD system has the function of sending monitoring information in real time to better monitor the emissions of vehicles running on roads, to judge the actual emission of vehicles and determine whether the various emission control measurements and OBD work effectively and whether emission-related faults are repaired in time. This also suggests a new method of supervision for the emissions of non-road mobile machinery. At present, there is usually no registration system for non-road mobile machinery and no periodic inspection system for in-use machinery, so it is difficult for in-use machinery to achieve emission standards. The remote emissions monitoring technology from heavy-duty vehicles could be used as a reference and applied to non-road mobile machinery, providing a simple and feasible method for in-use machinery emissions monitoring.

3.4 Improvement of Fuel Quality

With the improvement of emissions standards, different aftertreatment systems need to be combined to reduce the final emission of pollutants. The application of aftertreatment system requires higher quality of fuel, especially the sulfur content. The sulfur content of reference fuel is 10 parts per million (ppm) in non-road stage IV regulation. Since 2010, reduction of sulfur content of fuel in China has been greatly accelerated. In 2013, the sulfur content in general diesel fuel decreased from 2000 ppm to 350 ppm; in 2017, the sulfur content was reduced to 50 ppm and in 2018, the whole country began to supply diesel fuel with 10 ppm sulfur content. The improvement of fuel quality is the basic condition to ensure the effective operation of emission control devices, which provides a guarantee for the implementation of more stringent emission standards for non-road mobile machinery in the future.

After the upgrade of fuel standards, it is important to strengthen the supervision of market fuel quality and ensure the supply and use of certified fuel. According to data released by the Ministry of Ecology and Environment in 2018, the per cent pass of diesel fuel in private gas stations of Beijing, Tianjin and Hebei and surrounding areas reached 50%. In response to the issue of fuel quality, the 'Three-Year Action Plan to Win the Blue Sky Defence War' released by the State Council was deployed to achieve the integration of vehicle diesel fuels and general diesel fuels and to crack down on the production, sale, storage and

use of unqualified fuel and urea, including banning unqualified gas stations (16).

4. Conclusions

In order to improve the air quality in China, stricter and more effective non-road mobile machinery emissions regulations should be developed and implemented in the future. The adoption of advanced emission control technologies will significantly reduce NOx and PM emissions. Emissions standards are the basic means of environmental management, so the formulation, content and form of emissions standards must serve environmental management needs. The main direction for future standards development is to reduce non-road mobile machinery pollutant emissions in the real world. It is also necessary to establish an applicable and operational on-board measurement method and to develop an effective online monitoring system and method. Supervision on the quality of marketed fuel should be strengthened to ensure the effective implementation of emissions standards and achieve the expected effect of pollutant emissions reduction.

Acknowledgments

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The Authors

CUI Huanxing, engineer, graduated from Southwest Jiaotong University, China. He has been engaged in the formulation and impact evaluation of non-road mobile machinery emission standards since 2016. He conducts research on non-road engine emission testing, especially the PEMS test method.

LI Gang, engineer, graduated from Tsinghua University, China, and joined the Chinese Research Academy of Environmental Sciences (CRAES) in 2007. Li Gang has been engaged in the formulation of environmental protection standards for mobile sources and related research work. He has participated in many mobile source emission standards. He is also one of the main writers for the emission standards for non-road mobile machinery (China III, IV).

YUAN Ying is a Professor at CRAES. She has been engaged in studying and managing emission control of transportation pollution sources since the 1980s, including: study and formulation of vehicle emission standards and regulations, study on engine emission control and testing technologies and study on alternative vehicle fuels. She managed or participated in formulating China's emission regulations from first stage to sixth stage for motor vehicles, non-road engines and marine engines.

JI Liang is an Associate Professor at CRAES. She has been engaged in studying and developing mobile sources emission standards and regulations since 2003. She managed or participated in formulating China's emission regulations from China III to China VI for motor vehicles, non-road engines and marine engines. She also focused on the impact evaluation of emission regulations.

LIU Shunli, senior engineer, graduated from Jilin University, China. He has been engaged in the formulation of mobile sources emission standards and regulations since 2006. He has participated in many mobile source emission standards. He is the main writer for the emission standards for non-road mobile machinery (China III, IV).