A Report to the China Council for International Cooperation on Environment and Development (CCICED)

Special Policy Study Program 2015

Coordinated Actions for Addressing Climate Change and Air Pollution

-- With a Focus on Short-Lived Climate Pollutants and Non-Road Mobile Sources

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Executive Summary

I. The rationale: Why this Special Policy Study?

Short-Lived Climate Pollutants (SLCPs) include black carbon (BC), methane (CH_4), ozone in the troposphere, and some hydrofluorocarbons (HFCs). Of particular interest, is the fact that strategies to reduce black carbon and methane will reduce both air pollution and near-term warming. Thus, implementing strategies to address SLCPs will improve human health and crop yields and also contribute to addressing climate change, especially in the near term. There are many linkages between SLCPs reduction strategies and action to prevent emissions from non-road mobile sources, which is an area neglected by current policy. Coordinated actions in this report address air pollution and climate change, with a focus on SLCPs and non-road mobile sources (NRMS).

1. China faces opportunity and challenge for accelerating coordinated actions addressing air pollution and climate change

2014-2015 is a critical time for achieving a range of energy, environment, and carbon intensity targets set for the current 12th Five-Year Plan (FYP) period. It is also a critical moment for the implementation of the Action Plan for Air Pollution Prevention and Control, which aims to significantly improve air quality by 2017. Furthermore, it is also an important window period for the development of the Outline of the 13th FYP and the Special Plan for Environmental Protection during the 13th FYP Period, and more broadly for the achievement of climate change adaptation and mitigation targets and air quality improvements in China in the coming years.

A new People's Republic of China (PRC) Law on Air Pollution Prevention and Control (called the new Air Law hereafter) was approved on August 29, 2015 and will come into force in January 2016, which will open up new opportunities to address SLCPs and NRMS. The new Air Law explicitly links air pollution and climate change as issues that need to be coordinated together. Article 2 in the Law, has the goal of improving atmospheric environmental air quality, and insists on treating emissions at their sources, prioritizing planning processes, transforming economic development, optimizing industrial structure and distribution and adjusting energy structures to prevent and control air pollution. The new Air Law addresses the prevention and control of air pollution from coal, industries, on and off road motor vehicles and vessels, fugitive dust, and agriculture as well as other pollution sources; promotes joint regional air pollution prevention and control to coordinate efforts to reduce air pollutants such as particulate matter (PM), sulphur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs), ammonia and greenhouse gases.

In the broader national context, ecological civilization has been enshrined as one of the five integral components and pillars of socioeconomic development in China that encompasses green, circular and low carbon development. The new Air Law is aligned well with the recently (11 September 2015) approved “General Plans for the Reform of the Ecological Civilization System”, which outlined a set of fundamental ideas and principles as well as specific management systems to ensure and operationalize those ideas and principles in continued social economic development as China deepens its modernization.

Air pollution and climate change are linked issues. In China, a lot of attention has been paid to the linkages between climate mitigation and air pollution and the multiple benefits that can be achieved from coordinated actions and policy coherence. Planned further action is outlined within the new Air Law. This CCICED Special Policy Study focuses on one particular aspect of climate and air pollution linkages, namely, the strategies that specifically address mitigation of substances that are short lived and warm the atmosphere, and which are also linked with air pollution – the Short-Lived Climate Pollutants or 'SLCPs'.

In regards to SLCP mitigations, recent scientific assessments have identified that the fast implementation of a small number of key measures in specific sectors can have benefits to reduce the rate and degree of warming in the near–term (i.e. over the next few decades), contribute to reductions in health impacts from reductions in $PM_{2.5}$ and ground level ozone concentrations, and also avoid losses in the yields of many important crops. Action in China will have the greatest benefit for environmental conditions and development in China, but will also provide global and regional climate benefits, and air quality benefits in neighbouring countries and over the northern hemisphere. This focus on the implementation of key measures that have been identified to achieve near-term reductions in warming and achieve significant air quality benefits, is the basis for a SLCP strategy.

One of the sectors where many mitigation measures are relevant to the SLCP strategy, and that has received only limited attention with regard to pollutant mitigation is the NRMS of emissions in China, such as construction and agricultural machinery and marine vessels. NRMS have large emissions of BC, a significant SLCP, making ships and ports, and other non-road machinery major sources of BC. There is increased attention on ships and ports as seaborne trade has grown significantly in recent decades. Controlling ship and port-related emissions is increasingly seen as a necessary component of an overall air pollution mitigation strategy for coastal areas. Ship emissions are further accentuating the importance of addressing both long-term greenhouse gas emissions and also implementing SLCP strategies, focusing on BC. For this reason, NRMS is selected as a special focus in this study.

This report assesses the benefits and opportunities afforded by focused strategies in China for SLCPs and NRMS, which are both areas where large benefits for climate and air quality could be achieved by targeted action and early implementation of key measures.

2. An SLCP strategy is helpful for mitigating near-term warming and other climate change over the next few decades

According to the Intergovernmental Panel on Climate Change (IPCC), climate change is occurring now and impacts will increase over the next decades. Peaking the emissions of long-lived greenhouse gases and limiting long-term climate change is of course vital if we are to avoid dangerous climate change in this century, and the focus for these strategies is carbon dioxide (CO_2) abatement, which is rightfully a major global and Chinese priority. However, there are important impacts that are occurring now and will intensify as warming increases over the coming decades. Research has found that regional and global warming in the near term can only be effectively reduced by an SLCP strategy, and that such a strategy is in fact very likely to have greater leverage over near-term impacts than CO2 reduction strategies.

An SLCP strategy will help reduce climate impacts to highly vulnerable areas and systems as well. This includes areas of snow and ice, such as in the Himalayas and Arctic. Analyses of more than 5000 glaciers in western China determined that more than 80% of them retreated during the second half of the 20th Century, with glaciers in the mountainous regions surrounding the Tibetan Plateau experiencing the greatest losses. Glacial lake outburst floods were also highlighted as being likely to increase in frequency due to climate change in the near-term. It was pointed out that at least 35 glacial outburst flood events have occurred over the last 100 years in Nepal, Pakistan, Bhutan and China, affecting people living in the valleys below. The near-term warming threatens to disrupt crop production for those crops that are sensitive to temperature change or changing water availability, both of which are influenced by SLCPs.

Rainfall patterns have shifted in China over recent decades and there is increasing and strong scientific evidence that SLCPs are a major cause of this shift. In addition, the intensity of rainfall and severe storms can also be affected by SLCPs. These near-term changes have significant economic and livelihood impacts related to agriculture and infrastructure.

3. Air pollution impacts can be mitigated further to certain extent with an SLCP strategy

Air pollution is a major issue in China, with very large impacts on human health, agriculture, quality of life and economic development. Studies have estimated that $PM_{2.5}$ pollution causes millions of premature deaths globally from outdoor and indoor exposure to $PM_{2.5}$ pollution. The $PM_{2.5}$ pollution causes increased incidence of strokes, heart disease, lung cancer and respiratory infections which leads to people dying earlier than they would in the absence of $PM_{2.5}$ pollution (i.e. the ‘premature mortality’). In addition, a much larger number of people are being affected by non-lethal, yet significant health impacts – including increased incidence of asthma, increased hospital visits, low birth weight, and lost work and school days. Thus, controlling air pollution is undoubtedly a top priority for China in the coming years.

An SLCP strategy can mitigate air pollution impacts in several important ways. First of all, SLCP strategies address some of the major sources of incomplete combustion, reducing a large part of the emissions that lead to the $PM_{2.5}$ concentrations causing the damage to health, and so can deliver substantial reductions in health impacts. Secondly, SLCP strategies can reduce impacts of tropospheric ozone on crop yields, forest growth and human health, which is an important area for air pollution control. Last and perhaps most importantly, an SLCP strategy is an important way to address near-term climate warming, which will be further enhanced by the planned rapid removal of sulphur and NOx from the atmosphere.

Sulphur and NOx are being controlled in China under the air pollution law to prevent human health impacts, which is a top priority and very necessary. High levels of sulphur in the atmosphere, however, cool the planet. Thus the SO_2 and NO_X emission reductions on their own would lead to accelerated near-term warming in China and globally. The SLCP approach is the most effective way to reduce the near-term warming and counteract this effect, making the SLCP strategy especially crucial for China.

In the case of the non-road mobile sources, reducing the sulphur content in their fuels is a widely used strategy for mitigating air quality and health impacts of NRMS emissions. Thus, reducing the sulphur in fuels will also lead to regional near-term warming, and therefore must be offset through an SLCP strategy, which includes further BC controls on NRMS sources. In light of the projected reduction in SO_2, there is an urgent need to accelerate the control of SLCPs, like BC, from the shipping and port sectors and other non-road machinery to offset the climate impacts of reduced SO_2 emissions. Lower sulphur content in fuels is necessary for the deployment of advanced control technology, which emphasize the need to coordinate SLCP, air quality and climate strategies.

- **The development of the SLCP approach**

A strategy to control SLCPs focusses on implementing those measures where there is a near-term climate benefit, as well as benefits for health and ecosystems from reduced air pollution. SLCP reduction measures are identified from evaluation of the net effect of all the emitted gases and particles on warming. The SLCP measures are those where the reduction in short-lived warming substances (BC, CH_4, tropospheric ozone and HFCs), outweighs the influence of substances that cool the climate (especially sulphate, organic carbon and nitrate).

BC only remains in the atmosphere for a few days, ozone weeks to months, CH_4 about twelve years, and the main HFCs of concern an average of 15 years. These are all much shorter than the residence time for carbon dioxide, a large proportion of which resides for more than a hundred years in the atmosphere. Therefore, any reduction in the concentrations of the pollutants BC, CH_4, many HFCs and ozone will give fairly immediate impacts, with nearly all reduction in climate and air quality impacts apparent between one to two decades after emissions have been stopped and often much more rapidly.

- **Complementing existing policy approaches**

An SLCP strategy would complement air pollution, climate change, transport, agricultural and other sector policies. The measures that are promoted under an SLCP strategy are currently implemented under different existing programmes, policies and regulations in China to some degree. For example, through the new Air Law and the Air Pollution Action Plan, the Chinese government is determined to limit the concentrations of $PM_{2.5}$ in three key metropolitan areas in China. Through the United Nations Framework Convention on Climate Change (UNFCCC) reporting mechanism, the Chinese government includes CH_4 emissions in its national communications. Through the Sino-US cooperation mechanism etc., the Chinese government will further reduce HFCs emissions both from consumption and production. VOCs and other precursors of tropospheric ozone will also be included into the environmental protection control systems. These domestic actions and policies have therefore already tackled most of the sources of SLCPs.

An SLCP strategy would emphasize earlier and deeper implementation of key measures in key sectors than is currently envisaged, but use existing mechanisms, where these exist, with modifications to ensure the most efficient abatement of the SLCPs. Understanding the gaps in abatement is needed to set priorities for action under an SLCP strategy. Thus an SLCP strategy is one that promotes the implementation of measures, rather than concentrating on substances alone. Essentially, these include all measures that reduce CH_4 and HFC emissions. However, these include only some of the measures that prevent incomplete combustion and that reduce a complex mixture of BC and co-emissions. The SLCP strategy concentrates on the BC-related measures that provide a reduction in near-term warming. The main measures considered in an SLCP strategy have been identified in the UNEP/WMO Assessment and follow up work under the Climate and Clean Air Coalition (CCAC) and include:

- ✧ CH_4 measures: including reductions in coal mine releases, emissions from rice paddy fields, from the oil and gas sector including storage and transmission; from municipal landfills; from manure management.
- ✧ BC: emissions from diesel engines; from residential use of coal and solid biomass fuels; from inefficient combustion in small scale industry.
- ✧ HFCs: Replacement of high global warming potential (GWP) HFCs with low GWP alternatives, efficient cooling of buildings, etc.

II. Summary of Key Findings

1. SLCPs and NRMS emissions exert a strong impact on climate and air quality, which current policies regarding air pollution prevention and control have not adequately taken into account.

China has long focused its attention regarding air pollution control to urban air quality and acid rain. This is appropriate since China has an extremely serious and widespread air pollution problem with enormous adverse impacts on public health and the environment. As composite air pollution worsened in recent years, much more management and research resources have been delivered to air pollution prevention and control while SLCPs attracted much less attention compared with conventional air pollutants.

As to non-road mobile sources, there were more than six million pieces of construction machinery at the end of 2013 in China and the average annual increase rate exceeds 10%. Studies have shown that on-road and NRMS account for 60% and 40% of NO_x emissions respectively, while the latter has a larger role in the primary $PM_{2.5}$ emissions. Currently, the ocean-going vessels entering the country mainly rely on heavy oil which has sulfur content as high as 3.5%. This results in huge SO_2 and $PM_{2.5}$ emissions from marine vessels.

2. The current management systems for SLCPs and NRMS are insufficient to ensure effective control of SLCPs from the non-road sector; the new Clean Air Law offers an opportunity to improve such systems.

On controlling air emissions from NRMS, the ongoing management system lacks unified monitoring and regulatory requirements, making it impossible to identify the actual level of emissions from non-road machinery. In terms of fuel quality management, the quality of fuel used by engineering machinery is poor with high levels of sulphur, and that for ships is worse. Therefore, it is urgent to improve the management systems and technical roadmap for controlling SLCPs and NRMS emissions. The new Clean Air Law now provides the legal foundation for the environmental agencies at the national and local levels to control air pollution from construction machinery and vessels, and mandates improvements in fuel quality. This offers an opportunity for improving the existing management system for SLCPs and NRMS at the national levels and in key regions that have severe air pollution problems.

3. **Emission standards and policies for SLCPs and NRMS emissions lag behind international best practices, and the new Air Law and standards present an opportunity for improving the regulatory system.**

In terms of SLCPs, the *Environmental Protection Law* and *Air Pollution Prevention and Control Law*, two basic laws addressing air pollution, do not specify requirements for SLCP control. In current air pollutant emission standard system in China, only the *Standard for Pollution Control on the Landfill Site of Municipal Solid Waste* (GB16889-2008) and *Coal-Bed CH_4 (Coal Mine CH_4) Emissions Standards (Tentative)* set requirements for CH_4 emissions control, but there is no specific standard towards BC and HFCs emission, and also CH_4 emission from other sources such as oil & gas extraction and agriculture are not regulated. SLCPs are not the major target of control in China's current emission control policy.

On non-road machinery, China has requirements on type approval of engines for use on non-road mobile machinery (NRMM), but there has not been effective control of emissions from in-use NRMM. There is currently no air emission regulation for engines over 37 kW for use on inland and coastal marine vessels and railroad locomotives. Currently, aircraft and ocean-going vessels are only required to comply with the relevant international conventions. In addition, the lax fuel quality standards (relative to developed countries) hinder the wide application of advanced emission control technologies in NRMS. The new Air Law stipulates that all new marine engines for use on domestic vessels must conduct emission tests to certify compliance with emissions pollution standards and the designation of emission control areas (ECAs) around key regions. ECAs require the approval of the International Maritime Organization (IMO) and allow countries to designate coastal areas which require cleaner fuels or more stringent emissions standards for ocean going vessels. Also, a set of air emission standards for marine engines over 37 kW is now being developed. It also requires improvements in fuel quality. These new legislative and regulatory developments present a unique opportunity for strengthening control of the non-road sector.

4. **Some of the advanced technologies to control SLCPs and NRMS emissions are available and used around the world; international experience offers opportunities for rapidly enhancing their application in China.**

In the process of technology selection, SLCPs are not well considered, except BC. Among the ongoing policies towards BC emission reduction, the measures aimed at increased combustion efficiency, including “clean” coal utilization and combustion improvement of stoves and furnaces, facilitate the control of BC emissions. The plan for the Air Pollution Prevention and Control promulgated by the State Council requires, by 2017, the elimination of all yellow-label vehicles (gasoline vehicles registered before 2005 and not meeting the national I emission standards, and diesel vehicles not meeting the national III emission standards). However, these policy actions were not designed to reduce BC emissions, even though they can control BCs from difference sources. The main measures and strategies for China to reduce emissions of CH_4, HFCs and products of incomplete combustion, including BC, can be identified from current knowledge.

Advanced technologies to reduce emission from non-road machinery include selective catalytic reduction (SCR) and diesel particulate filter (DPF). They can effectively reduce NO_x and PM emissions, but have not yet been widely used on non-road machinery, due to poor fuel quality and a lack of urea storage capacity. Advanced technologies for the control of shipping emissions include using shore power at berth and switching to low-sulfur marine fuel. However, the installation of shore power equipment is constrained by the power supply network and equipment standardization, so shore power has not yet been widely used, except for pilots in a few ports, such as Shanghai, Shenzhen, Lianyungang, Ningbo, Qingdao and Guangzhou. In the absence of ECAs, vessels operating in China's waters do not switch to low-sulfur marine fuel.

5. **Further research and more comprehensive data will improve the ability to target action on SLCPs and NRMS.**

SLCPs are not covered as pollutants specified in China's existing statistical reporting system. Emissions of CH_4 and some HFCs are reported in National Communications on Climate Change and relevant government documents, but are not included in the annual emission statistics, and the statistical timeliness is relatively poor. As to other SLCPs, there are no emission reports at the national level. Under the support of research programs, domestic research institutes study the emissions and distribution of SLCPs in China, but due to limitations in methodology and underlying data, these emissions inventories are not sufficient to provide adequate support for policy formulation and impact assessment.

There has not yet been a comprehensive study on NRMS and the research findings to date provide only test results about certain kinds of machinery. Therefore, the basic data about emission factors is relatively limited. In addition, the wide range of activities and diverse areas of application add to the difficulty in collecting activity level data. In terms of vessels, China currently relies on international data on emission factors and vessel activity levels in the study of domestic port emissions, which makes it difficult to fully grasp the true level of emissions from vessels.

III. Summary of Main Policy Recommendations

1. Accelerating the introduction of sound emission regulations, standards, and policies

SLCPs emission standards and caps should be specified based on the best available technology (BAT). Specific to BC-related sources that form part of the SLCP strategy, energy use policies should accelerate the ongoing transition away from solid biomass fuels. Regulations for on-road diesel vehicles, coke ovens and brick kilns should achieve BAT for reducing BC emissions. The methane emission standards for coal mine gas allowances and subsidies, as well as tax incentives should be improved so as to reduce emissions. It is recommended to recognize the *Coal-Bed CH_4 (Coal Mine CH_4) Emissions Standards (Tentative)* as an official document to increase the coal mine CH_4 utilization rate. BAT should also be applied to other sources of CH_4 including fugitive emissions from the oil and gas industry, manure management and landfills, while best practices (e.g. intermittent irrigation) should be used to reduce CH_4 emissions from rice growing.

Regulations to reduce emissions from both new and in-use construction and agricultural equipment and marine vessels should be accelerated with the goal of achieving international best practice norms during the 13th Five Year Plan. Since "general" diesel fuel in China will have a maximum sulfur content of 10 ppm by January 1, 2018, China should leapfrog to Euro IV non-road standards in the 13 Five-Year-Plan and even earlier in the Beijing – Tianjin – Hebei region (Jing-Jin-Ji), Yangtze River Delta region (YRD) and the Pearl River Delta region (PRD), Sichuan Basin, Northeast Provinces and other high polluted areas. For inland waterway and coastal vessels and harbor crafts, China should leapfrog to US Tier 4 or equivalent standards by 2020 with the goal to drive the wide adoption of most effective BC control technologies, like DPFs, and encourage early adoption of the strictest standards in the key port regions and major inland waterways.

To directly reduce BC emissions and enable the effective use of advanced emission control technologies (like Selective Catalytic Reduction (SCR) and especially Diesel Particulate Filters (DPFs)), tightening the standards for marine fuel oils is urgently needed. This could be implemented through setting up strong ECAs at key port regions in China that require the use of lower-sulfur fuel, striving to achieve 0.1% limits as soon as possible, when domestic vessels and ocean going vessels (OGVs) operate in those areas.

2. Building a management system that reduces SLCPs and NRMS emissions

(1) Regulatory bodies and responsibilities

Black carbon and ozone should be included in the target systems for air pollution prevention and control and non-carbon dioxide greenhouse gas (including CH_4 and HFCs) emission standards and abatement action plans should be developed to promote the improvement of relevant laws and regulations, under which regulatory departments and supporting departments are identified according to the SLCP sources. To address BC, a coordination group comprised of energy, environment, agriculture, transportation, and construction departments should be identified, responsibilities and relative rights for reducing end use of coal and other solid fuels, and reducing emissions from the on-road and non-road sectors of each and every department should also be clarified. To reduce CH_4 emissions in fossil fuel extraction, storage and transmission processes and in waste disposal, a working group is also expected to coordinate coal, petrochemical, municipal, and environmental departments. HFCs should be aggressively controlled under the current joint compliance mechanism with increased efforts to reduce HFCs in industrial and commercial air conditioning and refrigeration to augment ongoing progress in residential and mobile air conditioning, strengthen HFCs emission management, accelerate HFCs destruction and replacement, and promote the enterprises to carry out comprehensive control actions of HFC-23 abatement. While the department-specific responsibilities for controlling NO_X emissions and VOCs are to be further clarified.

The new Air Law has specified the departments responsible for addressing NRMS and vessel pollution and specified their responsibilities. The environmental protection authorities under the State Council now have the authority to strengthen NRMS regulation and enterprises must bear the main responsibility for the control of mobile source air pollution. The Ministry of Transport (MOT), in collaboration with MEP and the transport and environmental agencies at the national and local levels, should jointly develop plans for adopting and effectively enforcing stricter standards for marine fuel and engines. MOT is encouraged to set strong ECAs that require use of lower-sulphur fuel oil when vessels operate in Chinese waters.

(2) Establishing an NRMS environmental management mechanism that clarifies the

responsibilities of state and local departments

MEP should establish a national environmental compliance system of new NRMS products, covering product model examination and approval, conformity of production, in-use compliance, recall, and environmental labeling. Local environmental protection departments should establish an environmental management system of in-use NRMS products, covering routine inspections, random inspections, low-emission zones, upgraded environmental governance, and accelerated phase-out.

(3) Enhancing compliance management and introducing innovative implementation mechanisms

Related departments should build up the capacity of environmental regulation by creating networks for monitoring and regulating SLCPs and NRMS emissions and for supervising fuel quality of NRMS based on their duties and responsibilities. The new Clean Air Law provides authority to impose strong fines (up to three times the value of the products in violation) for excessive or illegal emissions to ensure more stringent emissions standards and measures are complied with; these new tools should be applied aggressively.

Institutional innovation based on policy studies, Green Top Runner Programs, emission trading and environmental taxes, are also expected to improve the flexibility and effectiveness of emission standards. China should establish strong ECAs covering coastal and inland waters. Key port regions should adopt region/city-specific clean port programs considering international best practice.

3. Launching the "National Clean Diesel Engine Campaign"

Drawing on the U.S. successful practice in NRMS pollution prevention and control, China should launch the National Clean Diesel Engine Campaign during the 13th FYP period, in line with China's initiatives of "the Belt and Road" and "Made in China 2025". The campaign will be led by the State Council and supported by ministries including MEP, MOT, Ministry of Housing and Urban-Rural Development, Ministry of Agriculture, National Development and Reform Commission, Ministry of Industry and Information Technology, and Ministry of Finance. The campaign will encompass clean diesel engine projects for on-road diesel vehicles, construction machinery, agricultural machinery, and vessels. The goal should be to require wall flow particle filters which greatly reduce particle mass, particle number and BC on as many vehicles and engines as quickly as possible. Recent decisions to require low sulfur fuels for both on and off road applications facilitate this strategy. The system for mandatory retirement before the required deadline combined with financial incentives and market measures to encourage early elimination of old diesel engines and optimization of the fleet structure should substantially reduce both particulate matter and BC. The establishment and application of shore power facilities will be intensified and natural gas and other clean energy options will be favored for harbor utility craft, official boats, and ships on short fixed routes.

4. Strengthening technological innovation and application and international cooperation in the field of emission reduction

It is suggested to strengthen research on the integrated effects of SLCP strategies on air quality and climate change in the future. The Government should expand investment in the independent research on Best Available Control Technologies (BACTs) to control SLCPs and

NRMS emissions, such as development, demonstration and commercialization of advanced engine and after-treatment technologies (SCR/DPF, etc.) applicable to NRMS, as well as research, development and demonstration of advanced technologies and equipment for monitoring emissions relevant to SLCP strategies and NRMS.

For BC and ozone, a statistical and accounting system should be built that is consistent with the systems for other atmospheric pollutants and on-road source emissions.The methodological study should be deepened to facilitate the quantitative evaluation and analysis of benefits of integrated control of multiple pollutants and sources. For CH_4 and HFCs, the emission statistics system should be improved. Moreover, a platform for big data monitoring and control to better facilitate sound decisions and the mechanism for scientific and regulatory data disclosure and sharing should be established.

In addition, the emission reduction strategy should fully refer to and use the mechanisms of multilateral cooperation on SLCP governance, including the Global Methane Initiative (GMI), the Climate and Clean Air Coalition (CCAC), and Global Alliance for Clean Cookstoves. By way of intensive involvement in relevant actions and mechanisms, China can not only gain direct benefits, but also strengthen its voice and influence in international affairs. China should examine the benefits and opportunities of membership in CCAC, which is a major international network working on SLCP emission reductions.

Keywords: air pollution, climate change, collaborative governance, short-lived climate pollutants, non-road mobile sources

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Chapter I Research Progress and Policy Actions on Short-Lived Climate Pollutants (SLCPs) and Non-Road Mobile Sources (NRMS)

I. Research Progress in China and the World

(I) SLCPs

The SLCPs refer to substances that have a relatively short lifetime in the atmosphere and can cause climate warming especially in the near term. These are black carbon (BC), methane (CH_4), ozone (O_3) in the troposphere, and some HFCs. An SLCP strategy is one which implements measures that will reduce near-term warming and deliver air quality benefits from reduced $PM_{2.5}$ and ozone concentrations. The United Nations Environment Programme and World Meteorological Organization (UNEP/WMO) report of 2011 showed that emissions from sources that are the focus for SLCP strategies do harm to air quality, human health and crop production. This report also highlighted the potential magnitude of the benefits of action to mitigate SLCPs – in scale, cost-effectiveness and speed of impact - and argued the case for early international action. Studies show that taking into account all anthropogenic BC sources, and the influence of all co-emitted substances from these sources, the integrated warming effect is negligible. For this reason the UNEP/WMO assessment of BC and tropospheric ozone took a different approach – it only identified those measures that reduce BC but which also reduce net warming of the atmosphere. It did this by concentrating on those measures that reduced the emissions of short-lived warming substances (especially BC, but also CH_4, carbon monoxide and non-CH_4 VOCs) to a greater extent than they reduced the emissions of cooling substances (sulphur dioxide, organic carbon and NOx). Efforts to reduce SLCPs should therefore focus on a subset of BC sources, and also on the CH_4 sources which are large contributors to global warming (UNEP, 2011a), while seeking synergies in air quality improvement and climate change mitigation. UNEP led research also looked into the impact of HFCs and the reduction or use of alternative technologies (UNEP, 2011b). HFCs are mainly used as coolants in refrigeration and air conditioning such as in motor vehicle air conditioning, domestic and commercial refrigeration and cold storage, and blowing agents in insulating foams, and to a lesser extent, in some aerosol, fire suppression, and solvent applications. HFCs are powerful greenhouse gases that are currently increasing rapidly and if no action is taken to halt emissions, it is estimated that global HFC emissions could amount to up to 8.8 Gt CO_2 equivalent[1].

With the introduction of a series of released reports by UNEP, the SLCP studies at the international level have been stepwise refined and have recommended a global rapid implementation of a number of BC, CH_4 and HFC measures that would provide a significant reduction in the rate of warming over the next few decades, as well as preventing millions of premature deaths and avoiding the loss of millions of tonnes of four staple crops

1 Guus J. M. Velders, David W. Fahey, John S. Daniel, Mack McFarland, & Stephen O. Andersen (2009) The large contribution of projected HFC emissions to future climate forcing, PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA 106:10949-10954. And Velders G. J. M, et al. (2012) Preserving Montreal Protocol Climate Benefits by Limiting HFCs, SCI. 335:922-923.

(UNEP/WMO 2011). In 2012, the US Environmental Protection Agency (USEPA) submitted the Report to Congress on BC (USEPA, 2012), emphasizing BC as an important air pollutant and climate pollutant. The Report noted that the BC emissions have a negative impact on air quality, human health and crop yields and are mainly distributed in Asia, Africa and Latin America. Studies have shown that diesel combustion is an important source of the BC emissions (Jacobson et al., 2013). BC and its co-emitted pollutants lead to the formation of fine $PM_{2.5}$ which is a major cause of disease and premature death (Lim et al., 2012). The prevention of near-term warming brought about by implementing the SLCPs strategy can reduce impacts on threatened ecosystems and highly vulnerable areas including glaciers and snowfields, such as the Himalayas and the Arctic. According to the joint report of the World Bank and the International Cryosphere Climate Initiative (ICCI) (World Bank & ICCI, 2013), BC-included SLCPs in China can move with atmospheric circulation to the Tibetan Plateau, the Himalayas and the Arctic and exert a negative impact on ice and snow melt, snow and ice albedo, and near-term temperature rise. Meanwhile, the heat produced in China can affect the atmospheric temperatures of sensitive areas through heat circulation. In that sense, the reduction of emissions resulting from implementing SLCP strategies, especially on some specific sources of them, is crucially important in terms of mitigating near-term climate change and the impacts. This is because changes of emissions of CO_2 and other long-lived greenhouse gases do not rapidly change the concentrations in the atmosphere, as they can remain in the atmosphere for hundreds of years. This is why the SLCP strategies can affect climate in the near-term, but reducing GHGs is required now to protect the climate in the long term. Fortunately, all of the SLCP measures identified already exist and have been implemented to some extent and have been shown to be very cost-effective measures and, indeed, many of the CH_4 measures are expected to pay for themselves over the lifetime of the technologies implemented.

In China, holistic research on SLCPs has not taken place. While the studies on SLCPs, particularly socio-economic analysis, remain limited, current knowledge is able to identify key sources and mitigation options. Further research findings about emissions and source apportionment will be needed to support some of the decisions on integrated control and focus action in the most cost-effective manner. Considering air pollutants, research has progressed with regard to emissions, source apportionment, impact, abatement technologies and management practices. Chinese policies and actions are lagging behind the research on BC mitigation options. Current studies have noted the importance of BC emissions from the residential sector and the importance of abatement measures in this sector (Chen et al., 2009). BC has been considered as a component of $PM_{2.5}$ in air pollution source analyses (Cao et al., 2011; Zhang et al., 2013). A group of studies on the health impact of $PM_{2.5}$ dedicated an analysis to BC (Huang and Zhang, 2013). Overall, China has kicked off the analysis of urban point sources of BC based on PM capture and infrared monitoring. However, the dataset, mainly provided by the meteorological departments and environmental inspection departments, is unable to show the whole picture of BC emissions in major cities and rural areas, especially emissions from small and scattered sources and non-road sources. Research on the impact of BC is lagging behind, among which the health impact studies related to exposure of $PM_{2.5}$ based on epidemiological statistical methods have a small sample size and a relatively short time span.

CH_4 statistics and accounting rest on the First and Second National Communications on

Climate Change which provide cross-sectional data of the years 1994 and 2005 respectively. With regard to the CH_4 inventory, relative scattered findings have been made covering agriculture (rice, ruminant, livestock manure management), landfill (solid waste and waste water), and fossil fuel development and production (coal, petroleum, natural gas), with reference to IPCC Guidelines for National Greenhouse Gas Inventories. On CH_4 abatement technologies, studies have probed into technologies for the control of low-concentration coal mine gas (Han and Ying, 2012; Liu et al., 2013; Han, 2013). The factors of CH_4 and nitrous oxide (N_2O) emissions from urban solid waste and wastewater and the abatement technologies are also discussed (Liu et al., 2014; Ma et al., 2014; Cai et al., 2015). There are also studies of measures and technologies to address CH_4 in agriculture.

Regarding the HFCs research, the statistical data are mainly sourced from projects under the Clean Development Mechanism (CDM), of which the statistics on actual emission have been collected from 2013 onwards, but are not yet publicly available. Existing studies have covered the reduction of and alternatives to HFC-23 (Cui et al., 2013), HFC-134a and HFC-142b, and the general strategy of HFCs abatement (Lin et al., 2014; Hu et al., 2014; Han et al., 2015).

(II) NRMS

NRMS mainly include construction machinery, agricultural machinery, vessels, and aviation, etc. In China, the NRMS population shows a rising trend with the acceleration of urbanization and infrastructure construction. There were more than six million pieces of construction machinery at the end of 2013 in China and the average annual growth rate exceeds 10%. NRMS emissions become increasingly prominent in the absence of effective control. Studies have shown that on-road and NRMS account for 60% and 40% of NOx emissions respectively, while the latter has a larger role in the primary $PM_{2.5}$ emissions. Construction machinery, agricultural machinery and vessels are the three most important sources of NRMS emissions.

In the context of China, the construction machinery includes excavators, loaders, forklifts, rollers, bulldozers and graders, of which the former three take up 22.0%, 28.5%, and 28.0% respectively. In October 2010, China implemented US EPA Tier 2 emission standards to NRMM regardless of power difference. In this phase, NRMM mainly integrates the turbocharging and intercooling technology which improves combustion efficiency by increasing the intake pressure and reduces emissions, in particular NO_x, by intercooling. With the rapid development of shipping industry, China has occupied a dominant position in water transport in the world. In 2013, the cargo throughput reached 11.8 billion tons and vessels have become a major source of air pollutants in port cities (see Box 1-1). According to the range of activities, vessels can be divided into inland vessels and ocean-going vessels. Currently, the regulation of vessel emissions is largely absent (except for engines smaller than 37kW) with no specific emission standards adopted, resulting in a very grim situation of vessel sourced air pollution control. In addition, the marine engine technology is also very outdated, and naturally aspirated engines are still used in inland vessels. These are responsible for poor fuel economy, but also a significant increase in exhaust pollutants.

Europe and the US have paid attention to NRMS since the 1990s. Studies show that non-road machinery and vessels are an important factor affecting human health and climate change. To this end, Europe and the US applied the Tier 1 emission standards to non-road machinery in 1996 and over time the standards were ratcheted down with Tier 4 being the current standard.

US also started regulating PM, NOx, HC and CO emissions from domestic vessels with the introduction of the Tier 2 standards between 2004 and 2007, and started phasing in Tier 4 standards in 2014. EU implemented State IIIA standards (equivalent to US Tier 2) for inland waterway vessels in 2007, and proposed Stage V standards that should require the use of wall flow filters to control PM and BC emissions. On ocean going vessels, the International Maritime Organization (IMO) also began to regulate NO_x emissions in 2000 and later, SO_2 emissions, and currently, the regulation follows the Tier 2 emission standards. In order to reduce emissions from in-use machinery, the European and US governments require constantly reducing the sulfur content of fuel and introduce economic subsidies and incentives to encourage non-road machinery to adopt new technologies. Diesel particulate filters (DPFs) which are effective in removing PM and BC have been widely used in California and Switzerland, but its applicability to different kinds of machinery needs further testing. In terms of testing and measurement, Europe and the US have begun to use the portable emissions measurement system (PEMS) to test emissions in the actual conditions, rather than the past regulatory conditions. PEMS produces data about actual emissions in mechanical operation, which helps to better understand and grasp the actual level of emissions from non-road machinery.

To reduce emissions from vessels, clean fuels and shore power are favored. The Clean Fuels Program require vessels to use low-sulfur diesel fuel in the ECAs prescribed in Europe and North America, in order to reduce the SO_X emissions and PM generated indirectly (and reductions in NOx in North America only, starting 2016), which is in line with the IMO's MARPOL Annex VI requirement. Furthermore, the North American ECA also requires reductions in NOx emissions from new vessels built starting in 2016 and operating in the ECA. The use of shore power in berthing vessels can effectively reduce emissions of auxiliary shops, thereby reducing pollution in the port area.

Box 1-1 Serious NRMS air pollution in Chinese port cities

Shanghai is the economic center of China, the core city of the Yangtze-River Delta and one of China's transportation and shipping center. Shanghai Port is the busiest container port in the world, with the cargo throughput in 2013 reached 780 million tons and a container throughput of 35 million TEU. Currently, Shanghai owns a total amount of approximately 90,000 non-road machinery with an annual diesel consumption about 500,000 tons. With the rapid development of urban construction and port logistics, emissions from shipping and non-road machinery become more and more significant, comparing with the decreased emission from industrial and motor vehicles sectors under stricter pollution control strategies. According to the data analysis of tonnage between port entry and exit, international ocean-going vessel accounts for the highest proportion of 51%. Inland vessels in the outer harbor waters, coastal vessels and inland river vessels account for 23%, 19% and 7%, respectively. In view of the pollutants emissions inventory, container shipping contributes to the highest share of 30% in all types of ocean-going vessels, followed by bulk carriers and tugs. In all types of the machinery, about 35-55% are old machinery of more than 8 years and complied with only "China 0" standard. Among the total emission of NOx and the primary $PM_{2.5}$ in Shanghai, shipping and non-road machinery contribute 30% and 7%, respectively. Based on the source apportionment of $PM_{2.5}$ in 2013, shipping and non-road machinery emissions contribute to 7-10% of the city's $PM_{2.5}$ concentrations, showing the important impact on air quality. Meanwhile, using the residual oil, heavy oil or diesel as the fuel, shipping and non-road machinery produce more BC (one major SLCP) with total share of 20%; among which, shipping contribute 13%. Therefore, strengthening the pollution control on NRMS will not only benefit the comprehensive air pollution in cities, but also provide a significant co-benefit on the reduction of SLCP.

As the third largest container port of the world, Shenzhen port (one major port in Pearl-River Delta Region) also faces the prominent problems of air pollution due to large emissions from ships. In 2014, the annual consumption of heavy fuel oil by the ocean-going vessels into Shenzhen Port was about 200,000 tons, with the annual $PM_{2.5}$, NO_x and SO_2 emissions as high as 1,250, 14,300 and 12,000 tons, respectively. They accounted for 5%, 16% and 59% of all emission sources in Shenzhen; and the emissions from container ships are the largest contributor to shipping pollution, accounted for about 74%. According to the $PM_{2.5}$ source apportionment results in Shenzhen, in 2014 the annual mean concentration of $PM_{2.5}$ was 36 $\mu g/m^3$, in which the primary emissions from ocean-going vessels contribute to about 5% (2 $\mu g/m^3$). The primary emissions from vessels have a higher contribution in summer, with the $PM_{2.5}$ concentrations varied between 2-4 $\mu g/m^3$; and have a lower contribution in winter with the $PM_{2.5}$ concentrations varied between 1-3 $\mu g/m^3$. Considering primary emissions and secondary conversion together, the contribution of vessels to annual mean $PM_{2.5}$ concentration accounted for about 13% (5 $\mu g/m^3$), among which local vessels contribute about 2 $\mu g/m^3$. Air quality modeling analysis indicates that vessel emissions will lead annual mean SO_2 and NO_2 concentrations to increase by 4 $\mu g/m^3$ and 8 $\mu g/m^3$, respectively.

II. International Policy Actions and Experience Analysis

(I) SLCPs

In recent years, new international initiatives to promote taking action to reduce emissions of SLCPs have emerged. Recent scientific assessments coordinated by UNEP were instrumental in raising awareness of the benefits in addressing SLCPs both for the near-term climate protection and clean air benefits. In February 2012, the Climate and Clean Air Coalition to reduce Short Lived Climate Pollutants (CCAC) was launched by 6 governments and UNEP as a first global effort to address SLCPs. It has since grown to include more than 100 partners. The Coalition, a voluntary international framework for concrete and substantial action, is a partner-led effort to accelerate and scale up action on SLCPs by catalyzing new actions as well as highlighting and bolstering existing efforts. The Coalition partners have identified seven sector[2]-based initiatives that could yield immediate and scaled-up climate and clean air benefits by reducing SLCPs (CCAC, 2014).

As the Arctic is disproportionately affected by SLCPs such as BC, the Arctic Council has undertaken several technical and scientific assessments in this area, as well as recommendations for policy makers on mitigation opportunities related to BC and CH4, and a number of pilot and demonstration projects. Recently, in April 2015, Arctic States agreed to a *Framework for Action for Enhanced BC and CH4 Emissions Reductions,* which commits Arctic States to take action, and it also calls on Arctic Council Observer States to join Arctic States in these actions. The Framework focuses on such things as the development of inventories, reducing emissions, regular reporting to the Arctic Council, sharing best practices, and enhancing scientific cooperation.

International efforts have also been proposed to address HFCs under the Montreal Protocol, as most HFCs are used as replacement to ozone depleting substances being phased out under the Montreal Protocol. All CCAC partners are dedicated to taking actions to reduce SLCPs. Specifically, the European Union (EU) and the United States take SLCPs and air pollution into combined consideration, emphasizing the associated health benefits as a policy focus. The EU has identified BC as a separate measure of air quality and rolled out strict abatement and alternative policies. HFC-134a shall no longer be used in all vehicles in EU since 2011, according to EU Mobile Air-Conditioning Directive. The United States and Canada have adopted stringent emission standards for diesel engines found in non-road machinery. As part of Canada's Air Quality Management System, new, more stringent ambient air quality standards for PM have been developed to inform policies and measures to address BC emissions from industrial sources and non-industrial sources. In addition, international efforts have increased, with regard to the regulation of CH4 from the oil and gas sectors. For example Canada, the United States and Mexico have announced their intent to regulate these

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[2] The seven sector of CCAC activities to reduce SLCPS emissions are 1) heavy duty diesel vehicles and engines; 2) brick production; 3) municipal solid waste sector; 4) promoting HFC alternative technology and standards; 5) oil and natural gas production; 6) agriculture and; 7) household cooking and domestic heating. Cross- cutting efforts include: 1) financing of SLCP mitigation; 2) supporting national planning for action on SLCPs ; 3) Regional assessments of SLCPs. Further information can be found at: http://www.unep.org/ccac/Initiatives

sources. In Canada, the government has announced the development of controls on the manufacture, import and use of HFCs. The United States is also committed to landfill CH4 reduction and high GWP HFCs alternatives. It has designed the Biogas Roadmap to encourage CH4 recovery and utilization and the Natural Gas STAR Program to address CH4 emissions from oil and gas exploration, production, transmission and distribution. Mexico incorporates SLCPs into the National Special Program on Climate Change (2014-2018) and both Mexico and Chile have committed to achieving reductions in BC of 70% by 2030 in their Intended Nationally Determined Contributions（INDCs）. A number of other countries, including Morocco, have included SLCPs in their INDCs. Bangladesh, Colombia, Nepal and other mountainous countries have launched plans about BC emission inventories and reduction actions.

(II) NRMS

For Europe and the US, the NRMS emissions are still too high. The study of California showed that NRMS accounts for 14% of the NOx emissions in the state. In the US, the new non-road engines are currently subject to the Tier 4 emission standards which keeps the CO limits, but tightens the limits on HC, NOx and PM, compared with previous standards. In terms of emission control technologies, the Tier 4 emission standards intended to require exhaust after-treatment. Among them, DPFs which can effectively remove PM[3] and SCR can greatly reduce the formation of NOx. In terms of certification, the NRMS engines are tested on the Non-Road Transient Cycle (NRTC) and must pass the 1,000-hour durability test. In Europe and the US, low-sulfur diesel fuel is also a common requirement for NRMM. In addition, the US implements an NRMM registration system to grasp the actual situation of emissions. Under this system, each machine has an identity number which is installed in a prominent position on the fuselage so users can identify the emissions limits to which the machine was certified by querying the identity number. Meanwhile, financial subsidies are allocated to encourage the installation of after-treatment devices in old machinery to reduce emissions. It is worth noting that Portable Emission Measurements Systems (PEMS) has been used in compliance testing and inspection in Europe and the US. PEMS performs well in measuring emissions under the operating conditions of construction machinery, which makes up for the deficiency in regulatory conditions.

Europe, the US and Canada have realized the impact of vessels on human health and the environment and taken measures to control air pollution caused by vessels and ports. To address emissions from ocean-going vessels, the International Maritime Organization (IMO) develops SOx, PM and NOx emissions standards. ECAs have been created in the Northern Europe and North America (except Mexico). Among them, ECAs in the North Sea and Baltic Sea focus on SOx emissions; and North America and the Caribbean Sea ECAs, SOx and NOx. Vessels shipping and docking in the ECAs of North America and Europe shall ensure the sulfur content of fuel below 10,000 ppm which was reduced to 1,000 ppm (0.1%) in 2015. The limit is much lower than the world average sulfur content of fuel for vessels (25,000 ppm,

[3] Some manufacturers have been able to meet the standards without the use of DPFs and regulators are considering an additional tightening of the requirements.

2.5%) (Smith et al., 2015) and the upper limit for global marine fuel (35,000ppm, 3.5%). Since 2016, all newly-built ocean-going vessels that operate in North America and the US Caribbean Sea ECAs (waters within 200 and 50 nautical miles from shoreline respectively) shall cut the NOx emissions by 75% compared with existing ones. The ECAs are expected to be highly effective: The EU ECAs, America ECAs are expected to result in health and environmental benefits worth four times and 10 times the cost of compliance, respectively. (AEA, 2009; USEPA, 2010). The above-mentioned regulations and incentives have promoted the development and application of alternative fuels and advanced emission control technologies in the shipping industry. In particular, main ports in North America and EU offers incentives to promote the use of clean shipping and port technologies and practices that go beyond regulatory requirements, and for example, leading ports like Los Angeles and Long Beach reduced diesel PM by over 80% in less than a decade as a result. (Port of Los Angeles, 2014; Port of Long Beach, 2015). As sulfur content of fuel becomes lower, shipping companies are trying to reduce the SOx and NOx emissions by installing after-treatment devices, and some have applied SCR and Exhaust Gas Recirculation (EGR). In addition, liquefied natural gas (LNG) as an alternative marine fuel has attracted increasing attention. LNG has an advantage over the low-sulfur fuel in NOx, SOx and PM emissions, but also price in North America and Europe. Given this, more and more European ports have begun to scale up LNG facilities. In addition, a number of ports in Europe and North America encourage, even mandate that ocean-going vessels use shore power when docking and reduce speed, in order to further reduce emissions in the port area.

III. Policy Actions and Challenges Facing China

(I) SLCPs

In recent years, the Chinese government has released many laws, regulations, policies and action plans on air pollution prevention and greenhouse gas mitigation. In 2013, the Air Pollution Prevention and Control Action Plan was released as a milestone of the national actions in these areas. And in August of 2015, the lately amended Law of the People's Republic of China on Prevention and Control of Atmospheric Pollution is another significant national action, in which some very detailed air pollution prevention measures are stressed. These actions and measures will greatly reduce the air pollution and achieve some co-benefits in the reduction of SLCPs emissions. However, China has no dedicated policy actions to address SLCPs.

An SLCP strategy focuses on sources of emissions from incomplete combustion where the balance of all emissions indicates that the measures will reduce climate warming in the near term. These measures include emission reductions through coal policies covering clean coal combustion or fuel substitution outside the power sector which will reduce significant emissions of BC. Examples include residential stove and industrial furnace improvement, lowering emissions from diesel vehicles, vessels and non-road machinery. In particular, the Chinese National Improved Stove Program (NISP) vigorously promoted by Ministry of Agriculture (MOA) (Smith and Keyun, 2010) sets an example for the global action to improve stoves. Moreover, the Chinese Government has also rolled out a series of national standards to improve combustion efficiency and reduce emissions. All such policy actions, though not specific to BC, can simultaneously reduce BC emissions from different sources.

All measures that reduce methane will reduce near-term warming and ozone formation. Research has been conducted on rice production, animal manure management, urban waste, industrial waste water and coal bed methane (CBM). However, policy actions are aimed at increasing resource utilization, with CH_4 emission reduction as a by-product of policy effects, rather than a concerted and coordinated effort to comprehensively reduce methane emissions. Among the policy actions, the Rural Biomass Energy Industry Development Plan (2007-2015) and the National Rural Biogas Construction Plan (2006-2010) issued by MOA in 2007 established the principles and objectives for biogas development; the 12th FYP for National Economic and Social Development stressed the need to accelerate biogas development. Fugitive CH_4 emissions from fossil fuel extraction, storage and transport have not yet been robustly addressed (though there has been some initial progress on coal-bed CH_4 utilization).

China has been making efforts to reduce the emission of HFCs. It is known that China has committed itself to reduce its HFC production, consumption and emission by using various options, especially by being actively involved in the negotiation and implementation of the Montreal Protocol and by various bilateral agreements. It is worth mentioning that China binds itself to an HFC emission reduction target in its "Energy Conservation, Emission Reduction, Low Carbon Development Action Plan for 2014-2015" issued by State Council, which estimated that about 0.28 billion tons of CO_2 equivalent will be reduced during 2011-2015. China has already issued two batches of central budget investment plan of HFCs reduction major demonstration projects to support relevant enterprises building HFC-23 combustion facilities. Next step, China will continue to organize the yearly subsidy arrangements for HFC-23 emission reduction before 2019, develop non-carbon dioxide greenhouse gas emission standards and abatement action plans, promote the improvement of relevant laws and regulations, and accelerate the research and development of HFCs alternative technologies, aiming to achieve effective control of HFC-23 emissions by 2020. In addition, emission of HFC-23 has been reduced significantly (over 0.44 billion tons of CO_2 equivalent) by enterprises via the CDM mechanism.

(II) NRMS

In the regulatory aspect, China implements Tier 2 emission standards for construction machinery. In Europe and the US, however, Tier 4 emission standards prevail, requiring new machinery integrated with post-processing technologies (DPF, SCR, etc.). China lags even more behind in the regulation of emissions from domestic vessels, as it has not yet issued the relevant emission standards. Europe is now implementing Stage IIIA standards for all inland waterway vessels (which is equivalent to US Tier 2 standards.) The US is now phasing in Tier 4 emission standards for Category 1 and 2 engines for domestic vessels to further reduce NO_x, PM, CO, HC emissions. The MEP is now developing a regulation that will control air emissions from marine engines (at or above 37 kW) for use on inland waterway vessels, sea-river vessels and coastal vessels. The proposed Stage I and II standards are equivalent to the US Tier 2 and 3 standards for Category 1 and 2 marine engines. Even if China Stage I standard were enacted in 2017 as proposed, China's standards would still be at least 10 years behind those enforced in the US and EU.

In the aspect of NRMS management, China has not yet introduced the law on the prevention and control of construction machinery pollution. The ongoing management system lacks unified monitoring and regulatory requirements, making it impossible to identify the actual level of emissions of non-road machinery. The mandatory retirement system for construction machinery has not been established. At this stage, there is a considerable amount of old machinery (older than 10 years), of which engines are poorly maintained, giving rise to large emissions. In regard to mechanical transformation, government departments have not yet introduced support policies and incentives. Similar to the case of construction machinery, the regulation of marine engine emissions remains absent. The regulation of vessels currently relies on the Department of Marine Management of Ministry of Transport (MOT) and focus on sewage discharge.

In terms of fuel quality, construction machinery mainly uses regular diesel fuel which has high sulfur content (up to 350 ppm, while that of road on-road diesel contains less than 50 ppm). The quality of fuel-oil used by vessels is worse. At present, ocean-going vessels entering the country largely use heavy fuel-oil with sulfur content as high as 3.5% (35,000 ppm).wt. High sulfur content results in huge SO_2 and PM emissions from vessels. In Europe and North America, however, four ECAs have been established, where vessels are required to use lower-sulfur fuel oil (sulfur content less than 0.1%) in order to reduce SO_X emissions. California is phasing in a mandate on the use of shore power for the purpose of reducing emissions at berth.

IV. Findings and Recommendations

Overall, China is facing many challenges in controlling of SLCP and NRMS pollution. Among the challenges is an absence of specialized regulations and standards; a lack of overall consideration to collaborative governance of conventional air pollutants and SLCPs; inadequate technology research and development, promotion and application; weak research base and insufficient statistical data supporting policy-making. This includes a lack of an official and comprehensive emission inventory for all sectors and emitted substances. Therefore, the following two areas need to be strengthened.

(I) Strengthening the scientific research and technology development on SLCPs and NRMS

It is suggested to strengthen the research on the integrated effects of SLCPs on air quality and climate change, and carry out in-depth research into emission sources, emission characteristics, environmental impact and emissions reduction potential of SLCPs and NRMS strategies. The Government should expand investment in the independent research on BATs to control SLCPs and NRMS emissions, such as development, demonstration and commercialization of advanced engine and after-treatment technologies (SCR/DPF, etc.) applicable to NRMS and research, development and demonstration of advanced technologies and equipment for monitoring emissions and concentrations.

(II) Fully drawing on advanced international experience and promoting international cooperation in emission control and governance

It is suggested to strengthen experience sharing in SLCPs and ECAs under existing international governance mechanisms, and fully refer and use the mechanisms of multilateral cooperation on SLCPs governance, including the Global Methane Initiative (GMI), Climate and Clean Air Coalition (CCAC), and the Global Alliance for Clean Cookstoves (GACC). By way of intensive involvement in relevant actions and mechanisms, China can not only gain direct benefits, but also strengthen its voice and influence in international affairs. Furthermore, China should set the agenda to develop, in line with national conditions and in the interest of public welfare, the SLCP control plan and introduce relevant policies.

China lags far behind the European and American counterparties in the level of NRMS emissions control and needs to quicken the alignment with international standards. It is suggested to refer to the successful experiences of Europe, the US and Canada in NRMS emissions control, including speeding fuel, tightening implementation of cleaner fuels, the emissions standards to reduce emissions of new machinery, strengthening the supervision of new machinery and in-use machinery, encouraging mechanical technological upgrading, synchronizing regulations and developing incentives to promote cleaner fuels and emission control technologies, setting up ECAs in key port regions and encouraging key ports to implement clean port plans.

Chapter II Status and Industrial Characteristics of SLCPs and NRMS Emissions in China

I. Status and Industrial Characteristics of SLCPs Emissions

(I) BC and its Co-emissions

In China, BC mainly comes from incomplete combustion of coal, biomass, motor vehicles, and in particular from heating and cooking activities in rural areas. It is estimated that China's BC emissions (excluding Hong Kong, Macao and Taiwan) during the years from 2000 to 2008 were 0.963-1.811 million Mt per year. There are large emissions of fine particles from coal combustion and straw and firewood burning in the residential sector as a combined result of low temperature and insufficient oxygen (i.e. giving rise to incomplete combustion) relative to large industrial boilers and power plant boilers (where the combustion is more complete), and inadequate or no corresponding control measures. It is generally believed (Cao et al., 2006) that the residential sector presents a high BC emission factor and is responsible for 40%-85% of the estimated BC emissions (Zhi et al., 2011), and the control of residential sources can effectively cut the BC emissions in the short term. In latest emission inventories (Cao et al., 2011), industrial coal and fuel combustion accounts for approximately 30%-40% of the estimated total BC emissions and should also be brought under control. Relevant data are presented in Table 2-1.

The estimates of BC emissions are quite uncertain due to the lack of localized, measured emission factors, especially data about coal and straw used as energy sources in rural area (Bond et al., 2004; Zhang et al, 2009b) and the emission inventory uncertainty is generally above 100%. Experiments conducted in developing countries show that the emission factors of both vehicles and straw in rural areas are higher than estimated (Shen et al, 2010; Subramanian et al, 2009; Wang et al., 2012).

Table 2-1 BC emissions inventories in different studies (10,000 tons)

Emissions inventory	Year	Industry	Power	Household	Biomass burning	Transportation	Total
Zhang et al., 2013	2008	69.50	1.16	63.60	6.77	19.46	160.49
G. et al., 2003	2000	8.89	0.68	78.07	11.24	5.98	104.86
Ohara et al., 2007	2000	9.9	1.8	93.8		3.8	109.3
Lei et al., 2011	2005	61	1	70		19	151
Zhang et al., 2009	2006	57.5	3.6	100.2		19.8	181.1
Cao et al., 2011	2007	52.9	1.3	65.1	10.4	14.5	139.9
Wang et al., 2012	2007	64.6	5.07	98.8	7.77	18.8	195.7
Lu et al., 2011	2008	51.0	1.9	88.8	11.0	25.9	178.7
M. et al., 2014	2007			39.2		8.6	96.34

Multiple aerosol particles and precursor gases are emitted into the atmosphere together with BC, and the synergistic effect deserves further study. Among these substances are POA, SO_2, CO, NOx, and VOCs. Relevant research shows that the emissions of CO, NOx and VOCs from the residential sector accounted for 34%-43%, 5.6%-11% and 16%-33% of the total. The importance of understanding the emission of all substances and the impact of measures upon them are not only from the perspective of near-term warming, where the balance of emissions of substances that affect radiative forcing is important. It is also from the perspective of $PM_{2.5}$ pollution, where the emissions of several substances that give rise to $PM_{2.5}$ and ozone concentrations can be affected by the SLCP measures implemented.

(II) Tropospheric Ozone-related Emissions

Carbon monoxide, NOx and VOCs are sometimes co-emitted with BC. These are the precursor gases with that lead to O_3 formation under the action of sunlight. Together with methane, CO also controls the background levels of ozone, and the peaks are mainly related to non-CH_4 volatile organic compounds (NMVOC) and NO_X distributions. In 2010, China's NOx emissions totaled 25.82 million tons, of which power plants, industrial boilers and road traffic were responsible for 31%, 18% and 17% respectively. Compared with 2005, the total emissions in 2010 showed an increase of 34.3%, of which road traffic, industrial boilers and cement sector contributed 24.6%, 21.7% and 19.3% respectively (Fig. 2-1). There is also an intense interest in NO_2 in Europe, where it is believed that it is responsible for a greater impact on health than previously thought.

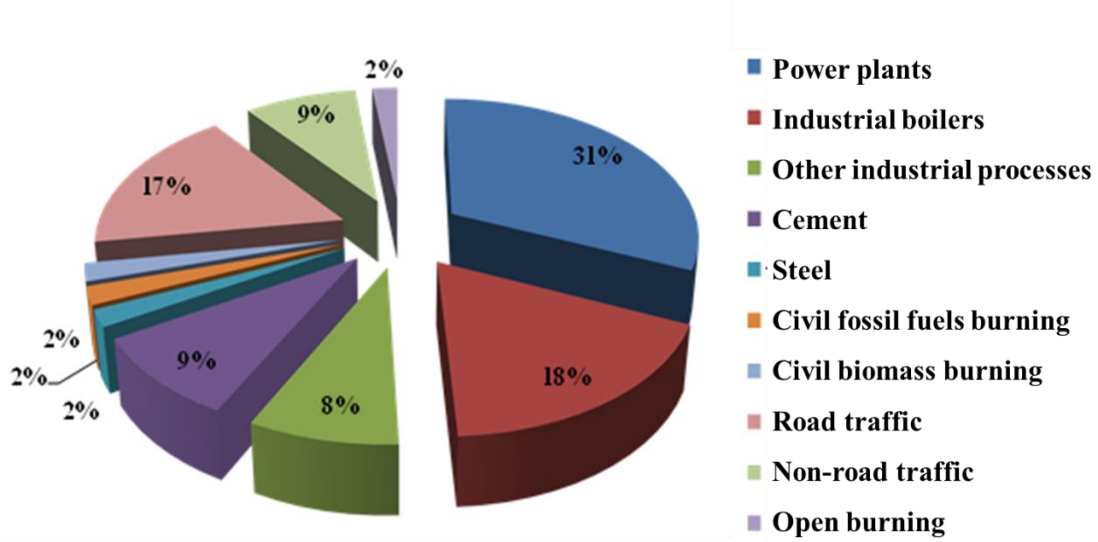


Fig. 2-1 China's NO_x emissions sources and distribution in 2010

According to Zhao et al (2013), China's NMVOC emissions amounted to 22.86 million tons in 2010, of which industrial processes, industrial solvents and household burning accounted for 25.0%, 24.4% and 18.8% respectively (Fig. 2-2). Compared with 2005, there was an increase of 21.0% in total, of which 90% was sourced from industrial solvents. While the VOC emissions arising from the use of industrial solvents grew by 102%, the emissions from households and road transport sector declined with the implementation of vehicle emission standards and the gradual control of biomass direct combustion.

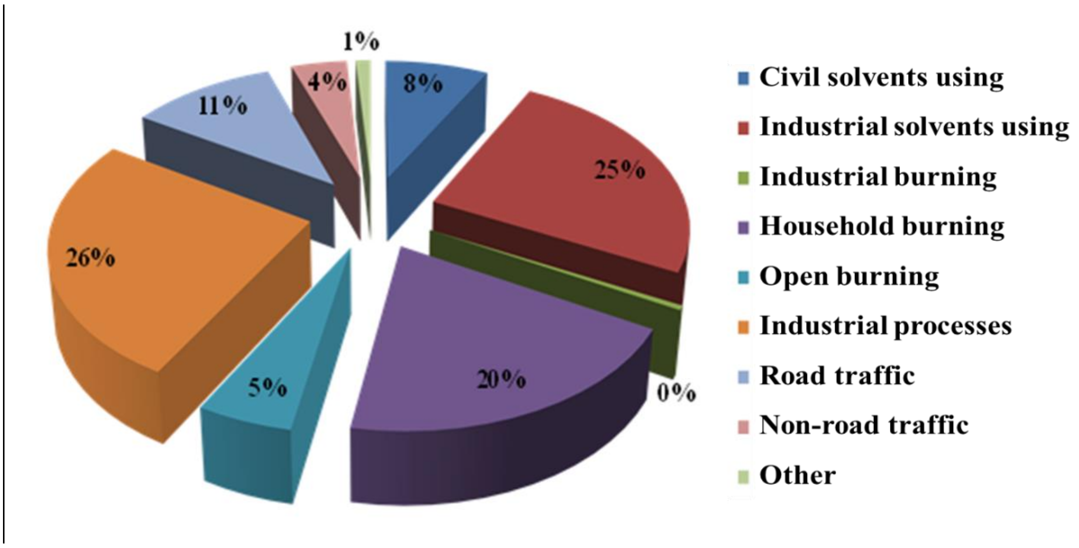


Fig. 2-2 China's VOCs emissions sources and distribution in 2010

(III) CH_4

Atmospheric CH_4 comes from natural sources and anthropogenic sources, where the former include wetlands, termites, oceans, vegetation and CH_4 hydrates and the latter include coal mining, natural gas production, landfills, livestock, rice paddies and biomass burning (Olivier et al, 2005.). According to the Fifth IPCC Assessment Report (IPCC AR5), up to 50%-65% of the global CH_4 emissions in the past 30 years can be attributed to anthropogenic sources (Change, 2013).

The Second National Communications of the People's Republic of China on Climate Change said that in 2005, CH_4 emissions amounted to 930 $MtCO_2e$ in China, taking up about 12% of the national GHG emissions. USEPA suggested that China's CH_4 emissions totaled 920 $MtCO_2e$ in 2010, equivalent to about 13% or so of the global total, and per capita emissions were less than that of the world's top two emitters: the United States and India (Zhang and Chen, 2014). An SLCP strategy would place further emphasis on reducing methane emissions rapidly, as from the following text, it is clear that there is a lot of opportunity for further methane emission reduction in China.

It is worth noting that, based on estimates in 2010, coal mining, enteric fermentation, rice cultivation and sewage treatment have become the major sources of CH_4 emissions, accounting for 83% of China's total CH_4 emissions, and among them, coal mining takes up the largest share, which can be regarded as the situation in China.

1. CH_4 from energy-related activities

Zhang and Chen (2014) estimated that energy-related activities contributed up to 45% of the national CH_4 emissions in 2007, of which coal production, biomass burning and oil and gas production took up 38%, 5.3% and 1.6% respectively (Zhang and Chen, 2014). USEPA (2012) estimated that in 2010, the CH_4 emissions from energy-related activities reached 383.3 $MtCO_2e$ (USEPA, 2006), accounting for about 42% of the national total. In recent years, CH_4 emission sources and their proportion change little in China, and the energy sector remains the largest contributor through coal production, oil and gas production, and fossil fuel combustion (including fixed and mobile sources), as well as biomass burning. In 2010, the key CH_4-emitting sources in the energy sector were coal production (295.5 $MtCO_2e$; 32%), biofuels (48.5 $MtCO_2e$; 5.3%), and oil and gas production (4.2 $MtCO_2e$, 0.5%).

CH_4 emissions from coal production are concentrated on coal mine methane (CMM) extraction. From 2006 onwards, the extracted CMM increased at an annual rate of 1.0 billion m^3. In 2014, the national CMM extraction attained 13.26 billion m^3, of which 4.53 billion m^3 was utilized, up by 503% and 466 % respectively compared to 2005 (Figure 2-3). Gas extraction exceeded 200 million m^3 in 10 provinces, namely Shanxi, Guizhou, Anhui, Henan, Chongqing, Heilongjiang, Sichuan, Liaoning, and Shaanxi. The volume even hit 5.534 billion m^3 in Shanxi, accounting for 42% of the national total.

Currently, CMM is mainly used for residential and industrial fuel, power generation and vehicle fuel. From 2006 to 2014, a cumulative amount of 24.66 billion m^3 CMM was used, equivalent to 29.85 million tons of standard coal savings and 369.90 $MtCO_2$ of GHG emission reduction. In 2020, the national drainage volume will reach 20 billion m^3, 60% of which can be used, according to the Action Plan for CBM/CMM Exploration and Development issued by National Energy Administration on February 2, 2015. By then, the CMM installed capacity will exceed 4000 MW and CMM benefit more than 6 million families, posing a huge potential of emission reduction in the coal field.

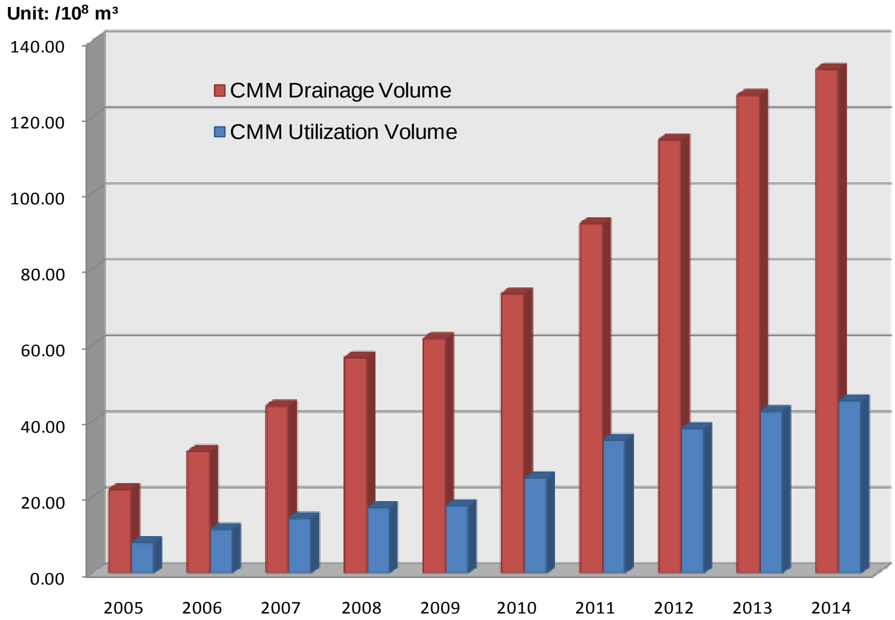


Fig. 2-3 China's CMM drainage and utilization volume, 2005-2014

Due to complex conditions and low permeability of coal seam, the CMM drainage rate and concentration remain low in China, though recoverable CMM has increased significantly in recent years. According to statistics, the current national CMM drainage rate averages about 30% and the CMM with a concentration of less than 30% accounts for 70% of the total. In 2014, the national CMM utilization rate was only 34.2%, basically the same as 2007, and about 8.73 billion m^3 was directly discharged into the atmosphere. Low drainage rate results in a huge quantity of low-concentration (less than 1%) ventilation air methane (VAM). In 2014, the CH_4 emitted into the atmosphere via the ventilation systems, i.e. VAM, registered at 20 billion m^3.

2. CH_4 from agricultural activities

In 2010, China's agricultural sector contributed 358 $MtCO_2e$ CH_4 emissions, representing 39% of the national total, and became the second largest source of CH_4 emissions. The emissions from enteric fermentation, rice cultivation, manure management and biomass burning (crop residues) registered at 212.5 $MtCO_2e$, 124.6 $MtCO_2e$, 20.1 $MtCO_2e$ and 1 $MtCO_2e$ respectively, taking up 23%, 14%, 2.2% and 0.1% of the total.

3. CH_4 from urban solid waste

In 2007, Zhang and Chen, 2014 estimated that 14% of China's CH_4 emissions came from urban waste, including urban solid waste landfills, industrial waste water and urban wastewater, with a share of 8.2%, 4.1% and 1.5% respectively.

(IV) Some HFCs in China

Due to data constraints, HFCs in China mentioned herein include: (1) HFC-134a in the automobile air conditioning industry; (2) HFC-410A (mixture of HFC-125 and HFC-32 with equal proportion) from room air conditioning systems; (3) HFC-23 unintentionally produced and emitted during hydrochlorofluorocarbon (HCFC)-22 productions.

1. HFC-134a in the automobile air conditioning industry

HFC-134a is mainly applied in mobile air conditioners, refrigeration equipment, refrigerators and pharmaceutical aerosols, wherein the latter two accounts for a small proportion (less than 100 tons annually for refrigerators and to be replaced). Hence, the focus is put on the automotive air conditioning industry.

Figure 2-4 shows HFC-134a annual emissions in the automotive air-conditioning industry and emissions in each link of the life-cycle process of mobile air conditioners during 1995-2010 (Su et al., 2015). Total HFC-134a emissions increased at an average annual rate of 53.3% from 30 tons in 1995 tons to 16,700 tons in 2010, and the consumption further expanded with CFC-12 phase-out in the automotive air-conditioning industry and the rapid development of automobile industry. In the life cycle of mobile air conditioners, the maintenance and repair process sees the largest HFC-134a emissions, accounting for about 80%, which is largely related to the high maintenance and repair rate and immediate discharges of remaining refrigerants in the process.

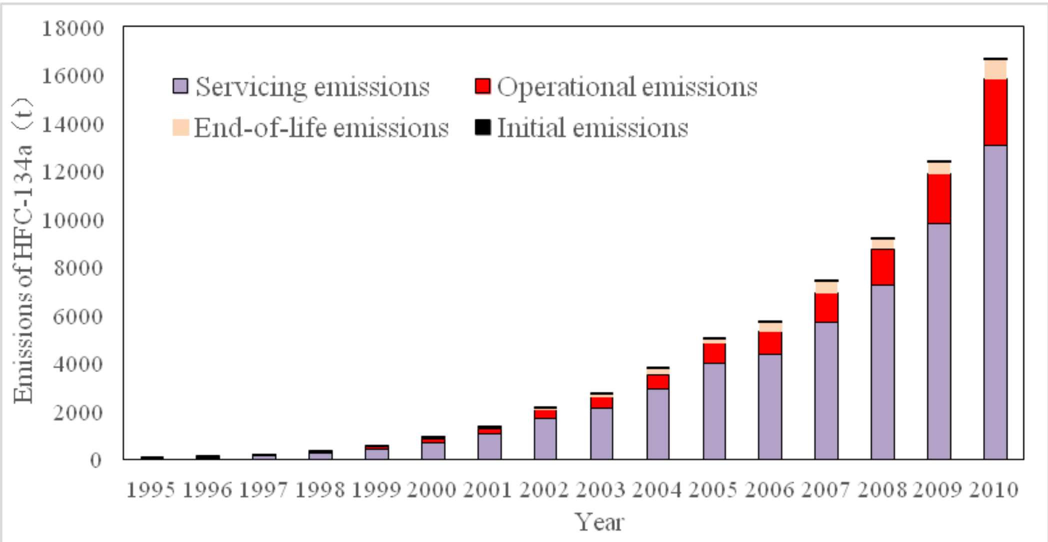


Fig. 2-4 HFC-134a emissions in the lifecycle of automobile air conditioners, 1995-2010 (tons)

2. HFC-410A from room air conditioning systems

HFC-410A is a mixture of HFC-125 and HFC-32 in equal proportions with a combined GWP value of 2060 and is mainly used as refrigerant in room air conditioners.

Figure 2-5 shows HFC-410A annual emissions in the room air conditioning systems and emissions in each link of life-cycle process of room air conditioners during 2006-2014 (Su et al., 2015). Total HFC-410A emissions increased at an average annual rate of 175% from 127 tons in 2006 tons to 11,000 tons in 2014. It is a result of substantially increased use in room air conditioners for exports to Europe and the United States and supply in China after the phase-out of HCFC-22. In the life cycle of room air conditioners, the maintenance and repair process sees the largest HFC-410A emissions, accounting for nearly 59.6%, while the proportion of the operation, retirement and production processes register 30.6%, 6.7% and 3.1%, respectively.

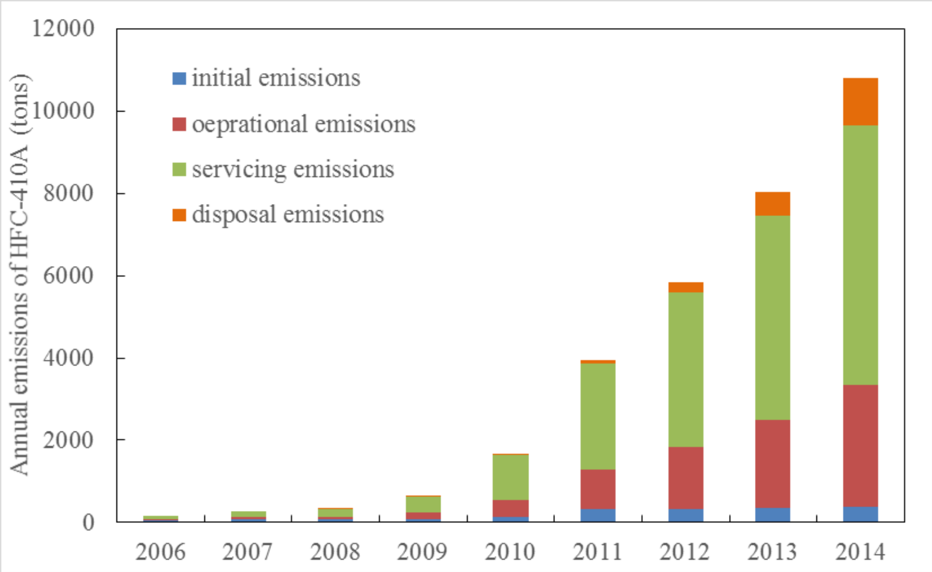


Fig. 2-5 HFC-410A emissions in the life cycle of room air conditioning systems, 1995-2010 (tons)

3. HFC-23

HFC-23 production, incineration and emission in China during 1980-2012 (Fang et al., 2014) are shown in Figure 2-6, where global emissions are drawn from top-down estimates (1980-1989) and bottom-up estimates (1990-2008) (Miller et al., 2010), as well as predictions for the future (2009-2012) (Miller and Kuijpers, 2011). The results showed that the HFC-23 production expanded from 0.08 ± 0.05 Gg/yr in 1980 to 15.4 ± 2.1 Gg/yr in 2012, with a particular fast increase of annual production in the late 1990s. The annual growth of HFC-23 production reached 0.04 Gg/yr during 1980-1990, 0.18 Gg/yr during 1990-2000 and 1.1 Gg/yr after 2000.

HFC-23 production and emission are not always equal. Prior to 2006, the emission was almost equal to production, but became smaller with the launch of CDM projects that destroyed HFC-23 from 2006. During 1980–2012, HFC-23 emission peaked at 10.5 ± 1.8 Gg/yr in 2006, but fell down to 7.3 ± 1.3 Gg/yr in 2008 and 2009, followed by gradual increase to 8.5 ±2.1 Gg/yr. In 2012, up to about 45% of HFC-23 was destroyed (incinerated).

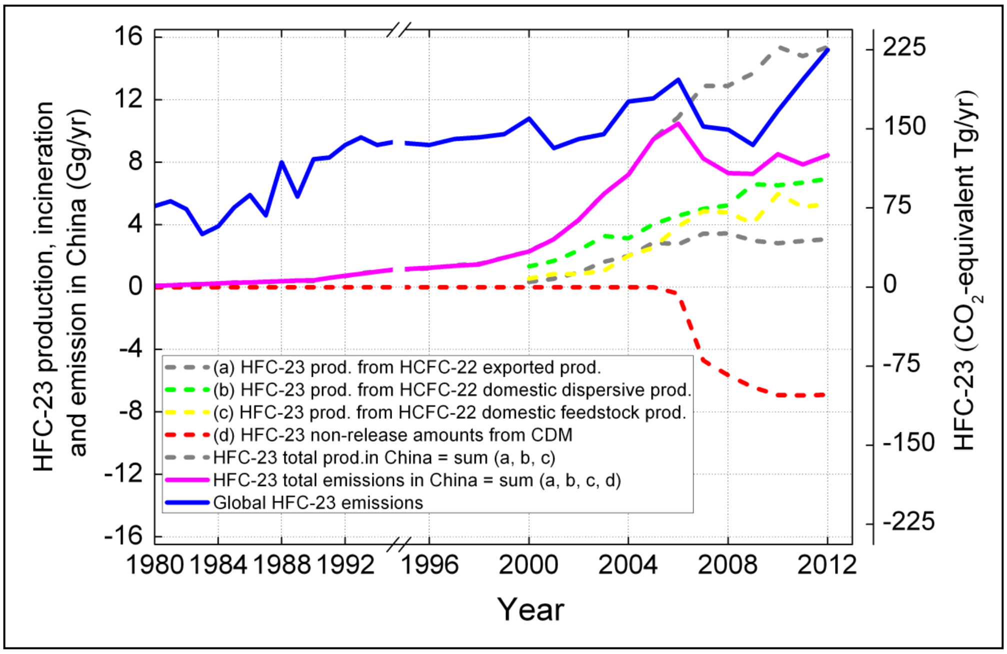
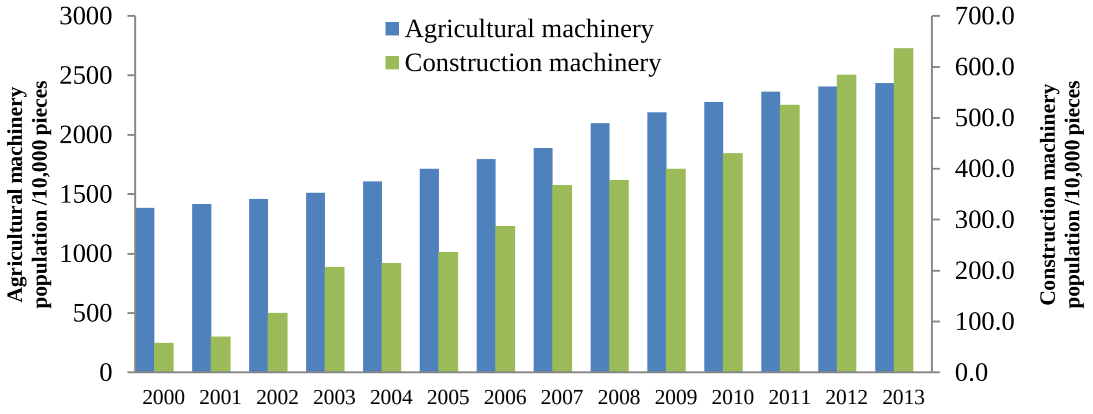


Fig. 2-6 HFC-23 production, reduction and emission in China, 1980–2012 (Fang et al., 2014)

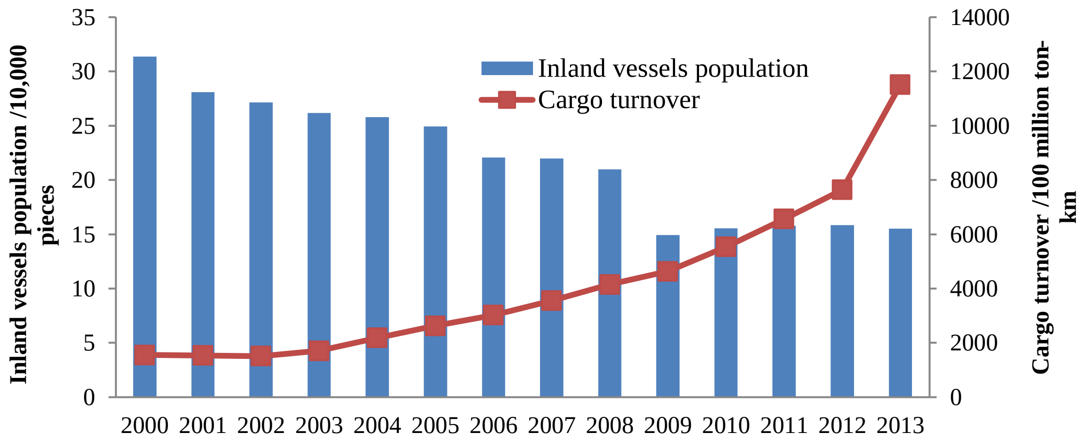
II. Status and Industrial Characteristics of NRMS Emissions

NRMS includes construction machinery, agricultural machinery, inland and ocean-going vessels, internal combustion engines for railway, portable generators, aviation, forestry machinery, and small gasoline engines. Construction machinery is the general term of machinery used for construction. In the process of rapid urbanization, there is a substantial growth in total operating time of construction machinery every year. Agricultural machinery mainly covers farm power, tillage, farmland construction, agricultural irrigation, plant protection, harvesting, planting and fertilizing, livestock production, agricultural product processing and agricultural transport. The number of agriculture machines in China is very high and they have very weak pollution control requirements. In China, civilian vessels include fishing vessels and transport vessels. According to the application of vessels, transport vessels can be divided into passenger ships, general cargo ships, container ships, oil tankers and chemical tankers, etc. and by sailing area, they are divided into river vessels, coastal vessels and ocean-going vessels. Emission from vessels have a significant impact on urban air quality and public health, particularly given the fact that major coastal ports and river ports are mainly located in developed, densely populated cities.

By the end of 2013, construction machinery population totaled 6.1-6.6 million in China. As shown in Figure 2-7 (a), the population of construction machinery was on fast rise during 2000-2013. Agricultural machinery population amounted to 24.35 million in 2013, the population of agricultural machinery during 2000-2013 is shown in Figure 2-7 (a). Inland vessels numbered 155,000 in 2013. As shown in Figure 2-7 (b), despite a decline in the number of inland vessels, the cargo turnover exhibited an upward trend during 2000-2013, implying that vessels develop towards large capacity.



(a) Agricultural machinery and construction machinery population /10,000 pieces

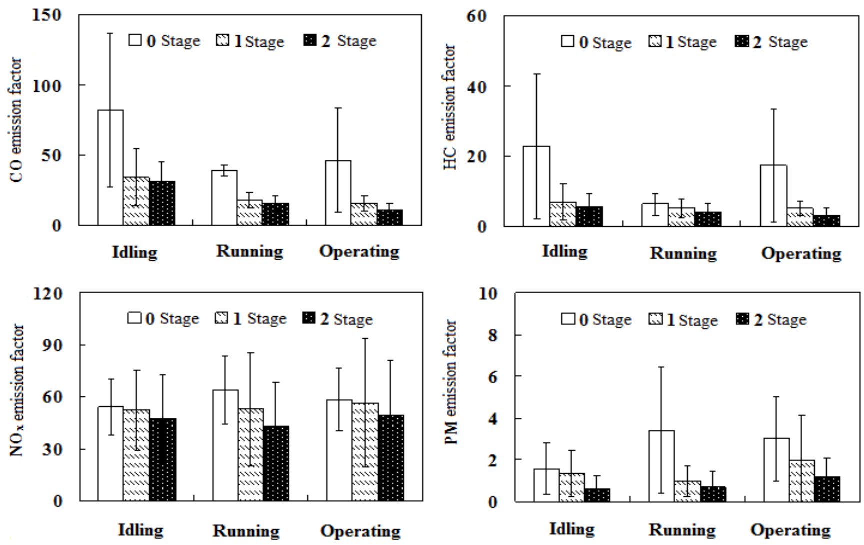


(b) Inland vessels (10,000) and cargo turnover (100 million ton-km)

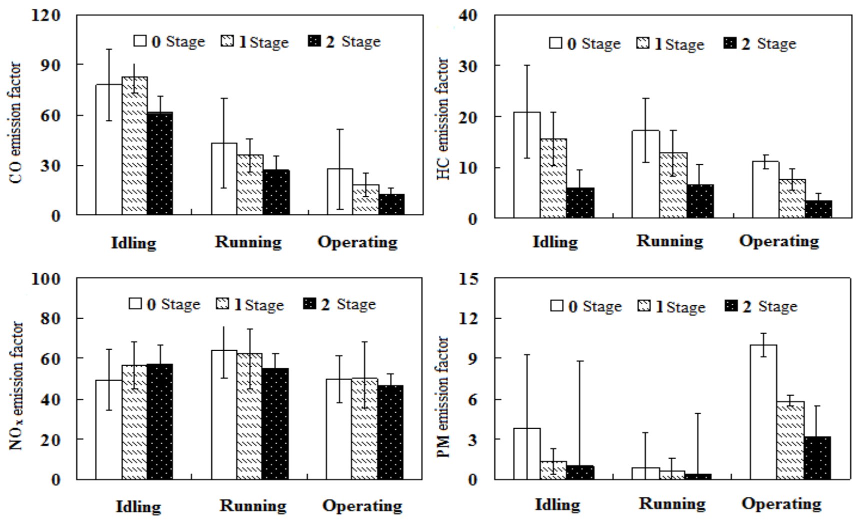
Fig. 2-7 Population of typical non-road machinery, 2000-2013

The studies on mobile source emissions in recent year have mainly focused on road motor vehicles while the study of emissions from non-road machinery is basically in its infancy. With the effective control of vehicle emissions, emissions from non-road machinery start to attract attention. For a systematic assessment of emissions emitted by non-road machinery, the Beijing Institute of Technology (BIT) and its partners conducted emission tests on 45 construction machinery products with different power, including 16 excavators, 19 loaders, 7 rollers, 2 bulldozers and 1 grader, under actual operation state. Rotary tractors and combined harvesters were selected for emission tests under the actual operation state according to the actual usage of agricultural machinery in rural areas. Given China's extensive network of inland waterway, heavily trafficked waterway systems, and numerous lakes, Jiangsu section of Beijing-Hangzhou Grand Canal and the Guangzhou section of the Pearl River, the most developed river systems in China, were selected for real ship emission test. The actual emission factors of non-road machinery are obtained through tests mentioned above.

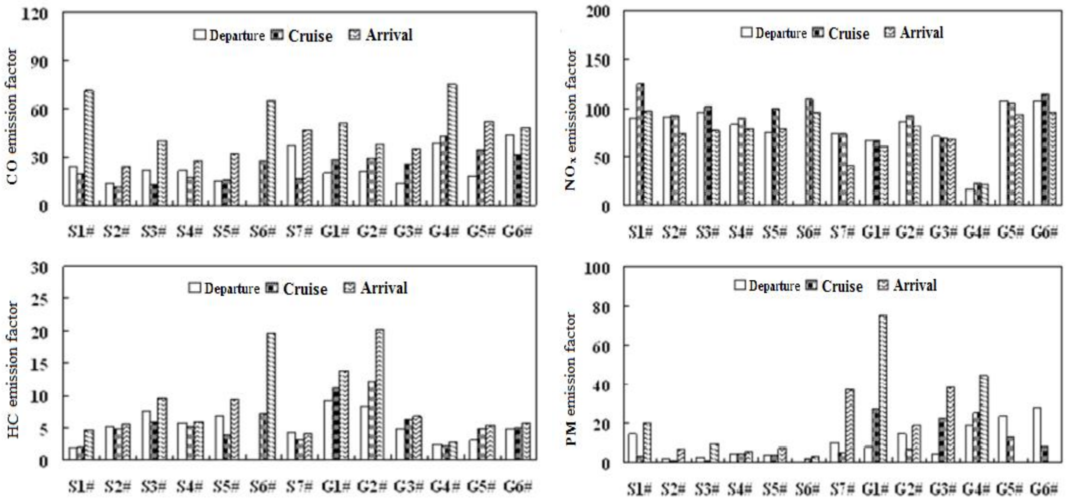
According to the test results of non-road machinery emission factors based on fuel consumption (Figure 2-8), CO and HC emission factors are at their highest in idle conditions of construction machinery, while NO_x and PM, in operating conditions. The emission factors of various pollutants increase with power. With the implementation and tightening of the NRMM diesel engine regulation, the emission factors based on fuel consumption are drastically reduced. From Tier 1 to Tier 2 stage, CO, HC, NO_x and PM measured emission factors are reduced by 8.5%-29.1%, 17.8%-36.7%, 8.9%-19.3% and 31.2%-53.3% respectively. Agricultural machinery were tested in farmland in idle, walking and operating conditions. Among emission factors based on fuel consumption, CO and HC emission factors reached the maximum in the idle conditions, NO_x in walking conditions and PM in operating conditions. In operating conditions, NO account for over 93% of the total NO_X emission due to relatively larger load of diesel engine. From Tier 1 to Tier 2 stage, the CO, HC, NO_x and PM emission factors in rotary tillage reduced by 32.4%, 56.9%, 7.2% and 44.9% respectively.



(a) Fuel-based emission factor of construction machinery (g/kg fuel consumption)



(b) Fuel-based emission factor of agricultural machinery (g/kg fuel consumption)



(c) Fuel-based emission factor of inland vessels (g/kg fuel consumption)

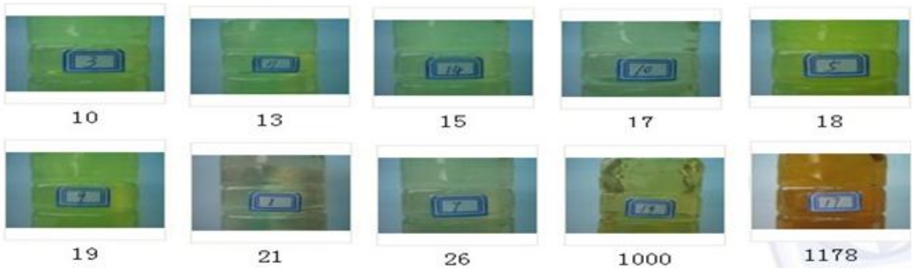
Fig. 2-8 Observed emission factors of construction and agricultural machinery and inland vessels in China

It should be noted that the measured emission factors of non-road machinery in China are generally higher compared with the test results of other countries, which can be attributed to backward emission control and poor oil quality of diesel used by diesel engines. A sample survey of the quality of diesel actually used by diesel engine of non-road machinery was conducted in Beijing and the surrounding area, as described in Box 2-1.

Based on emission factor obtained from above-mentioned experimental tests, combined with fuel consumption of various NRMS in China, the Vehicle Emissions Control Center (VECC) and BIT produced the NRMS emissions inventories of the main pollutants, as shown in Figures 2-9 and 2-10. According to the calculation results, the ratio of the NO_x emissions from non-road and on-road mobile sources is close to 4: 6, wherein construction machinery, agricultural machinery and inland vessels are major contributors. NRMS accounts for a larger proportion of the primary $PM_{2.5}$ emissions than on-road mobile sources, and among all the mobile sources, agricultural machinery, construction machinery and inland vessels are the most responsible. It is clearly urgent to intensify the control of emissions from non-road diesel machinery.

Column 2-1 Survey on current diesel fuel market for non-road machinery

A sample survey of sulfur content of diesel sold in 30 stations was carried out in Beijing, mainly located along the 4th-6th Ring Roads, the Beijing-Yanqing section of G110National Highway, and Beijing-Zhuozhou section of G107 National Highway (pictures of some sample shown below). In addition, a sample survey of sulfur content of diesel actually used by diesel engine was carried out. Diesel samples were taken directly from various operating construction machinery covering all kinds of construction machinery in 20 sites distributed in Beijing, Tianjin, Hebei. The results showed significant price differences and refined oil market turmoil. Low-quality oil is much cheaper and small oil workshops are common which cannot guarantee oil quality. The vast majority of samples have the sulfur content greater than 400ppm, and low-sulfur diesel is found only in Beijing samples, coexisting with high-sulfur diesel.



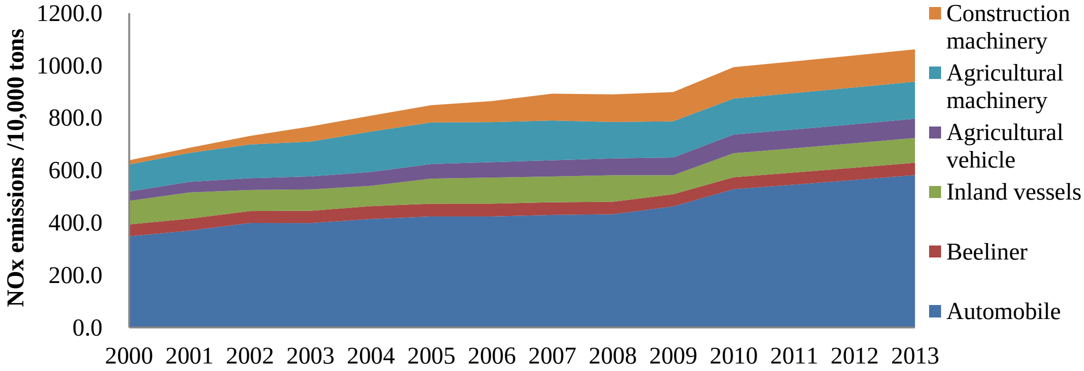


Fig. 2-9 Estimated NO_x emissions from diesel machinery (10,000 tons) in China, 2000-2013 (note: beeliner is locomotives)

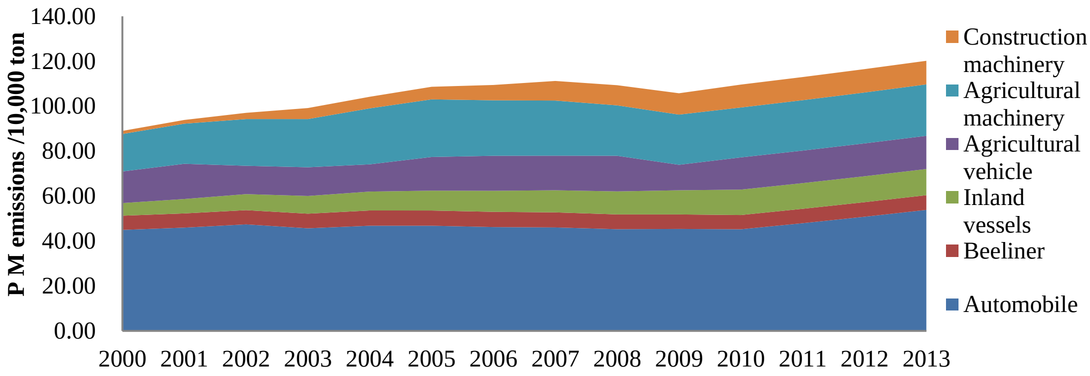


Fig. 2-10 Estimated PM10 emissions from diesel machinery (10,000 tons) in China, 2000-2013

III. Findings and Recommendations

(I) Establishing a sound basic data compilation and accounting system for SLCPs and NRMS emissions

Complete emission inventories for SLCPs or NRMS have not been included in the pollution statistics for China, and the relevant data, scattered in various studies, are not systematic and comparable, or able to support the science-based policy formulation. It is suggested to establish a sound basic data compilation and accounting system for emissions relevant for SLCPs and NRMS that is consistent with the system for other atmospheric pollutants and on-road mobile source emissions. It is also necessary to strengthen the quantitative assessment of co-benefits of multi-pollutant and multi-source reduction, and also the study on analytic methods.

The research on integrated effects of removing multiple pollutants (SO2/NOx/POA/BC) on climate should also be strengthened.

(II) Strengthening capacity building of environmental protection department and emission compliance management

Environmental protection departments should strengthen capacity-building to improve the management of SLCPs and NRMS. It is suggested to build a monitoring and regulatory network targeted at major SLCPs and NRMS emissions and an NRMS fuel quality regulatory network. Penalties for excessive or illegal emissions should be raised while more stringent emissions standards and measures are put in place.

A big data platform for monitoring and control decision-making and a mechanism for scientific and regulatory data disclosure and sharing are also favored.

(III) Cutting sharply the SLCPs emissions in key industries and sectors

Effective reduction measures for black carbon are mainly identified as: decreasing the use of lump coal in the suburbs and rural areas in the residential sector, cutting down black carbon emission of diesel engines in the transport sector, reducing black carbon emission of small and medium industrial boilers in the industrial sector. For the methane reduction, it is a good way to improve the extraction and utilization efficiency of coal mine methane in the suburbs and rural regions.

(IV) Upgrading the NRMS regulation

Accelerate adoption of stricter non-road diesel emission standards, import a variety of effective diesel emissions control technology by strengthening the standard, and reduce emissions of newly manufactured non-road diesel engine.

It is suggested to establish an NRMS registration system and non-road diesel emissions periodic inspection system; define regulatory responsibilities for the whole life cycle of NRMS; accelerate the phase-out and updates of old machinery, and carry out the studies and pilots on technological innovation for non-road diesel engine.

It is also necessary to strengthen the non-road diesel engines (including engines on domestic ships) and diesel fuel quality management, narrow the gap between ordinary diesel and automotive diesel, and strengthen upgrading the quality of marine fuel oil and the use management.

Chapter III Analysis of SLCPs and NRMS Control Technologies & Emission Reduction Potential

I. Analysis of SLCPs Control Technologies & Emission Reduction Potential

(I) Black Carbon

The UNEP and the WMO (2011) proposed nine major measures that at global scale would reduce global emission of BC and co-emitted substances. Generally speaking, such measures include DPF applied to modern engine technology, prohibited use of high-emission vehicles, shift from lump coal to briquettes in households, energy-efficient stove alternatives, clean fuel alternatives, prohibition of open burning of agricultural residues etc. BC emission measures can be grouped into those that aim to eliminate or reduce the use of fossil fuels for some uses, those that aim to improve fuel combustion efficiency, and those that apply end of-pipe technologies. All the measures provide air pollution and climate benefits through reducing all emissions from these sources, including BC.

BC emission reduction technologies in the residential sector are mainly identified as follows: the first one is about stove improvement (stoves with high combustion efficiency); second, improve coal type in the suburbs and rural areas by shifting from lump coal to briquette coal; third, try to avoid the use of bituminous coal with medium maturity & higher ash content; fourth, facilitate community central heating system in the suburbs and rural areas; fifth and finally, substitute lump coal in the rural areas with clean energy such as electricity, solar energy and biogas. The research of Zhi et al. (2009) shows the emission of PM, organic carbon and BC can be brought down efficiently by burning honeycomb briquette in updated stoves. According to the research conclusions, China will be able to reduce the emission of PM by 63%, organic carbon by 61% and BC by 98% if the stoves are updated efficiently and uses honeycomb briquette in civil use sector. It is also discovered in this research that the improvement measures decrease the emission rate of BC / organic carbon and help slow down climate warming.

In the industrial sector, BC discharged by coke production accounts for over 50%, followed by brick production, use of industrial diesel and other industrial use of coal. The latest coke industry admittance standard of China, issued by the Ministry of Industry and Information Technology (MIIT), was implemented in April, 2014. It requires applying coal-based gas cleaning measures, including desulfurization and denitrification, to coke ovens, which greatly improves the efficiency of BC emission reduction, and applying BC control measures such as CDQ (Coke Dry Quenching) technology to facilitate $PM_{2.5}$ reduction. In accordance with Emission Standard of Air Pollutants for Brick and Tile Industry (GB 29620-2013), brick kilns are required to install electrostatic precipitators and fiber filters on the end-of-pipe process, so as to reduce $PM_{2.5}$ emission effectively and cut BC emission efficiently. Dust removal, desulfurization and denitrification in the power sector also play an important role in reducing the BC emissions. Measures of reducing BC emission in those industrial sectors taking diesel or coal as fuel range from fuel switching, use of clean energy, optimization of combustion technology and installation of end-of-pipe treatment facilities (such as de-dusting by ventilation, static, wetness and fiber) (CLRTAP, 2012). Since January 2015, China has imposed limitations on the use of coal with over 30% of ash and over 1.5% of sulfur, which provides favorable policy support for cleanliness of future fuel consumption and promotes BC emission reduction.

In the transport sector, technical measures to cut the BC emissions include emission control of new vehicles and non-road mobile devices, control of heavy-duty diesel vehicles, and fuel and energy conversion for heavy-duty vehicles. Presently, China adopts the national emission standard IV for new heavy diesel engines. Improving from III to IV, China raises its emission standard for PM from diesel engines from 0.1g/kWh to 0.02g/kWh, reducing emission by 80% (Shao et al., 2014). Accelerating the phase-out and upgrading of old and high-emission vehicles, by retrofitting wall-flow DPFs, is another approach, which reduces emissions of PM by 85% and BC by 90%. Besides, the improvement of the operation of heavy trucks also helps reduce BC emissions. For example, the plan of "Green Freight" was carried out in Guangdong Province, committed to raising the efficiency of freight service and decreasing fuel consumption. Related measures include using energy-efficient engines, low rolling resistance tyres and parts with smaller aerodynamic drag. Additionally, China has been implementing the plan of “Inspection and Maintenance (I/M)”, in order to keep motor vehicle operation at a minimum emission level. In accordance with the Air Pollution Control Action Plan issued in September 2013, National Motor Gasoline/Diesel Standard V (sulfur content ≤10ppm) regarding gasoline and diesel will be implemented in major cities of China by the end of 2015; and it will be carried out throughout China by end of 2016. It is predicted that motor gasoline/diesel standard upgrading will then reduce BC emission by 20%..

China has made great efforts to control the open burning of biomass. The Ministry of Environmental Protection monitors by satellites the daily changes in the distribution of straw fires and provides powerful technical security for the implementation of related regulations. Generally speaking, some technologies, such as straw turnover, bio-produced coal, biogas, biodiesel and deep plough (burying biomass deep under the land), can replace the open burning of biomass and thus reduce the emission of BC and co-emitted pollutants.

(II) CH_4

In China, CH_4 emissions mainly come from fossil energy exploitation, especially oil and gas exploitation (including shale gas) and coal mining. Meanwhile, there is an increasing emission of CH_4 from livestock sector, but the relevant reduction measures are not so clear yet. These can include improved manure management, changes to animal feed, and general improvements in animal husbandry that can decrease the amount of CH4 emitted by kg of meat or liter of milk produced. Measures to reduce CH4 emission from coal production will be mainly discussed in this report.

China attaches great importance to the development and utilization of CMM, takes active part in greenhouse gas emission reduction activities under the CDM, GMI and other cooperative mechanisms and has produced a complete set of technical systems of CMM extraction, transportation and utilization that fits China's coal geology conditions, where civil and industrial use of CMM and high-concentration CMM power technology have been applied widely, low-concentration CMM power technology is becoming mature and key technology breakthroughs have been made in the utilization of VAM and low-concentration CMM purification. See Table 3-1 for more details.

In addition to fossil-fuel related CH_4, intermittent irrigation of rice fields and increasing the capture of fugitive CH_4 from landfills have been identified as control measures that could provide large benefits in China (Shindell et al., 2012).

Table 3-1 China's major technologies of reducing coal mine methane (CMM) emission

Technology	Details	Parameters	Application
Domestic fuel	Domestic fuel technology is to collect, store, transport by pipe network and pressure regulating to urban residential areas the gas in the coalmines, whose concentration is over 40%, to provide residents with daily-use fuel gas for heating up water, cooking, firing boilers and warming.		Applied in many regions, such as Anhui, Guizhou and Shanxi
Industrial chemistry	Industrial utilization includes substituting coal-fired boilers and producing chemical products such as carbon black, methanol and methanal. CMM with the concentration being 40-90% can be used to produce carbon black. Production of methanal by CMM includes direct oxidation and indirect production, where CMM is made into methanol and then oxidized into methanal.		Production of methanol directly by CMM is classified as a state forbidden item currently.
CMM power technology	CMM may produce power by gas-fired turbine or gas-fired engine according to its concentration. The principle is to mix CH_4	Investment reaches 3000-4000	High-concentration gas (>30%) and low-concentration

	and air until they reach the explosion limit (5%-15%) and deflagrate the mixture in the anti-explosion air cylinder for acting that promotes piston motion and drives the synchronous generator.	RMB/kWh generally	gas (<30%) power generations have been major methods of CMM utilization.
CMM purification and compression technology	CMM of high and low concentrations can be used to produce compressed natural gas products through purification and compression, which enlarges the application of CMM. Currently, CMM is processed and purified through adsorption and analytical separation, osmotic separation and low-temperature separation.	About 22 million RMB shall be invested for a compressed gas plant with 20 million m^3 pure CH_4.	
CMM Purification and liquefaction technology	CMM is generally liquefied and used to produce LNG products after being processed by adsorption and analytical separation, osmotic separation and low-temperature separation. LNG cuts down transport cost significantly and transport route can be changed according to gas source and users' demands. What's more, existing natural gas pipelines can be used at peaks.	A CMM liquefaction plant with 20,000 tons annual production consumes about 32 million m^3 pure CH_4 and requires an investment of around 90 million RMB.	
VAM utilization technology	There is a tremendous volume of VAM whose concentration is below 1%. A major measure adopted is evacuation. Available technologies include thermal and catalytic oxidation, and utilization as auxiliary fuel. The first one has been mature and applied in industries.		China Oilfield Shengli Power Machinery Group Company LTD, Megtec and Haroworth have established pilot projects regarding VAM thermal oxidation technology.

(III) Some HFCs

1. HFC-134a emission reduction technology and potential of automotive air conditioners

Substitution technology is mainly applied to reducing HFC-134a emitted from automotive air conditioners. At present, there are five or more kinds of HFC-134a substitutes with a low GWP, namely HFO-1234yf, HFC-152a, CO_2 and hydrocarbons (HCs) etc. Among them, HFO-1234yf system alone has been commercialized, whose production and utilization, however, are expensive due to patent protection. As for China, economic cost, market feasibility and safety risks incurred by slight combustibility should be taken into consideration in the selection of substitution technology. In addition, due to its vast territory, China is likely to raise diversified requirements regarding automotive air conditioning systems. So the substitution technology being developed is of great significance.

Table 3-2 HFC-134a substitution technologies in global automotive air conditioning industry

Substitute	GWP-100yr	Cost of Cooling Agent (US$/kg)	Market Status	Region of Commercialization
HFC-134a (Baseline)	1300	$3-$4	Fully commercialized	Many regions
HFO-1234yf	<1	$20-$30	Commercialized	EU, Japan, Korea, U.S., Canada
HFC-152a	138	$11	Experiment	None
CO_2	1	~$1	Experiment	None
HCs	1.8~5.5	$1-$10	Rejected	None
AC6 mixture	~130	＞HFC-134a; ＜HFO-1234yf	Test	None

Source: Alternatives to High-GWP HFCs (Published by the Institute for Governance & Sustainable Development and in cooperation with the UNEP Ozone Action Team)

Hu et al. (2015) considers no HFC-134a elimination in the automobile industry as the Business-as-Usual scenario (BAU). The consumption of HFC-134a will increase year on year under the BAU scenario and will reach a peak in 2037, after which it will remain around 166,000 tons. Emissions will lag slightly behind consumption, reach its peak in 2038 and then remain around 160,000 tons annually. Two substitution scenarios, namely phasing out HFC-134a from new autos from 2021 to 2025 as elimination scenario A and phasing out HFC-134a from all autos by 2040 as scenario B, are used in this paper. Analysis indicates that if HFC-152a is used as the substitute, totally 4.5 billion tons CO_2-eq emission will be reduced by 2050 under Scenario A and 4.1 billion tons CO_2-eq under Scenario B; if HFO-1234yf is taken as the substitute, totally 5.3 billion tons CO_2-eq emission will be reduced by 2050 under Scenario A and 4.8 billion tons CO_2-eq under Scenario B. It can be seen that HFO-1234yf realizes a bigger emission reduction, compared with HFC-152a.

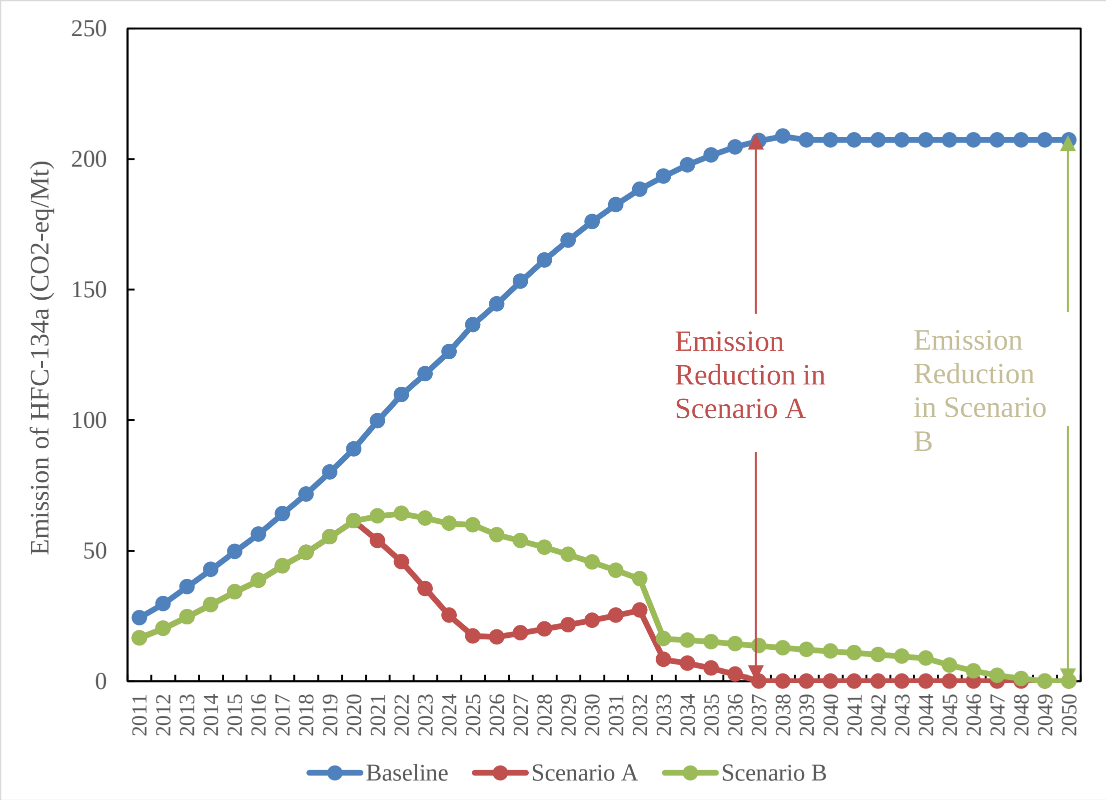


Fig. 3-1 HFC-134a emission reduction potential for automotive air conditioning in China, 2016-2050

2. Emission reduction technology and potential of HFC-410A for room air conditioners

Currently, a major substitute for refrigerant of room air conditioners is a carburetted hydrogen-propane, whose GWP is only 3.3. There are also various lower-GWP chemicals containing mixture of hydrofluoroolefins (HFOs) and HFCs currently being trialed and that are expected to come to the market within a few years. It is anticipated that the use of some of these alternatives will be demonstrated under pilot projects under the Montreal Protocol's Multilateral Fund in the next few years. In addition, a lower-GWP HFC, HFC-32 is already being used in some countries instead of the higher-GWP HFC, R-410AHFC-410A. HFC-32 is available in China, though it should be noted that it still has a GWP of 675.

In 2011, Gree - the largest air conditioner manufacturer of China - launched a production line, with the production being 100,000 propane household air conditioners. Currently, large enterprises are actively promoting the marketization of such products. Godrej, an air conditioning pioneer, has developed HC-290 room air conditioners, whose efficiency is 11% higher than the minimum value of the 5-star energy efficiency specified by India Energy Agency. This research also takes HC-290 as the substitute to predict the future elimination of HFC-410A. Under mitigation scenario A (MIT-A), HFC-410A emission will grow year by year and reach its peak from 2031 to 2037 and then remain at around 150,000 tons. After that, it will fall down substantially and by 2050, be less than 50,000 tons. Under MIT-B, HFC-410 emission will grow at a rate smaller than that under BAU after 2018 and reach the peak of 86,000 tons in 2030, and fall year by year afterwards. HFC-410A emissions in the MIT scenarios are shown in Figure 3-2. For room air conditioning industry, HFC-410A emission trends and emission reductions are different in the MIT scenarios. Using HC-290 as an alternative, the cumulative reductions by 2050 will reach 3.29 billion tons CO_2-eq under MIT-A and 7.74 billion tons CO_2-eq under MIT-B. An important consideration for promoting the wide use of hydrocarbons in air conditioning is the development and implementation of appropriate standards to ensure safety.

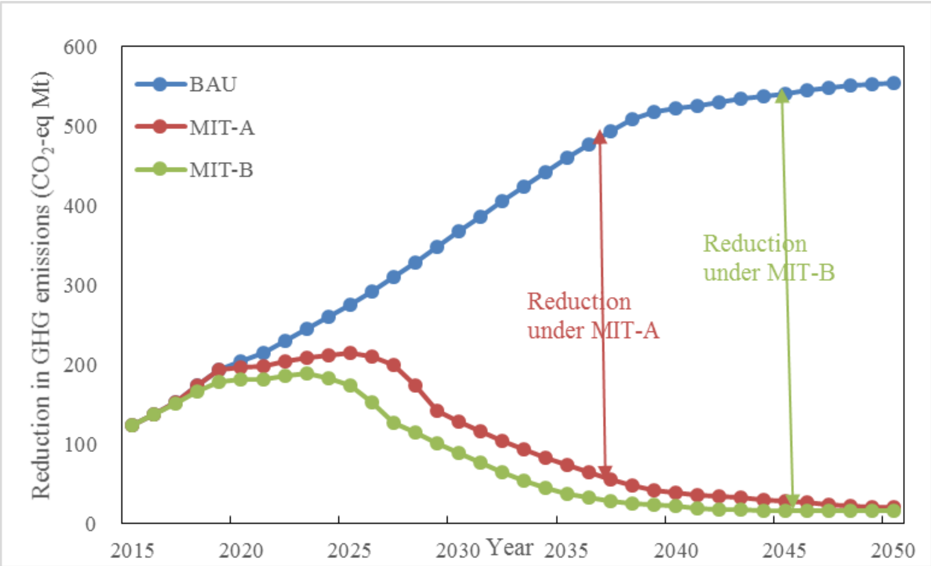


Fig. 3-2 HFCs emission reduction potential for room air conditioners in China, 2016-2050

3. HFC-23 emission reduction technology

HFC-23 emission reduction technology is divided into high-temperature decomposition and trans-utilization (Han et al., 2012). Regarding high-temperature decomposition, mature technology and practical application have been realized. Trans-utilization remains in the exploratory stage (Yang et al., 2014; Han et al., 2014). See Table 3-3 for the technical assessment.

Table 3-3 Major HFC-23 emission reduction technologies

	Method	Basic Principle	Characteristics
High-temperature Decomposition	Thermal decomposition of fuel gas	Decompose HFC-23 in an oxidation container under 1200℃	Post-combustion is needed for keeping temperature due to the low heat value of HFC-23. No Dioxin will be produced if the decomposition temperature surpasses 1200℃.
	Superheated steam decomposition	Replace fossil fuel by an electric heating device to obtain the needed heat	It can be conducted in a small-scale fuel combustor under a relatively low temperature (800-1000℃), with high safety, maintainability, space

			efficiency and energy efficiency.
	Plasma high-temperature decomposition	Decompose HFC-23 under a super-high temperature by argon plasma arc facilities	Swift cooling is involved, which can prevent the formation of such unnecessary organic molecules as dibenzo-dioxin and furan. A large amount of non-degradable gas can be decomposed under a high temperature in the compression reactor. The washing system is more economical.
Trans-utilization	Convert gas by dissociation into C_2F_4 and C_3F_6	Similar to using HCFC-22 as raw material	A higher temperature is required. The low yield can hardly compete with industrial routes. Under proper catalyst effects, reaction temperature can be brought down greatly and yield can be raised. It remains to develop appropriate catalyst.
	React with CH_4 to produce VDF ($CH_2=CF_2$)	Similar with producing VDF via gaseous dissociation of HCFC	C-F is more stable than C-Cl and C-Br and can hardly activate CH_4 to produce the needed CH_3 free radical. Many by-products are brought about.
	React with I_2 to produce CF_3I	HFC-23 and I_2 react in gaseous phase under catalyst to produce CF_3I	CF_3I is most similar to Halon 1301 ($CBrF_3$) in property. It is more expensive to use CF_3I as fire extinguishing agent or freezing medium. Industrial pilot production has been realized by Japanese companies.
	Work as trifluoromethylation raw material to produce drug and other organic intermediates.	Preliminary lab attempt. The process requires rigor conditions and is more expensive. It will take a long time to study it for HFC-23 treatment.	

II. Analysis of NRMS Control Technologies & Emission Reduction Potential

Existing measures to control NRMS emissions include the application of advanced technologies, fuel quality upgrade, and clean energy.

(I) Application of Advanced Technologies

1. Non-road machinery

Currently, non-road machinery mainly integrates the after-treatment devices to meet emission control requirements. Exhaust after-treatment refers to the treatment of exhaust using a variety of filtration and purification devices and catalytic converters to reduce the emissions of various pollutants. To meet the requirements for NOx and PM emission from non-road machinery, engine manufacturers mainly follow two technical routes: exhaust gas regeneration (EGR) + DPF and combustion optimization + SCR. In the first route, the NOX emissions from engines are cut through EGR and PM is trapped in DPF, and to avoid causing regeneration problems and prevent catalyst deactivation, the sulfur content of fuel must be strictly controlled. The second route increases the fuel injection timing to reduce PM emissions and applies SCR to reduce NOx emissions which increase dramatically with combustion temperature. For non-road engines, the application of the second route is faced with such problems as urea supply facilities, onboard urea storage devices, and forced continuous use of urea solution, but it is still a feasible technical program.

2. Vessels

Measures to control emissions from vessels mainly focus on shore power, engine improvement and engine exhaust after-treatment.

1) Shore power technology

The technology realizes the connection through cable between shore power system and power supply system of vessels when docking and turns off the auxiliary power generation of vessels for the purpose of reducing emissions. It has become widely used overseas after being introduced in Gothenburg, Sweden, in 2000. From January 2014 onwards, California requires an increased application of shore power in container ships anchored in ports and cruise ships and refrigerated cargo vessels berthing in ports. According to a directive of EU, the member states are required to, by the end of 2025, put in place shore power supply equipment and facilities in ports, to ensure the shore power supply for ocean-going vessels and inland vessels.

Up to present, shore-based power supply systems have been built in Shanghai Port, Lianyungang Port, Shenzhen Port, Guangzhou Port and Ningbo Port. However, the application is not satisfactory for two reasons: a) the capital and operational costs of providing shore power supply exceed the revenue, and the ports can hardly obtain direct economic benefits from offering shore power supply; b) ocean going vessels lack the motivation to use shore power because the cost of generating electricity using auxiliary engines are less than the cost of using shore power.

According to the newly revised *Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution*, the new ports should build shore-based power; the existing ports should add shore-based power facilities, and the vessels should give priority in use of shore-based power. The *Special Action Plan for the Prevention and Control of Vessel Pollution Control (2015 - 2020),* recently published by Ministry of Transport, proposed that 90% of harbor crafts and government vessels should be equipped with shore power equipment, and 50% of terminals serving container ships, roll on roll of (ro-ro) passenger vessels and cruise ships should provide on-shore power supply by 2020. It is estimated that SOx, NOx and PM emissions will be cut by 2%, 7% and 8% in the Bohai Economic Rim, Yangtze River Delta and Pearl River Delta due to this measurement.

2) Marine engine technology

With advances in marine engine technology, more purification technologies could be used to reduce exhaust emissions. Technology upgrades of newly-built marine engines were based on the tightening of emission standards, and the emission reduction mainly reflected in the upgrading of the ship fleet. The Specifications of Inspection Specification for Ocean and Inland Vessels required that diesel engines of vessels built in and after March 2015 shall meet the IMO Tier II emission standards. The *Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution* raised that the high emission vehicles and vessels scrapping in advance were encouraged and supported by the government. According to the estimated number of old vessels that will be retired and newly-built ones from 2015 to 2020, the NOx emissions will be roughly reduced by 20% in the Bohai Economic Rim, Yangtze River Delta and Pearl River Delta in 2020, compared to 2015, due to the implementation of IMO Tier II standards. However, the *Ship Engine Exhaust Emission Limits and Measurement Methods (phases I and II*) being formulated by the Chinese government, might be more strict than IMO Tier II, which might lead to bigger emission reduction.

3) Exhaust after-treatment technology

Technologies for marine engine exhaust after-treatment, including SCR, SOx scrubber and DPF, are effective in reducing the emissions of in-use vessels. Fast international progress is seen in the vessel-based SCR research and adoption, due to the urgent need to cut NOx emissions and the limited effects of front-end emission control measures. The installation of an SCR system in in-use vessels entails little change to ship equipment, does not cause much impact to fuel economy and does not require high fuel and lubricant quality. It will reduce more than 90% of the NOx emissions without increasing fuel consumption and the PM emissions. Nevertheless, the wide SCR application is confronted with a series of problems, for example, high installation cost and large equipment size that makes it difficult to fit into the engine room. The development of the SCR technology is subject to such factors as exhaust gas temperature control, catalyst deactivation, quantitative urea injection, and exhaust mixture uniformity, so we need to intensify the equipment research and localization.

(II) Fuel Quality Upgrade

The fuel quality has great impact on emissions of non-road diesel machinery. Particularly, the sulfur content of diesel fuel not only directly affects emissions, but also restricts the use of advanced emission control technologies. Reducing the sulfur content of diesel fuel can produce a 10%-15% reduction of PM in exhaust gas. Presently, the quality of diesel used by non-road machinery is uneven in China. Agricultural machinery mainly uses ordinary diesel oil, heavy diesel oil and agricultural diesel oil, while vessels, mainly distillate fuel, residual oil and mixed oil. Fuel oils used by large low-speed vessels have the worst quality. They are commonly derived from recycled oil and industrial waste oil and do not have compelling fuel quality standards to follow. Investigation found that the sulfur content of such fuel oils is up to 2.0%-3.5%, far higher than the level prescribed by on-road diesel standards (50 ppm). Improving the non-road fuel quality is the first step to raise NRMS emissions standards and advance engine technologies.

Setting vessels Emission Control Area and using low-sulfur fuel in particular regions for the purpose of cutting the SOx and PM emissions are adopted by several developed countries. According to The International Convention for the Prevention of Pollution from Ships (also known as the MARPOL Convention) published by International Maritime Organization (IMO), the current sulfur content limit for marine fuel is 3.5%, which will be further lowered to 0.5% in 2020 or 2025.The limit is 0.1% in the ECAs under MARPOL framework, covering the Baltic Sea, North Sea, North America, and the Caribbean Sea.

PM can also be reduced with SOx by using low-sulfur fuel. Ocean going ships switching from residual oil to distillate fuel reduce BC by 30-80% (Litehauz et al., 2012). The newly revised *Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution* regulated that inland vessels and river-to-sea vessels must use standard diesel fuel and the transport competent department have the authority to designate the ECAs off the coast, which can improve the quality of fuel substantially. If ECAs are established in the Bohai Economic Rim, Yangtze River Delta and Pearl River Delta, we calculated huge emission reductions. Specifically, the SOx and PM emissions from vessels will be reduced by 65% and 30% by 2020, respectively, compared to 2015, in accordance with the requirement of fuel sulfur content not more than 0.1% for international and domestic voyage ships and 0.001% for inland vessels.

(III) Alternative Clean Energy

In the context of global climate change and growing energy shortage, biodiesel, as a clean alternative fuel and an important complement to fossil diesel, enjoys great potential. Biodiesel is non-toxic, renewable, and biodegradable, and reduces harmful emissions from diesel engines. It is easy to apply biodiesel which enjoys storage and replenishment convenience due to the small range of movement compared with diesel vehicles.

LNG powered vessels were considered as another effective energy-saving and emission reduction measurement. Internationally, the existing LNG powered vessels mainly use technically mature dual-fuel engines. China has intensified efforts to promote LNG application in vessels and ports and LNG filling systems. Presently, China has transformed 30 LNG powered inland vessels and built more than 10 new vessels. Now, 70 LNG vessels are under construction. LNG has also been used by nearly 700 port-related vehicles and its application in gantries and harbor tugboats is studied. LNG filling systems have also been gradually improved.

Imperfect regulations and standards on LNG powered vessels hamper the LNG integration in ports. Especially the decline of oil prices significantly weakens the motivation of manufacturers to build LNG powered vessels. Under the combined impact, the large-scale promotion of LNG powered vessels is meeting resistance.

(IV) Other Control Measures

Oil vapor recovery technology addresses oil vapor (mainly VOCs) discharged from storage tanks during tanker shipment and has applied in the developed countries. Its application has been made mandatory in certain ports in Netherlands and South Korea, and strict emission standards and technical regulations for oil vapor recovery have been introduced in the US and

EU. In China, however, oil vapor recovery is still in the inception stage, and only about ten units of oil vapor recovery facilities have been installed, but most of them have never been used or have stopped operation due to security and financial reasons.

Speed control is also an effective measure to reduce emissions from vessels, given that the fuel is proportional to the cube of speed. Measurements show that a 10% reduction in ship speed is accompanied by a 15%-20% reduction of fuel consumption and reductions in NOx, SOx, PM and CO_2 emissions. It also helps to cut the operating costs by 8%-10%. However, energy savings and emission reductions brought about by speed control will be limited because ship speed has been restricted in a reasonable range, due to congestion in ports and measures of shipbuilding enterprises driven by significant energy savings.

III. Findings and Recommendations

(I) SLCPs

1. Considering the collaborative control of SLCPs and conventional pollutants

Co-control of SLCPs and conventional pollutants can be achieved by integrating SLCPs into the overall strategy and the target system for air pollution control and climate change mitigation.

2. Developing sound SLCPs control regulations, standards and policies

Effective reduction of SLCPs emissions relies on energy use policies, decreasing the use of lump coal in the suburbs and rural areas, promoting a transition in residential and industrial sectors away from use of coal to efficient and clean energy consumption, comprehensive straw utilization, and facilitating continued decreases in SLCPs emissions from vehicles. Standards for allowances and financial subsidies for CMM utilization should be evaluated and additional reductions in CH_4 emissions from landfills and rice agriculture should be paid more attention. Relevant preferential tax policies should also be further improved.

3. Drawing up a recommended list of measures and technologies for emission reduction

A recommended list of technologies and measures to reduce the SLCPs emissions in China should be drawn up based on analysis and assessment of technologies and measures available in all sectors and recommended by UNEP.

(II) NRMS

1. Accelerating the improvement of engine technologies

To meet more stringent NRMS emission standards, engine manufacturers should apply advanced control technologies to reduce emissions. These technologies cover the optimization of engine block and combustion system, valve timing, and improvement of intake system and cold start performance. High-pressure common rail and turbocharged intercooler which effectively reduce emissions of diesel engines are also needed.

It is necessary to promulgate and apply the *Engine-based Exhaust Emission Limits and Measurement Methods for Ships* (*phases I and II*) to ocean-going, coastal and river vessels according to the upcoming timetable, and to upgrade it to *phases III and IV* when appropriate. With standard upgrade, technological advances are expected in fuel efficiency and emission reduction of marine engines, especially coastal and inland marine engines. Environmental labeling and emission nameplates are also introduced to regulate marine engines. Technological studies covering SCR should be strengthened to quickly improve the level of domestic production. SCR and applications alike should be gradually integrated into vessels according to emission standards.

2. Speeding up the upgrade of marine fuel oil quality

Fuel quality regulation should be strengthened for construction machinery and agricultural machinery through market supervision and management. Technological research and development on desulfurization, such as catalytic hydrogenation of high-sulfur heavy oils, should be intensified to expedite the construction of desulfurized heavy oil production line.

Low-sulfur marine fuel should be gradually used in vessels within the supply capacity. China should strive to establish, before 2020, ECAs in key areas of air pollution control, where fuel used on coastal vessels should have less than 0.1% sulfur content, and fuel used on inland vessels meet *Ordinary Diesel* (GB252) requirements. After 2020 or 2025, depending on the results of an IMO Fuel Availability Study, international voyage ships and coastal vessels in all coastal and inland waters shall use fuel with sulfur content less than 0.1%, and inland vessels meet *Ordinary Diesel* (GB252) standards. Such fuel requirements would enable the use of diesel particulate filters, the most efficient PM / BC control technology. China should also consider creating ECAs covering coastal and inland waters in line with IMO requirements.

3. Speeding up technological research, development and promotion related to shore power facilities

Technological research, development and application should be advanced to facilitate high-voltage shore power supply system for international voyage vessels and coastal vessels and low-voltage system for inland, harbor, and official vessels. Key technologies in this regard include construction of shore power facilities, configuration of vessel-shore connection, oil circuit and power circuit switches of vessels. Appropriate technical standards should also be put in place. China should accelerate the penetration of shore power technology, with the goals of realizing shore power supply in coastal and inland ports in ten years and achieving, in 2025, shore power supply to 70-80% of cargo ships and 100% of harbor craft and government ships.

4. Expediting technological research and development on clean energy alternatives

Technological studies, and pilots and demonstration on biodiesel in the field of construction machinery and agricultural machinery should be advanced. Emissions standards equivalent to the IMO Tier 3 standards or more stringent NOx emission standards should be accelerated to simulate LNG marine engine research and development. For LNG powered ships, it is suggested to strengthen vessel block research, develop safety standards for LNG ships, conduct research to increase fuel storage capacity, and explore ways for extending distance travel between refueling. LNG powered ship. It is also necessary to study technologies on the construction, management and operation of LNG filling facilities in coastal and inland waters and regulate the safety design and operational management. Clean energy powered vessels should be promoted and supporting facilities built from inland waters.

Chapter IV Coordination Mechanism & Policy Analysis for SLCPs and NRMS Emission Reduction in China

I. Current Status of Coordination Mechanism among government agencies for SLCPs and NRMS in China

(I) SLCPs

China has long paid its attention of air pollution control to urban air quality and acid rain, without considering the influence on the climate as a consequence of air pollution control. As China has suffered more from air pollution in recent years, the attention at home and abroad on urban air quality in China imposed unprecedentedly large pressure on the country's control of air pollution. Under such circumstances, much more management and research resources of China are delivered to control of criteria air pollution, while SLCPs attract much less attention. Seen from policy and management points of view, China encounters problems regarding the control of SLCPs in the following respects:

Firstly, China lacks of SLCPs-related laws, regulations and standards. No specific SLCPs control requirement is specified in the Environmental Protection Law and the Air Pollution Control Law—basic laws of China to prevent and control air pollution. Besides, no requirement regarding the control of such major sources of BC, CH_4 and HFCs is specified in air pollutant emission standards, except the *Standard for Pollution Control on the Landfill Site of Municipal Solid Waste* (GB16889-2008), which specified a limit for the control of CH_4 emission.

Secondly, more consideration on abating SLCPs emissions shall be given when suggesting and promoting emission control technologies. As they have yet to be included in the scope of China's air pollution control, no goal of SLCPs emission control is set up in the control policies or control technologies being promoted. SLCPs are not taken into consideration in the selection of control technologies. Instead, only simple analysis on reducing BC emission is conducted during the evaluation of several policies and technologies.

Finally, China suffers from a shortage of adequate emission statistics data. SLCPs are not included in the statistical scope of pollutant emission in the existing statistical system of China. Though CH_4 emission is reported in such government documents as National Communication on Climate Change, it is still not included in annual emission statistics. Regarding other SLCPs, no official emission report is given at the national level. Although Tsinghua University, Beijing University and other universities and some research institutions have studied the overall emission and distribution of SLCPs in China in some scientific research, these emission inventories cannot provide sufficient support for policy formulation and effect evaluation due to limited basic data.

(II) NRMS

There is a wide range and a large number of NRMS widely used as an important tool for production and life, including machinery, vessel, locomotive, plane, etc. Due to the long-time lack of effective supervision and management, the NRMS products generally have, compared with motor vehicles, the characteristics of low level of technology, long service life, poor maintenance, high fuel consumption, poor fuel quality, and large emissions. NRMS mainly uses diesel and emits NO_x and PM and BC. It is rising as another important factor of influencing urban and regional air quality. Regulation of NRMS and control of the emissions encounters more difficulties due to NRMS' wide variety.

China has requirements on type approval of engines for use on non-road mobile machinery (NRMM). Emissions from existing NRMM, or engines larger than 37kW for use on larger inland and coastal marine engines, and railroad locomotives have not been managed effectively. Ocean-going vessels and aircraft emissions are subject to relevant international conventions as specific domestic emission standards have not yet been developed.

1. Non-Road Mobile Machinery (NRMM)

MEP is responsible for controlling the emissions from the NRMM products. Under the engine model examination and approval management, companies qualified according to information submitted as required, will be issued the model approval certificate. At the end of 2013, there were more than 14,000 diesel engine models and 1,280 small gasoline engine models of the NRMM products approved to meet the national emission standards. Existing NRMM products have not been included in the scope of management.

Among the NRMM products, the most important are agricultural machinery, construction machinery and garden machinery. Internal combustion engines are brought into the quality supervision and management of national competent departments. Machinery industries are subject to the management of respective authorities (for example, agricultural machinery is managed by the Department of Agricultural Mechanization of MOA), with assistances from industry associations (such as China Machinery Industry Federation, Small Gasoline Engine Branch of China Internal Combustion Engines Industry Associations, etc.).

2. Vessels

At present, only marine engines with rated net power of 37kW or less are subject to emission standards through type approval certification, and standards for those greater than 37kW are being developed. Ocean-going vessels mainly follow the requirements stipulated in Annex VI of the MARPOL Convention. Civilian vessels are divided by nature into transport ships and fishing vessels. The management of transport ships, undertaken by the departments for marine affairs and ship inspection of Ministry of Transport, covers ship inspection, certification, supervision and regulation, as shown in Figure 4-1.

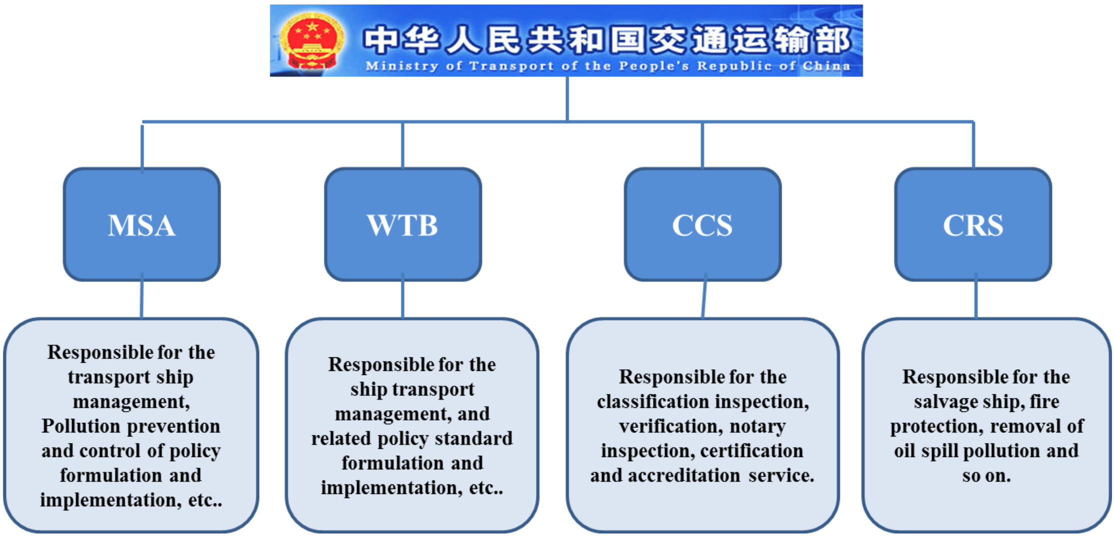


Fig. 4-1 China's transport ship management system

The management of fishing vessels, undertaken by the departments for fishing affairs and ship inspection of Ministry of Agriculture, covers inspection, certification, supervision and regulation, as shown in Figure 4-2.

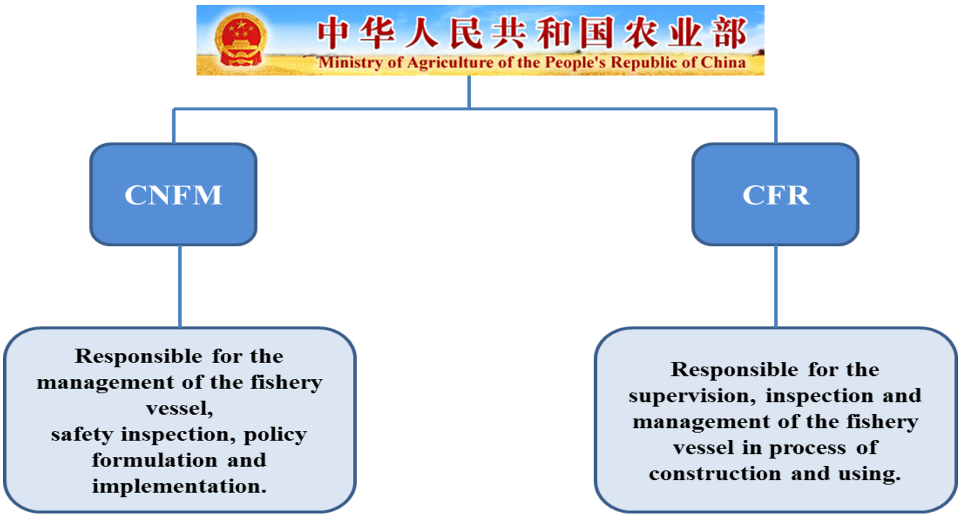


Fig. 4-2 China's fishing vessel management system

3. Fuel quality management

Diesel used by NRMM products, should comply with GB252-2011*Ordinary Diesel* and have the sulfur content of not more than 350 ppm. Marine fuel is more complex, including distillate fuel oil, residual fuel, and mixed fuel (a mixture of light oil and heavy oil by a certain percentage). Presently, the existing marine fuel standard is GB/T 17411-2012 *Marine Fuel Oils*, which recommends controlling the sulfur content of distillate fuel between 1.0% and 1.5% and residual fuel, between 2.0% and 3.5%.

Non-road fuel generally have higher sulfur content and the quality is not secured due to the absence of effective regulation, which undermines the control of SO2 and PM emission and the application of advanced after-treatment technologies. In May 2015, NDRC and other seven departments issued the Work Program to Speed up the Refined Oil Quality Upgrade, stipulating the national supply of standard V vehicle gasoline and diesel in January 2017, the national supply of standard IV ordinary diesel in July 2017 and standard V in January 2018, as shown in Figure 4-3. China also strives to issue the mandatory national standards for marine fuels before the end of 2015. 11 eastern provinces and cities have realized the supply of high-quality gasoline and diesel ahead of schedule. The accelerated process to upgrade fuel quality lays a basis for the implementation of more stringent emission standards.

Year / Item	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Gasoline	II	III				IV			V	
Diesel for Road	II		III				IV		V	
Diesel for Off-Road	II				III				IV	V

Fig. 4-3 Fuel oil quality upgrade process (2009-2018)

II. Inter-agencies Coordination Mechanism & Policy Suggestions for China's SLCPs Emission Reduction

(I) Including SLCPs control into air pollution control management and planning

SLCPs emission control is highly related with air pollution control in China. Seen from the pollution sources under control and the major measures adopted, many efforts produce a favorable effect in reducing SLCPs emission. Therefore, including SLCPs control into the existing air pollution control management system will not increase significantly the burden of air pollution control. Instead, it will help the Chinese government to build the image of a responsible great power that copes positively with global climate change. Attention shall be paid to the following three problems:

Firstly, a foundation of SLCPs management shall be constructed. Based on the existing pollutant emission statistics system, efforts shall be made to build a systematic and reliable national SLCPs emission statistics and analysis approach, which will help to figure out the SLCPs emission volume and characteristics in the country and lay a solid foundation for the future management.

Secondly, SLCPs control should be included in the national plans on energy conservation, emission reduction and pollution control. SLCPs emission reduction objectives shall be defined in the said plan and related policy measures shall be formulated.

Finally, a national roadmap of controlling SLCPs should be drafted. Efforts should be made to propose SLCPs emission reduction objectives and schedules according to the goals of climate change treatment and air pollution control and define all geographic areas and industrial areas of reducing SLCPs emission and major cooperative control measures for realizing SLCPs reduction aimed at every stage.

(II) Establishing collaborative emission reduction strategies

Since the sources of SLCPs are largely identical to those of criteria air pollutants, to which China pays much attention, the Chinese government should take wholly consideration of SLCPs and regular air pollutants and establish collaborative strategies that reduce their emissions as early as possible.

As for overall strategies of controlling air pollution, efforts should be made to set up overall targets for the implementation of SLCPs strategies that reduce emissions and air quality improvement as a whole, and put forward climate-friendly strategies that control air pollution. Based on this, detailed major objectives and indexes should be considered to guide the whole country to control air pollution.

Regarding specific control measures, priority should be given to the promotion of measures with the highest collaborative efficiency that improve air quality and reduce SLCPs emission. Special attention shall be paid to the measures that raise energy efficiency and improve energy structure, including decreasing coal consumption, cutting down the use of coal in small coal-burning facilities and raising the proportion of clean energy, which can relieve PM pollution and also reduce the emission of SLCPs.

(III) Intensifying cooperation among government agencies

The establishment of an inter-agencies cooperation mechanism is an important step for the implementation of the Air Pollution Control Action Plan. It will also be of help in controlling SLCP emissions and realizing SLCPs emission objectives. So, it is suggested definite SLCPs control requirements be proposed and responsibilities of every department be defined on the basis of the control objectives and the department responsibilities.

Major cooperative agencies shall be determined according to the major sources of every kind of SLCPs. Regarding BC, a coordination comprising of energy, environment, agriculture, transportation, and construction departments should be identified, responsibilities and relative rights should also be clarified. The work should start with decreasing the end use of coal, diminishing direct burning of biomass (such as straw) and controlling mobile sources. As for CH4, a cooperation team of chemical, coal, municipal and industrial departments should be built and the emphasis of the control shall be paid to reducing the emission ofCH4 from energy exploitation and waste disposal. Regarding HFCs, the work shall be carried out according to the existing tasks under the joint implementation mechanism. As for tropospheric O3, department responsibilities related to the control of NOx and VOCs emissions should be defined further under the existing air pollution control system.

(IV) Formulating and improving corresponding laws, standards and policies

During the amendment of applicable laws and regulations, efforts should be made to include SLCPs management into air pollution control system and authorize government organs to reduce SLCPs emission and on this basis, improve the emission standard system. During the amendment of emission standards, emission limits regarding major sources of BC and CH_4 should be specified based on the best available technologies.

In the short term, BC control technical policies should be improved, in combination with $PM_{2.5}$ control requirements. On the one hand, energy use policies should be improved to promote the conversion of coal use from inefficient and dispersive end-use facilities (such as small boilers and coal stoves) to efficient and concentrated end-use facilities. On the other hand, policies for comprehensive utilization of straw should be propelled to facilitate the production of biomass briquette by straw and decrease the direct burning of straw.

In the meantime, positive economic policies and incentive mechanisms should be introduced gradually to stimulate the application of SLCPs emission reduction technologies.

(V) Enhancing scientific research and technical development

Efforts should be made to enhance the studies on the BAT of controlling SLCPs emissions, reduce SLCPs emissions through tightening the emission standards, promote the research on SLCPs emission monitoring methodology and equipment and apply it to actual control management and emission reduction. Besides, more efforts should be made to propel the studies on the quantitative evaluation and analytical methods for benefits of SLCPs emission reduction coordination, establish model methods for evaluating climate change, health and agricultural benefits and on this basis, evaluate the comprehensive benefits of China's control of SLCPs.

III. Inter-agencies Coordination Mechanism & Policy Suggestions for China's NRMS Emission Reduction

That the State Council and relevant departments should gradually intensify the prevention and control of NRMS pollution by putting forward a series of requirements. *The 12th FYP for Air Pollution Prevention and Control in Key Areas* (MEP [2012] No. 130), jointly issued by MEP, NDRC and MOF, provided "investigate emissions of NRMS, including construction machinery, locomotives, vessels, agricultural machinery, industrial machinery and aviation, and establish a management ledger to control mobile sources of air control." The *Action Plan for Air Pollution Prevention and Control* (SC [2013] 37), issued by the State Council in September 2013, also proposed "control the emissions from construction machinery and other NRMM and vessels." The new *Law on the Prevention of Air Pollution* issued by the Standing Committee of the National People's Congress in August 2015, put forward clear requirements for the non-road mobile source emission control. The control of the NRMS emissions is gradually being put on the agenda as a priority of future work.

To further implement the new *Law on the Prevention of Air Pollution* and effectively control the NRMS emissions and strengthen pollution prevention and control, it is suggested to focus work on the following aspects:

(I) Establishing a NRMS emission control system for the purpose of air quality improvement

1. Strengthen the unified supervision of all mobile emission sources for the environmental protection departments

Strengthen the responsibility of environmental protection department under the State Council for the overall regulation of mobile sources, and clarify the division of responsibilities between the related departments and sectors, covering NRMM and vessels. Environmental authorities and local governments should be authorized to implement more stringent emission standards and create ECAs where needed. It is also necessary to strengthen the integrated control and unified supervision of air pollutants and greenhouse gas emissions, including PM and NO_x from mobile sources. Industrial enterprises bear the responsibility for complying with the requirements adopted by the environmental authorities.

2. Establish an NRMM environmental management mechanism that clarifies the responsibilities of state and local departments

MEP should establish a national environmental compliance system of new NRMM products, covering product information disclosure，type approval, conformity of production, in-use compliance, recall, and environmental labeling. Local environmental protection departments should establish an environmental management system of in-use NRMM products, covering routine inspections, random inspections, low-emission zones, upgraded environmental governance, and accelerated phase-out.

(II) Develop a the roadmap to prevent and control SLCPs and NRMS Emissions

1. Introducing more stringent emission standards and fuel standards

Standards for general diesel should be implemented as scheduled to strengthen fuel quality control. National standards IV for NRMM products should be formulated and implemented in key areas and nationwide according to the timetable with the goal of integrating NOx and PM after-treatment.

Emission standards should be introduced for new vessels, including coastal and inland vessels according to a phased schedule. Considering marine engine technology and vessel emission control, China should leapfrog early to US Tier 4 or equivalent standards. To smooth the successful implementation of these stringent emission standards, appropriate standards for marine fuel oils are urgently needed.

2. Enhance compliance management and introducing innovative implementation mechanisms

Environmental protection departments should build up the capacity of environmental regulation of mobile sources to ensure the implementation of stringent emissions standards. Institutional innovation based on policy studies, covering control of total mobile source emissions, Green Top Runner Program, emission trading and environmental tax, is also expected to improve the flexibility and effectiveness of emission standards.

China should establish strong ECAs covering coastal and inland waters requiring the use of 0.1% sulfur fuel, in particular at seriously polluted areas and waterways and ports with heavy traffic. Key ports should be encouraged to implement clean port plans through which the world's most advanced emission control technologies and strategies can be tested.

(III) Launch the "National Clean Diesel Engine Campaign"

Drawing on the U.S. successful practice in NRMM pollution prevention and control, China should launch the National Clean Diesel Engine Campaign during the 13th FYP period, in line with China's initiatives of "the Belt and Road" and "Made in China 2025". The campaign will be led by the State Council and supported by ministries including MEP, MOT, MOHURD, MOA, NDRC, MIIT, and MOF. The campaign will encompass clean diesel engine projects for on-road diesel vehicles, construction machinery, agricultural machinery, and vessels. The goal should be to require wall flow particle filters which greatly reduce particle mass, particle number and BC on as many vehicles and engines as possible as quickly as possible. Recent decisions to require low sulfur fuels for both on and off road applications facilitate this strategy. The system for mandatory retirement before deadline combined with financial incentives and market measures to encourage early retirement of old diesel engines and optimization of the fleet structure should substantially reduce both particulate and BC. The establishment and application of shore power facilities will be intensified and natural gas and other clean energy options will be favored for harbor utility craft, official boats, and ships on short fixed routes.

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