Summary of Sino-US Workshop on NO_x Emissions Control

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January 2013

1. Introduction: Key Messages

The "Sino-US Workshop on NO_x Emissions Control" was held in Kunming, China, on September 25-26, 2012. The purpose of the workshop was to enhance the exchange of ideas between China and the US, and to improve the total emissions control system for NO_x in China. Approximately 80 participants from the US and China attended the workshop. They included officials from the Ministry of Environmental Protection (MEP) and affiliated units of MEP, scholars from research institutes and Chinese universities, officials from provincial and city environmental protection bureaus (EPBs), representatives from industrial associations and companies related to NO_x control technologies, and US experts on NO_x emissions controls.

A total of 18 presentations covered the NO_x emissions control experience in China and the US. The presentations and discussions highlighted the following key messages:

- The actual total NO_x emissions reduction target, as compared to the baseline projections of new emissions during the 12th Five Year Plan (FYP), is 34%. This is significantly higher than the announced 10% target;
- Achieving the required NO_x reductions under the 12th FYP will be even more challenging, as economy-wide NO_x emissions during 2011 increased by 5.4% above the 2010 levels;
- The Chinese government has issued a suite of standards, administrative and economic policies, and technology guidelines to ensure the completion of the NO_x emissions reduction targets by 2015;
- Realizing the NO_x emissions reduction targets is estimated to require 300 GW of emissions control equipment on power plants. The large-scale application of denitrification technology in China faces substantial technological challenges and will need close coordination between regulators and grid operators to ensure electric system reliability;
- By 2015, China can cut NO_x emissions from mobile sources by 13% below the 2010 levels, if the projected number of outdated vehicles are eliminated and all provinces supply GB IV vehicle fuels;
- China's accounting and verification system for NO_x emissions reductions has heavily relied on administrative enforcement performed by MEP, regional supervision centers, and local EPBs. The role of citizens and the courts is unclear;

- The utilization of satellite remote sensing data provides an increasingly useful tool for assessing the real compliance of the NO_x emissions reduction targets at individual power plants and the provincial and city levels.

2. Review of Presentations: Control Policies, Technologies and Verification

The workshop presentations laid out the general framework for NO_x total emissions control at the national and provincial levels; described control strategies and challenges for the power sector, cement sector, and mobile sources; addressed NO_x control technologies and the development of China's denitrification industry; and discussed accounting and verification of NO_x emissions reductions.

This section reviews the presentations with a focus on China's NO_x emissions control policies and practices. It incorporates US experiences whenever relevant.

2.1. Overall NO_x Emissions Control Framework

Total NO_x Emissions Control Policies in China

The presentation on "Total NO_x Emissions Control Policies in China" by Wu Xianfeng from MEP's Total Emissions Control Department provides a comprehensive overview of China's NO_x control framework. Wu started with a brief introduction to the evolution of China's total emissions control programs:

- The first attempt during the 9th FYP (1996-2000) involved twelve pollutants
- More stringent requirements were incorporated during the 10th FYP (2001-2005), which involved five pollutants.
- Binding targets committed to reducing COD and SO2 emissions were introduced during the 11th FYP (2006-2010).
- The 12th FYP (2011-2015)expanded the mandatory targets to include ammonia discharge and NO_x emissions. The emissions reduction requirements were also extended to two new sectors, i.e., mobile and agricultural sources.

The NO_x emissions reduction target during the 12th FYP is to cut total emissions by 10% below the 2010 level by 2015. This target was established based on the existing emissions conditions and emissions factors, the need to improve air quality and mitigate acid rain problems, and the assumption of projected new emissions and reduction potentials. If the projected new emissions during the 12th FYP are reached, the actual emissions reductions required for existing sources are about 34%; this is significantly higher than the announced 10% target. The key sectors, i.e., the power and cement sectors, will need to cut their emissions by 29% and 12% respectively.

The allocation of responsibilities to meet the national reduction target during the 12th FYP is differentiated among the eastern, middle, and western regions. In general, the reduction target for provinces and cities in the eastern region is greater than 10%, the target for those in the middle region is approximately 10%, while the target for those in the western region is generally lower than 10%, with a few provinces allowed to increase NO_x emissions. For example, Jiangsu Province in the eastern region needs to cut its NO_x emissions by 17.5%, the reduction target for Anhui Province in the middle region is 9.8%, while low-emissions Qinghai Province in the western region is even permitted to increase its emissions by 15.3% above the 2010 level.[1]

MEP has adopted three main strategies for meeting the ambitious NO_x emissions reduction target:

1. Strengthen the management of emissions sources in order to strictly control new emissions. This strategy includes constraining the excessive growth of high-energy and high-emissions industrial sectors, controlling total energy consumption at the regional level, developing pilot projects for total coal consumption control in the key NO_x control areas, and optimizing regional industrial structures. The Chinese government will also attempt to control the total production of high-polluting industrial sectors, such as electricity, iron and steel, and paper mill sectors;
2. Lower NO_x emissions intensity by emphasizing structure-based and project-based emissions reductions. This includes eliminating outdated production capacity, promoting cleaner production and clean fuels, installing denitrification facilities on new production lines/equipments and enhancing their operations;
3. Adopt integrated measures to control NO_x emissions from mobile sources. This includes measures such as demonstration projects of motor vehicle ownership control, raising the entry bar for new motor vehicle models, eliminating outdated vehicles, and raising fuel quality. The Chinese government has been very progressive in eliminating vehicles that were produced before 2003 and which fail to meet national vehicle emissions standards.

MEP also aims to increase investments to build capacity for supervising emissions reductions, such as improving the automatic monitoring networks at the national, provincial, and city levels and for national vehicle supervision organizations. The target responsibility system will continue to be implemented to hold local leaders accountable for meeting the emissions reduction targets.

A number of environmental standards have been issued or revised to assist in the attainment of the emissions reduction targets. Examples include air quality standards, emissions standards, cleaner production standards, technical guidance for emissions reduction projects, standards on vehicle fuel consumption, and fuel quality standards. The Chinese government has adopted a dual-control approach that combines emissions standards and total emissions controls.

Economic instruments have also played an important role in reducing NO_x emissions. Examples include:

- raising the notably-low pollution levies for NO_x;
- punitive electricity prices for sources failing to control their NO_x emissions;
- an electricity price premium for power plants installed with well-functioning denitrification facilities;

[1] The State Council. *"Comprehensive Workplan for Energy Saving and Emission Reductions During the 12th Five Year Plan,"* issued on August 31, 2011: http://www.gov.cn/zwgk/2011-09/07/content_1941731.htm, accessed on November 9, 2012.

- tax incentives for NO_x reduction projects; and,
- green credit policies.

Total NO_x Emissions Control in Chongqing Municipality

The presentation on the "Total NO_x Emissions Control in Chongqing Municipality" by Deng Xiaowei from Chongqing EPB provides a detailed summary of NO_x total emissions control strategies and challenges in Chongqing, a city of 33 million people. By 2015, Chongqing is required to cut its NO_x emissions by 6.9% below the 2010 level, equivalent to 26,375 tons. The new NO_x emissions level during the 12th FYP is projected to be 127,789 tons. Together, the total amount of needed reductions is nearly five times more than the allocated 6.9% reduction rate. In other words, Chongqing's actual NO_x reductions by 2015 will be 40.3% of the 2010 baseline emissions. In order to achieve such a steep reduction, the city has implemented the following control strategies and measures:

1) *Strictly control new* NO_x *emissions*. The city decided not to build any new coal-fired and heavy oil-fired projects in the main urban areas and not to approve any new cement projects. The thermal power and cement plants in the construction process must install denitrification facilities simultaneously. The newly-completed projects must meet the related emissions reduction requirements before trial production;
2) *Strengthen the adjustment of industrial structures*. The city aims to vigorously develop some emerging strategic industries (e.g., information technology and low-energy and low-pollution manufacturing industries) and circular economy. It has also accelerated the elimination of outdated production capacity with an emphasis on backward iron and steel, small cement and paper production capacity. An important aspect of Chongqing's strategies in adjusting industrial structure is to move polluting sources out of the main urban areas and to relocate the related industrial parks before 2014.
3) *Fully implement the total emissions reduction projects*. All coal-fired power generators with a generating capacity of 300 MW or higher must install denitrification facilities, while others need to strengthen the management of low NO_x burners. All coal-fired boilers with 10 tons of steam or higher must install or modify denitrification facilities and further improve their denitrification efficiency. All dry cement kilns must implement low NO_x burner technological innovations; the cement production lines whose clinker production scale are at 2000 tons/day and above must build denitrification facilities. In terms of emissions controls at mobile sources, the city has closely implemented the national emissions standards at mobile sources; newly-purchased cars will not get registered without meeting the standards. The city also aims to enhance routine monitoring and supervision of emissions from vehicles, to accelerate the elimination of high-emissions cars that failed to meet the related national standards even if the related compensation policies were implemented, and improve vehicle fuel quality.
4) *Enhance the implementation of several safeguard policies that, when fully effective, will help to assure that the* NO_x *emissions targets are met*. These policies include establishing a city-level emissions reduction office in charge of overall emissions reduction work, signing target responsibility contracts between the city and county/city-district governments, and formulating a set of total emissions control management rules and sectoral NO_x emissions standards. For example, the NO_x emissions limit for the cement industry is 250 mg/m^3 for plants located in the downtown area, 200 mg/m^3 for those in the designated affected area, and 550 mg/m^3 for those in other areas. In line with the

national trend, the Chongqing City has also aimed to introduce an electricity price premium for coal-fired power plants with denitrification facilities installed, to implement an emissions trading program, and to promote green credit policies, such as limiting loans to the enterprises that fail to fulfill their total emissions reduction tasks. In addition, the city has increased funding for total emissions reductions by setting up a special fund and requiring county and city-district governments to provide matching funds. The city government has also provided additional funding of 1.6 billion RMB particularly for emissions reduction projects and increased financial subsidies for key denitrification projects at coal-fired power plants and cement plants.

5) *Improve the management structure to coordinate responsibilities for emissions reductions among several different agencies*. This includes a quarterly coordination meeting held by the city government to investigate the process on emissions reduction work and implementation of key reduction projects. The city government will publically expose the reduction projects that are seriously behind the completion schedule and hold the managers of those projects responsible for completing the projects within a specified deadline. The city government has also improved its early warning and notification system such as giving a warning to pollution control facilities that failed to operate normally or to a new project whose emissions exceed the projected quantity without adding new control projects, and publically disclosing the emissions reduction conditions. Similar to the national policy, the city government has introduced an accountability system, which holds the head of counties and city districts responsible for attaining their assigned emissions reduction targets.

Deng's presentation also included a couple of denitrification cases. One is a SCR control facility installed at a coal-fired power plant. It demonstrates that the installation and operation of the SCR facility has significantly reduced NO_x emissions (the denitrification rate is no less than 91.7%), and the NO_x concentration has been reduced to less than 200 mg/m^3(no original NO_x concentration was given). The cost for installing SCR is approximately 138 million RMB and the annual operational cost is about 111 million RMB. Another case highlighted was about denitrification in the cement industry. Of the 36 cement factories operating in Chongqing, the Taini cement plant is China's sixth largest cement factory. The factory adopted staged combustion and selective non-catalytic reduction (SNCR) technology for NO_x emissions controls. The combined control approach reduced the NO_x concentration from 1,206 mg/m^3 to less than 350 mg/m^3, a reduction rate of 70%. The presentation also provided an analysis of the control costs.

In his conclusion, Deng Xiaowei proposed several measures for decreasing NO_x emissions. One is the nation-wide adoption of an electricity premium for power plants installed with efficient and well-functioning denitrification facilities. The second recommendation is the issuance of NO_x emissions standards for the cement industry as soon as possible. A third recommendation is to improve fuel quality as a result of coordination among the relevant national agencies.

NO_x Total Emissions Reduction Strategy: a Multi-Pollutant Co-Control Perspective

The presentation on the " NO_x Total Emissions Reduction Strategy: a Multi-Pollutant Co-Control Perspective" by Mao Xianqiang of Beijing Normal University pointed out that reductions in a single pollutant usually led to new emissions of other pollutants. For example, if the NO_x reduction in 2009 through the implementation of SCR control technology were approximately

1.30 million tons (15% reduction), there would be an annual increase of 7800 tons of SO2 emissions and 2.5 million tons of CO_2 emissions in 2009. The electricity and coal use associated with SCR installation would also increase by roughly 2.6 billion kwh and 0.83 million tons respectively. Therefore, the structural reduction measures, such as replacing coal-fired electricity generation with renewable energy and closing down small coal-fired power plants, could have co-control effects such as simultaneously reducing energy consumption, regional pollution (SO2 and NO_x emissions), and CO_2 emissions.

The presentation provided an overview of the co-control evaluation and design methods, and suggested the design of multi-pollutant co-control measures should be based on unit cost of pollutant reduction. The power sector and the iron and steel industries were used as case studies to illustrate how co-control measures might be designed and how to estimate their control effects. A regional co-control case was also provided.

NO_x Control in Bay Area in the Context of Multi-pollutant Control and Air Quality Management

While Mao's presentation suggested an integrated multi-pollutant control approach is more cost effective than a single-pollutant control approach for improving air quality in China, the presentation by Jack Broadbent on the "NO_x Control in Bay Area in the Context of Multi-pollutant Control and Air Quality Management" provides a practical case of multi-pollutant control approaches. The presentation showcased the San Francisco, California, US Bay Area 2010 Clean Air Plan as a comprehensive multi-pollutant plan for integrating greenhouse gas emissions reductions, which also maximized co-benefits and minimized trade-offs (i.e., emissions controls that reduce criteria pollutants may increase CO_2). The multi-pollutant plan has led to significant improvements in air quality in recent decades and helped prioritize control strategies to reduce air pollution and premature deaths.

NO_x Emissions Control - The US Experience

Anna Wood's presentation, "NO_x Emissions Control - The US Experience," addressed a critical part of any effective NO_x emissions control program, which is a comprehensive checks-and-balances system. A number of actors have been involved in the US NO_x emissions control program: Congress, US EPA, state agencies, courts, citizens, and sources of NO_x. There are a number of opportunities for stakeholders to comment on NO_x emissions control programs as citizens can comment on state and local air quality agency decisions and actions before they are final, can petition the courts to review actions (and absence of action) by EPA, can petition the courts to review whether a NO_x source is complying with the laws and regulations, and can ask their representatives in Congress to investigate or question EPA. In addition, courts can order EPA to take an action required by the Clean Air Act when EPA delays too long, can order EPA to change an action if it was not consistent with the law, can order NO_x sources to install better emissions controls, and give official approval to settlements and consent decrees worked out between citizens, EPA, and/or sources.

None of the presentations on China's NO_x control policies and experience at the workshop mentioned a similar checks-and-balance system in China's NO_x control program. However, there are some Chinese laws and policies that permit citizens and courts to take action, similar to those in the US, against NO_x pollution.. It is important for Chinese environmental policymakers and enforcement agencies to make good use of those legal provisions and policies to achieve real and long-lasting emissions reductions.

2.2. NO_x Control at Stationary Sources

Total Emissions Control of NO_x in Power Sector in China

Yang Jintian at Chinese Academy of Environmental Planning delivered a presentation entitled "Total Emissions Control of NO_x in Power Sector in China." It provides an excellent overview of the impacts of NO_x emissions on atmospheric environment, emissions control strategies, and challenges faced by the Chinese power sector in cutting down its NO_x emissions. First, NO_x is a key pollutant contributing to multiple air pollution problems (e.g., $PM_{2.5}$, ozone, and acid rain) so controlling NO_x emissions is a key to resolving China's regional complex air pollution problem. For example, $PM_{2.5}$ concentrations in a number of large cities exceeded the newly-revised air quality standard by 14% to 157% in 2010. The average $PM_{2.5}$ concentration in China's major cities, according to the new NASA data, reached as high as 80 ug/m^3 in 2001-2006. There is also a high ratio of secondary PM on $PM_{2.5}$, such as the high percentage of soil dust in $PM_{2.5}$ in the seasons and regions heavily affected by sandstorms. The number of hazy days has increased since the 1961 - 1965 period when relevant information became available and has become more dominant in the past three decades in the middle and east coast regions. The ozone concentration in some regions often exceeded the European warning level of 240 ppb. In addition, acid rain pollution continues to be severe in the southeast area.

Second, since the power sector is the largest contributor to China's national NO_x emissions, it should play a key role in reducing NO_x emissions. NO_x emissions from the power sector are primarily concentrated in the highly-populated, industrialized, and fast developing areas: together, the emissions from Neimengguo, Jiangsu, Shandong, Henan, Shanxi, and Hebei provinces were responsible for roughly 43% of the national NO_x emissions. Yang Jintian suggested that the actual NO_x control target (not the announced 10% target), a total of 29% reduction below the 2010 level by 2015, be allocated to individual generators and plants based on emissions performance to ensure the compliance. The technical path for reducing NO_x emissions at the power sector involves the following five main tasks:

1) Strengthen controls on the sources of NO_x emissions, particularly new emissions. The installed generating capacity of China's thermal power sector increased by 320 GW during the 11th FYP and is projected to be further increased by 250 GW during the 12th FYP. To control the new emissions generated from all those new power plants, new coal-fired plants are required to install gas denitrification facilities with NO_x control efficiency greater than 80%. Approval of any new projects must ensure that new emissions will not lead to an increase in local NO_x total emissions.
2) Emphasize structural reductions. This involves eliminating small coal-fired power plants with a total generating capacity of 20 GW and closing small-scale thermal power generators within a power plant in order to build a large-scale thermal generator in the same plant.
3) Promote project-based reductions. This refers to the NO_x reductions generated from switching fuels, adopting low NO_x burner technology, and installing denitrification technologies (SCR, SNCR, and combined SCR-SNCR). All coal-fired power generators

that have not installed low NO_x combustion technologies or have inefficient low NO_x combustion technologies will need to be transformed. Moreover, all coal-fired generators throughout China with a generating capacity of more than 300 MW, and those with a generating capacity of more than 200 MW in the eastern region and other provincial capital cities, must implement the transformation of denitrification; the overall NO_x control efficiency must be greater than 70%.

4) Implement supervision reductions. This task involves improving the operational rate of installed denitrification facilities, enhancing NO_x control efficiency, and strengthening the management of installed denitrification facilities.
5) Enhance safeguard measures. A number of policies have been and will be adopted to ensure the attainment of the NO_x emissions targets. Examples include financial subsidies for eliminating outdated coal-fired power generation capacity, experiments of a denitrification-based electricity price premium in 14 provinces/cities, and NO_x emissions trading experiments.

To date, China's NO_x emissions controls have made notable progress. The government has signed target responsibility contracts with provinces and six national corporations. More than 80% of the existing coal-fired power generators have employed low NO_x combustion technologies and the average reduction rate is 30-45%. As of the end of 2011, a total of 289 denitrification devices were installed at coal-fired power generators, consisting of an installed generating capacity of 129 GW.

Yang Jintian's presentation also summarized the following main challenges faced by the power sector in NO_x controls:

- with an economy projected to grow 7% annually and an increase of 16% in coal consumption during the 12th FYP, NO_x emissions are projected to increase by nearly 24%. The actual control task of reducing 34% of NO_x emissions below the 2010 level by 2015 is daunting;
- the 2011 NO_x emissions increased by 5.73% above the 2010 level, instead of declining, and is making the completion of the mandatory NO_x emissions reduction target by 2015 extremely difficult to achieve;
- the efficiency of installed denitrification devices is low. Among all the generators installed with denitrification devices, more than half (58% of the total installed power generating capacity) of those devices had a NO_x control efficiency of less than 40%;
- the adoption of denitrification technologies in China faces significant technological challenges including supply and re-generation of catalysts and stable operation of denitrification devices during low power generation loads. Also, the supporting measures/policies, such as a nation-wide denitrification-based electricity price premium and a NO_x emissions trading system for the power sector, have not been put into place.

Actively Promoting NO_x Emissions Reductions at China's Cement Industry

The presentation on "Actively Promoting NO_x Emissions Reductions at China's Cement Industry" by Kong Xiangzhong from the China Cement Association described the current conditions of China's cement industry and related NO_x control policies. China's cement production has steadily increased since 2006, while the investment in new cement lines dropped sharply since 2009. The cement market concentration has improved as the production of the top

10 largest cement plants consisted of 43% of the national clinker production and 28% of the national cement production in China in 2011. Nearly 800 outdated cement companies were closed and 150 million tons of backward cement capacity was eliminated. Moreover, energy consumption of China's cement production has greatly declined since 2005.

Kong outlined the NO_x emissions control policies and regulations in the cement industry during the 12th FYP. MEP started the revision of "Emissions Standards of Air Pollutants in Cement Industry (GB 4915-2004)" in April 2012; the NO_x emissions concentration is expected to drop from 800 mg/m^3 to less than 500 mg/m^3 and will be implemented in 2013. The government will provide economic compensation for the installation of denitrification facilities on cement plants.

The presentation raised three interesting concerns, which might represent the perspectives of the cement industry. The concerns are whether using the current NO_x emissions limit of 800 mg/m^3 (2.4 kg/t clinker) is appropriate for new suspension preheater (NSP) cement production, whether the lower emissions standard is necessarily better, and whether the cement industry should implement the emissions standards or complete the mandatory emissions reduction targets as the differentiated provincial-level NO_x emissions targets will result in significant differences in production cost. Kong compiled the emissions standards currently being used by several nations to illustrate that China will likely have the most stringent emissions limit in the world for its cement industry. Kong also demonstrated that the cement industry in Europe primarily uses SNCR technology for reducing NO_x emissions (SCR is rarely used) and indicated that any NO_x emissions limit lower than 350 mg/m^3 is not economic. In China, the cement sector has mainly used low NO_x combustion and SNCR technologies in NO_x controls.

2.3. NO_x Control at Mobile Sources

NO_x Control Policies of China's Mobile Sources During the 12th FYP

The presentation on the "NO_x Control Policies of China's Mobile Sources During the 12th FYP" by Yin Hang from MEP's Vehicle Emissions Control Center outlined the reduction potential of mobile sources, current situations, related policies, challenges faced, and suggestions. The presentation first analyzed the quantity of reductions that could be achieved during the 12th FYP. It is projected that new NO_x emissions during the 12th FYP from motor vehicles will be roughly 2.16 million tons. If the following two conditions were met by 2015, the total NO_x emissions reductions from motor vehicles would be roughly 780,000 tons, equivalent to 13% below the 2010 level by 2015:

1) Eliminating the vehicles registered before 2000 and the medium- and heavy-duty diesel vehicles registered in 2001-2005. Among them, assuming 50% of the private ones will be eliminated as there are no mandatory elimination requirements for these vehicle classes. As a result, approximately 7.6 million vehicles will be eliminated and subsequently result in about 2.67 million tons of NO_x emissions reductions;
2) All provinces implement plans for supplying GB IV vehicle fuels. This will lead to 280,000 tons of NO_x emissions reductions.

Yin then provided an explanation of why the annual NO_x emissions reduction target for mobile sources was not attained in 2011 and summarized the main challenges involved. While there were fewer new cars than what was initially projected for 2011, new NO_x emissions were higher than what was projected and therefore reductions were much lower than planned. The main reason for failing to meet the annual reduction target in 2011 was the low number of eliminated vehicles; only 60% of the anticipated number of vehicles were eliminated. Yin outlined the major challenges China has faced in reducing NO_x emissions from motor vehicles:

- New NO_x emissions continue to rise. This is primarily related to rapid growth in car ownership, delayed implementation of GB IV emissions standards for heavy-duty vehicles, and the late issuance of environmental protection certificates for new cars. The incomplete certification has led to a large number of GB IV light-duty vehicles being treated as GB III vehicles, which have significantly higher NO_x emissions limits;
- Actual emissions reductions are far lower than projected. The progress in eliminating outdated vehicles has been slow, as China has not formulated the related compensation policies. Lack of qualified environmental protection certificates has led to a lower number of reductions being verified. The supply of vehicle fuels meeting GB IV standards is very limited. Currently, the state has not published the GB IV diesel standard, and GB IV gasoline standards will not be provided nationwide until January 1, 2014. Only a few regions have started providing gasoline and/or diesel with a sulfur content less than 50ppm, and the diesel supply cannot be guaranteed. In addition, most regions cannot reduce NO_x emissions merely through strengthening vehicle management alone;
- The environmental certification system for new vehicles has not been well established. Only about 50% of 338 Chinese cities have created the certification programs, and a few provinces have not even started. According to some incomplete statistics, merely 30% of the registered vehicles were certified. This has greatly affected the verification and accuracy of NO_x emissions reductions data from mobile sources.

The State Council's documents on energy-saving and emissions-reduction work during the 12th FYP contain general NO_x emissions reduction policies for automobiles. They emphasize the elimination of outdated motor vehicles and ships, implementation of GB IV emissions standards, upgrading of vehicle fuels, promoting environmental certification for motor vehicles, exploring the total car ownership control system, establishing emissions standards that meet the total NO_x emissions control requirements, and financial incentives.

Yin's presentation also gives an overview of local NO_x emissions reduction measures on vehicles. Beijing, Shanghai, Guiyang and Guangzhou City started adjusting and controlling car ownership. Nearly two-thirds of the provinces, 21 in total, have issued rules for total NO_x emissions reductions aimed at motor vehicles. Several key regions, Beijing, Shanghai, Nanjing, and Guangdong, started implementing the vehicle emissions standards ahead of time. GB IV vehicle fuels are now available in Beijing, Shanghai, Guangzhou, Shenzhen, and Dongguan city. The incentive policies for eliminating high-emissions vehicles are promulgated in Beijing, Jiangsu, and Zhejiang. A few cities, Guangzhou, Hangzhou, Zhenjiang, and Huhehaote, have established a database for the planned elimination of vehicles. Moreover, a number of cities have specified areas in which the soon-to-be-eliminated vehicles are not allowed to travel.

Yin concluded his presentation with a number of suggestions for meeting NO_x emissions reduction targets set for mobile sources during the 12th FYP:

- Accelerate the elimination of high-emissions vehicles. The emphasis is on the close cooperation among local EPBs (emissions monitoring), public security bureaus (car registration), transportation bureaus (road transport business licensing), departments of commerce (scrapping and dismantling old vehicles), and finance bureaus (subsidy policies);
- Upgrade the quality of vehicle fuels. This suggestion also emphasizes the respective responsibilities of each related government agency and collaboration between the agencies, e.g., supervision of the fuel market by departments of commerce, random check of fuel quality at gas stations by industrial and commercial departments and quality control bureaus;
- Advance the implementation of more stringent new vehicle emissions standards. The areas with low-sulfur fuels should implement GB V emissions standards on light-duty gasoline vehicles and GB IV or even GB V standards on heavy-duty diesel vehicles ahead of time. The government should provide subsidies or consumption tax breaks for the areas implementing GB V standards on heavy-duty diesel vehicles ahead of time. The owners of public service vehicles and buses should be required to purchase vehicles meeting more stringent standards when updating their vehicle fleets;
- Accelerate the establishment of environmental certification systems for motor vehicles. Local EPBs need to establish and follow the certification procedures. Public security bureaus shall deny car registration and transport bureaus shall not issue business licenses if new vehicles fail to retain certificates from local EPBs. Similar rules are applicable to in-use vehicles;
- Encourage public transportation and taxi fleets to use vehicles that meet more stringent emissions standards. This will need policy support from local governments;
- Strengthen the supervision of annual inspections and institute road checks of in-use vehicles. This includes uncovering noncompliant vehicles and prohibiting their use by increasing inspection frequency, using more advanced technologies for uncovering noncompliant vehicles, and providing maintenance/emissions control guidance to vehicle owners.

US Mobile Sources NO_x Control Emissions and Fuel Standards

Michael Walsh's presentation on the "US Mobile Sources NO_x Control Emissions and Fuel Standards" provided some useful insights for China's NO_x emissions controls from vehicles. For example, treating vehicles and fuels as a single system meant that vehicle technology can bring large emissions reductions and fuels must be suitable for the vehicles to perform well. Walsh also analyzed the problems with Euro IV/V type-approval process and indicated that China has established supplemental testing requirements to fix the resulted vehicle excess NO_x emissions problem.

2.4. NO_x Control Technologies

Status and Challenges of China's Denitrification Industry

The presentation on the "Status and Challenges of China's Denitrification Industry" by Li Yong at CPI Yuanda Environmental Protection Engineering Company reviewed the current status of NO_x control technologies in China and highlighted the challenges that exist in adopting those technologies. The prevention and control technological policies published by MEP listed low NO_x combustion technology as the first choice for NO_x emissions controls at coal-fired power plants. When the adoption of low NO_x combustion technology fails to meet the total NO_x emissions control requirements, flue gas denitrification measures must be utilized.

The presentation compared technical characteristics, construction costs, operational costs, and overall costs of the three technologies: SCR, SNCR, and SCR-SNCR. SCR is most expensive, and SNCR is the cheapest. As of today, only 15% of the coal-fired power generators in China installed denitrification devices; 93.31% of those installed devices use SCR technology, 6.28% use SNCR technology, and only 0.41% use combined SCR-SNCR technology. In general, the NO_x control efficiency of SCR technology is significantly higher than that of SNCR. NO_x emissions concentrations of the power plants installed with SCR technology is between 38-57 mg/m^3, which meets the new emissions standard of 100 mg/m^3 established for coal-fired power plants; the NO_x removal rate is greater than 82.7%. In contrast, the control efficiency of SNCR technology is usually about 40%. Such low efficiency cannot lead to compliance with the new emission standard.

Clearly, the two major sources of NO_x emissions, the power and cement sectors, will have to install SCR control technology in order to meet the stringent NO_x emissions standards. But the large-scale adoption of SCR technology in China is facing the following main challenges:

- China has not mastered the core technical parts of SCR technology, such as the design of the SCR process system, catalyst technology, and physical flow model/CFD flow simulation technology;
- Lack of systematical technical specifications. For example, there are no technical specifications for SCR design, equipment, trial testing, checks and examination. The installation of each SCR technology followed the foreign standards of the imported SCR producer. Also, denitrification is closely related to dust removal and desulfurization so China needs to establish unified and coordinated technical specifications regulating a variety of pollution control devices;
- Lack of unified standards and supervision for the domestic denitrification catalyst industry. Each domestic catalyst producer uses the directly-translated industrial standards from foreign catalyst producers for product testing. Significant differences exist among various foreign companies, and such differences make it hard for users to assess quality and choose a product. In addition, third-party evaluations of catalyst quality based on a set of unified standards are currently missing for the development of domestic catalyst industry;
- The catalyst cost is high as the core technologies and raw materials for domestic catalyst production heavily depend on foreign companies. All raw materials needed for catalyst production are imported. Compared with foreign coal-fired units, flue gas from China's

coal-fired power plants is characterized as high ash, high calcium, high sulfur, and high dust content. As a result, the mechanical lifespan of the catalyst produced with foreign technologies and raw materials is greatly reduced;

- The high cost of catalyst production results in high operational costs for SCR and difficult catalyst regeneration. The average service life of a catalyst in China is 3-5 years. But catalyst regeneration, which can reduce the SCR operational cost, is still in the laboratory research stage in China;
- Currently, no SCR catalyst is available for meeting the denitrification needs of the cement industry.

NO_x Emissions Controls: Operating Experience in the US

The presentation on "NO_x Emissions Controls: Operating Experience in the US" by Chris James of the Regulatory Assistance Project provides some useful insights on how China might improve the effectiveness of its NO_x control technologies. For example, although SNCR does have a relatively low NO_x removal rate (30-60%), the removal efficiency can be improved on smaller boilers as it is easier to achieve uniform reagent distribution. The smaller boilers in China could learn from the US experience in using relatively inexpensive SNCR technology to achieve a relatively high NO_x removal efficiency.

James's presentation reveals that SCR technology has achieved 90%+ reduction rate in both new and existing plants. This indicates that there is room for improvement in SCR operations in China, as the average NO_x reduction efficiency is merely about 82.7% (mentioned in a previous presentation). To enhance SCR performance, where a plant has flue gas with high PM, which is common in China, it should install a soot blower. One important suggestion for improving the operation of NO_x control technologies, is to train staff to assure proper equipment operation and maintenance and to prolong the life of the equipment.

2.5. Accounting and Verification of NO_x Emissions Reductions

Accounting and Verification System of China's NO_x Emissions Reductions

The presentation on the "Accounting and Verification System of China's NO_x Emissions Reductions" by Wang Feng from MEP's Total Emissions Control Department provides an excellent overview of how emissions reductions have been accounted and verified in China. This system is not well understood outside of China. In 2007, MEP started implementing a comprehensive accounting and verification system in order to provide a basis for assessing the compliance with the total emissions reduction targets established during the 11^{th} FYP. The system was designed to conduct routine and random audits of emissions reduction measures and data and to examine the authenticity and consistency of reduction data. The methods, such as detailed accounting rules for total emissions reductions of major pollutants and the verification methods for total emissions reductions of major pollutants, have been published. The general accounting and verification framework is as follows:

- MEP is in charge of the overall accounting and verification work;
- The main targets for accounting and verification are key centrally controlled enterprises and provinces (including cities and counties/city-districts);

- The main subjects are changes in the total emissions of major pollutants, implementing conditions of various emissions reductions measures, implementation of annual emissions reduction plans, completion conditions of the assigned emissions reduction targets, and performance of government departments supervising emissions reductions work;
- The main verification methods are audits of relevant materials and on-site field inspections. It is a combination of daily inspections and semi-annual and annual verifications.

The accounting and verification procedures are outlined below:

1) *Basic preparation work*. Provincial, municipal, and city district/county EPBs are required to collect basic materials on new emissions of major pollutants, historical environmental statistical data and emissions reduction projects, a detailed inventory of all reduction projects for verification, and other relevant supporting documents;
2) *Check and verification work*. MEP's regional supervision centers (six in total) collect relevant data for emissions reduction verifications, conduct field inspections of emissions conditions of key polluting enterprises, investigate construction and operating conditions of reduction projects, and randomly check and verify the authenticity and consistency of the new emissions reduction data calculated and reported by localities;
3) *Auditing and identifying work*. MEP conducts documentary and field audits of the reported new emissions reductions and identifies the real reductions;
4) *Public disclosure of reduction information*. MEP has routinely published both local and provincial actual emissions levels and a list of the enterprises cited for violations.

Three principles govern the emissions accounting and verification system. The first is to "follow baselines (遵循基数)," which is to use the 2010 environmental statistical data and ensure the convergence of environmental statistical data with the reduction accounting data. The second principle is to "accurately calculate new emissions (算清增量)," which combines the macro accounting methods with the sectoral accounting methods. The third principle is to "verify emissions reductions (核实减量)." This uses a combination of daily supervision and routine verification as well as a combination of documentary audits and random field inspections. The audits and inspections usually target the accumulative emissions reductions generated from structural adjustment (known as "结构减排"), projects (known as "工程减排"), and management (known as "管理减排"). The structural adjustment-based reductions involve primarily the elimination of outdated production lines and/or technological equipment. The project-based reductions refer to verification of the changes in emissions before and after pollution control projects are implemented.

The NO_x emissions reduction accounting system covers four major sectors (i.e., power, cement, transport, and other domestic sources), and the scope varies across these sectors. For example, the power sector includes more than 7,000 power generators, the cement sector involves 1,500 cement NSP production lines, and the transport sector covers 225 million vehicles. MEP has adopted a full aperture statistical method for accounting and verifying the emissions from the power sector, will gradually implement a full aperture statistical method for the cement sector, and has applied macroeconomic accounting for mobile sources (i.e., vehicles) and other industrial sectors.

Since the NO_x formulation process is complex, mass balance methods for estimating NO_x emissions are not applicable. Instead, the discharge coefficient method has been used for calculating NO_x emissions during the 12th FYP and will be gradually replaced with direct measurement using continuous emissions monitoring system (CEMS) data. For the facilities that switch fuels and adopt low NO_x burner or denitrification technology, the main task is to accurately verify the NO_x control efficiency. The presentation listed the formulas for estimating total NO_x emissions based on the discharge coefficient method and CEMS data. The role of the supervision coefficient, which increases the actual new emissions if the non-operation or abnormal operation of pollution control facilities is uncovered, was also briefly mentioned.

The key points of the NO_x reduction accounting and verification system are to judge the authenticity and accuracy of emissions reduction baseline data, to verify the conditions for acceptable emissions reduction measures, and to examine the consistency of emissions reduction data. Details are as follows:

- *Judge the authenticity and accuracy of emissions reduction baseline data*. This involves examining the data sources, which mostly come from statistical bureaus, e.g., energy consumption, installed capacity, power generation, cement production. It also involves judging the reasonableness of baseline data, e.g., correlation of product yields and fuel consumption. One can also examine the data quality by analyzing the in-furnace coal quality, enterprises' production statements, operation records of denitrification facilities, and invoices for reagent purchase and usage;
- *Verify the conditions for acceptable emissions reduction measures*. The outdated production lines and equipment being eliminated and counted for real reductions must be the ones included in the 2010 national database of polluting sources and be verified. The project-based emissions reductions must be continuous and steady, and the projects must be equipped with the CEMS connected to EPB monitoring centers at and above the city level. Moreover, any emissions reductions identified through improved reduction management must be highly efficient denitrification facilities and contain notable improvements in reduction efficiency;
- *Examine the consistency of emissions reduction data*. MEP uses three methods, i.e., CEMS data, facility operation records (DCS), and usage of reagents, to triangulate and verify the NO_x emissions and emissions reduction data.

Using Satellite Remote Sensing to Observe Changes in NO_x Emissions

The presentation entitled "Using Satellite Remote Sensing to Observe Changes in NO_x Emissions" by Zhang Qiang from Tsinghua University demonstrated an alternative method for verifying NO_x emissions reductions (or increases) in China. This was inspired by a study published in "Nature" in 2005 that analyzed satellite remote sensing data to illustrate rapid increases in China's regional NO_x concentrations. Zhang's presentation showed that the areas with high NO_x concentrations have expanded rapidly in 2005-2010. It also showed the average NO_x concentration in a particular area increased or decreased by a certain percentage in June 2012 below the 2011 level. Such information can be used to verify the reported increases/decreases in NO_x concentrations in a given geographic area. Future research will focus on using the satellite remote sensing data to analyze changes in NO_x concentrations at the city level.

Interestingly, the satellite remote sensing data demonstrated a sharp decline in the SO_2 concentrations of individual power plants in recent years; such data have also been used to assess FGD operation results. This indicates that the relevant data might be used to observe changes in NO_x concentrations of individual power plants. It is already noted that increases in NO_x concentrations in a given geographic area can be correlated to the construction of new power plants in the area. The satellite remote sensing data reveal the geographic change/expansion of NO_x emissions and provide a foundation for prioritizing the geographic areas for NO_x controls in the near future. For example, NO_x concentrations have risen rapidly in the middle and western regions of China and are increasing in middle- and small-sized cities at the greatest rate.

Power Sector NO_x Emissions Monitoring and Evaluation

The US verification program, as illustrated by Jeremy Schreifels' presentation on "Power Sector NO_x Emissions Monitoring and Evaluation," heavily relies on comprehensive electronic auditing. This is largely because the widespread application of CEMS on power generators allows automatic reporting and verification; random and targeted field audits are also used. Once the CEMS installed for NO_x emissions measurement becomes more widespread in China, the US experience in using the CEMS data for measurement and verification will be relevant and useful.

3. Policy Recommendations

China has made notable progress in NO_x emissions controls by establishing a suite of standards, policies, and technology guidelines. But enormous challenges remain for achieving the aggressive reduction targets established in the 12th FYP. The increase (not the anticipated decline) in 2011 NO_x emissions poses additional challenges for China's NO_x control efforts. The following policy recommendations are from the workshop presentations listed above:

- The Chinese government should consider developing an integrated multi-pollutant control approach that incorporates and reconciles the existing control policies regarding other major pollutants such as SO_2 and CO_2;
- The Chinese government needs to provide sufficient funding and incentives for the domestic development of core denitrification technologies in order to bring down the overall costs;
- China needs to develop systematic technical specifications for the design, equipment, testing, and verification of key denitrification technologies, such as SCR and SNCR;
- China needs to provide strong incentives for improving the efficiency of installed denitrification devices and to establish consequences for failing to operate denitrification devices;
- China needs to accelerate the elimination of high-emissions vehicles, to upgrade its fuel quality ,and to encourage the implementation of more stringent vehicle emissions standards in order to achieve the NO_x emissions reduction target set for mobile sources;
- The Chinese government should implement a nation-wide price premium for electricity generated from coal-fired power plants installed with well-functioning flue gas denitrification facilities;

The Chinese government should develop an effective checks-and-balance system for its NO_x control programs, one that involves non-governmental stakeholders. The system should be based on existing legal provisions and policies that encourage oversight by courts and citizens.