SO_2 EMISSIONS TRADING PROGRAM:

A Feasibility Study for China

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PREFACE ONE

On behalf of the U.S. Environmental Protection Agency, I would like to commend the research and findings of the Feasibility Study examining the potential use of market-based mechanisms for sulfur dioxide (SO_2) reduction in China.

Recognizing that the United States and China share a common interest in reducing the threat posed by SO_2 and fine particle pollution, EPA and China's State Environmental Protection Administration (SEPA) agreed to collaborate on this effort in April 1999. The basis for the study emerged from two Sino-U.S. workshops on SO_2 and emissions trading, as well as numerous small workgroup meetings. The use of market-based mechanisms—specifically the cap and trade approach in EPA's Acid Rain Program—has led to significant reductions in SO_2 emissions form the United States' power sector at a fraction of the expected costs. Moreover, reductions occurred at a time of rapid economic growth. The exploration of this policy option offers an appropriate approach to the pursuit of China's dual goals of increased economic output and a cleaner environment.

The Feasibility Study provides a history of U.S. acid rain programs and policies, with a detailed description of the design, operation, and results of our SO_2 cap and trade program. We continue to find that cap and trade delivers the most cost-effective approach with the greatest emission-reduction benefits from large sources. In fact, cap and trade is the cornerstone of our new Clear Skies Initiative, which will seek further emissions reductions from the U.S. electric utility sector.

This document details the fundamental elements for the development of an effective cap and trade program, and it identifies institutional barriers that need to be addressed. Highlighting some valuable lessons we have learned, the study should prove instructive to policymakers during the design of SO_2 control policies specific to the needs and circumstances in China.

With the study providing a strong foundation for progress, EPA looks forward to continued collaboration with SEPA on the reduction of SO_2 and fine particle pollution.

Christine Todd Whitman
Administrator
U.S. Environmental Protection Agency

PREFACE TWO

During Premier Zhu Rongji's visit to the United States in April 1999, Mrs. Carol M. Browner, former administrator of U.S. Environmental Protection Agency (EPA), and I co-signed a file of intent for bilateral cooperation on creating a Feasibility Study on Reducing SO_2 Emission through Market Mechanism in China. The cooperative project has been implemented by the Department of Planning and Finance of the China State Environmental Protection Administration (SEPA) and the Clean Air Markets Division of U.S. EPA. The objective has been to introduce market mechanisms to achieve SO_2 control targets in China, using the successful U.S. experience in SO_2 pollution control, especially in the field of SO_2 allowance trading as a reference.

Air pollution has long been one key field in environmental protection in China. From 1996 to 2000, China's GNP increased by 8.3 percent annually while the total amounts of 12 main pollutants, including SO_2, decreased by 10-15 percent, compared with the levels in 1995. The deteriorating trend of environmental pollution has been basically controlled, with environmental quality in some cities and areas improving. However, China's current environmental situation is still very challenging, and the total amounts of some pollutants are still high. In 2000, China's SO_2 emission was 19.95 million tones, much higher than the environmental loading capacity. In some areas, the environmental problem has been one significant factor that does harm to human health and restricts the economic development and social stability.

China has identified stricter national environmental protection objectives for the Tenth Five-Year Plan Period (2001~2005). By 2005, the total SO_2 emission should be reduced by 10 percent below 2000 levels, while the SO_2 emissions in SO_2 Pollution Control Areas and Acid Rain Control Areas should be reduced by 20 percent. This difficult task will directly affect the ability to realize the environmental protection objectives and socioeconomic strategic objectives in the Tenth Five-Year Plan Period. China is now under the key stage of implementing the Tenth Five-Year Plan. Controlling the total pollutants is the main method of environmental protection in the Tenth Five-Year Plan Period. It is very important to adhere to the combination of governmental regulation and market mechanisms, to create new mechanisms and implement scientific decision-making, and to comprehensively apply legal, economic, public participation, and other instruments, for the realization of environmental protection objectives for the Tenth Five-Year Plan Period, and

for promotion of coordinated economic, social, and environmental development.

The control of SO_2 requires significant manpower, materials, and financial resources, China's economy is still in a developing stage, and this study thus provides a good exploration for the use of market mechanisms in China to reduce SO_2 pollution with minimal costs. Over the last three years of implementation, officials, experts, and enterprise representatives from both sides have communicated widely and deeply on the platform created by the project. From November 1999 to October 2000, two Workshops on the Feasibility of SO_2 Emission Trading in China were respectively held in Beijing and Washington. Several visitor exchanges and personnel trainings have also been organized. Through these methods of communication, mutual understanding has been strengthened between both sides, which has laid a sound basis for the completion of the study.

This feasibility study is the result of great efforts of experts, enterprise representatives, and governmental officials from both sides. Local environmental protection bureaus in Chinese pilot cities have also contributed a lot. Herein, I, on behalf of China SEPA, express sincere thanks to all of these people.

Xie Zhenhua
Administrator
China State Environmental Protection Administration

ACKNOWLEDGEMENTS

This report is the result of the 1999 Sino-U.S. joint environmental protection project "The Feasibility of Using Cap and Trade to Achieve Sulfur Dioxide Reductions in China". The report was completed jointly by several agencies including the Chinese Academy of Environmental Planning, Chinese Research Academy of Environmental Sciences, and the Clean Air Markets Division of the United States Environmental Protection Agency (U.S. EPA), under the guidance of both the China State Environmental Protection Administration (SEPA) and the U.S. EPA.

As the final product of the Sino-U.S. joint environmental protection project, the respective project management offices played decisive roles in the completion of this report. As the China team's coordinator, Mr. Wang Yaoxian, the Vice Director of the Planning and Finance Department of SEPA, directed the research of the China team and contributed much effort to the report. Taking the perspective of China's air pollution control management, he made many constructive comments on the project's framework, report's contents, and workshop's organization. He also conducted final review of the report. Liu Qifeng and Hong Yaxiong, the former Directors, and Zhao Jianzhong, the current Director of the Planning and Finance Department of SEPA, and Fang Zhi of SEPA also managed and coordinated the China team's work. Zhang Shigang, Vice Director General, and Zhang Lei, Zhong Xiaodong, and Fang Li of SEPA's International Cooperation Department, Mrs. Li Lei and Mr. Liu Zi of SEPA's Pollution Control Department supported this project. We want to extent our sincere appreciation for their support and directions.

Dr. Brian J. McLean, Director of the Office of Atmospheric Programs of the U.S. EPA, led the U.S. team on this multi-year project. Dr. McLean participated in workshops in Beijing and Washington and in discussions of the nuances of designing a framework for cap and trade in China. He also provided useful direction and comments on technical drafts of this report. His dedication to refining the art and science of cap and trade programs has been an ongoing inspiration. We would also like to thank the staff of U.S. EPA's Clean Air Markets Division, including Kevin Culligan and Jennifer Macedonia. The commitment and enthusiasm of these staff and others in the Clean Air Markets Division helped make this project a success.

The U.S. based non-governmental organization Environmental Defense (ED) in partnership with the Beijing Environment and Development Institute helped with pilot

studies in two Chinese cities. We also want to express our appreciation to these organizations for their contribution of emissions trading experience in China, an indispensable part of the entire study.

Another U.S. based non-governmental organization, Resources for the Future (RFF), has also been instrumental in providing technical assistance for the implementation of emissions trading programs in China. Richard Morgenstern, Ruth Greenspan Bell, Alan Krupnick, and Zhang Xuehua of RFF, in cooperation with several experts from the Chinese Research Academy of Environmental Sciences (CRAES), including Prof. Wang Jinnan, Mr. Cao Dong, and Dr. Yang Jintian, helped create the infrastructure and understanding to make emissions trading programs possible in Shanxi province. Their experiences and insights are highlighted in this report.

We would also like to thank Professor Denny Ellerman of the Massachusetts Institute of Technology and Dr. Eric Zusman of UCLA. Professor Ellerman's contribution to the analysis of the integration of China's pollution levy fee with an emissions trading program, and his participation in the workshops has been invaluable. During Dr. Zusman's stay at CRAES in 2001, he spent over a month assisting with the translation of the China team's report sections. His rich technical knowledge and language capabilities (English and Chinese) enabled him to translate the report from Chinese into English accurately. Prof. Chen Fu, former President of CRAES, and Prof. Zou Shoumin, First Vice President of Chinese Academy for Environmental Planning (CAEP), coordinated work of Chinese experts in the initial and final stage of the project, and participated in discussions and provided comments. We wish to thank them for their contributions.

Appreciation and thanks are also offered to Roger Rihm, David Hathaway, and Maria Chen of ICF Consulting, Noreen Clancy, Paulette Middleton, and Hongjun Kan from RAND Corporation, and Gan Lin of WWF, for their assistance and support for this project.

Lastly, we want to give special thanks to Administrator Xie Zhenhua of SEPA and Administrator Christine Whitman of U.S. EPA for providing support to the successful implementation of the project.

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EXECUTIVE SUMMARY

This study explores the feasibility of using emissions trading in China to achieve reductions in sulfur dioxide (SO_2) emissions. It was developed through a multi-year collaborative process that examined lessons learned from the United States (U.S.) SO_2 emissions trading program and considered their implications for China. The U.S. and China have both determined SO_2 emissions and associated secondary particles to be damaging to human health, lakes and streams, forests, buildings, monuments, and visibility. The U.S. has successfully used emissions trading, a market-based mechanism, in concert with an emissions cap to reduce SO_2 emissions at the lowest cost. China is investigating policies that will meet the dual goals of promoting economic development and protecting public health and the environment. Based on this mutual interest, a strategic collaboration was initiated between China and the U.S. On April 9, 1999, China's State Environmental Protection Administration (SEPA) and the U.S. Environmental Protection Agency (EPA) signed a Statement of Intent to prepare a feasibility study on the use of market mechanisms to achieve SO_2 emission reductions in China.

Background

Controlling SO_2 in China

SO_2 emissions in China are produced at numerous large and small stationary sources, primarily as a result of coal-fired boilers for producing electricity or running other industrial and commercial processes. Sources of emissions in China include a wide variety of enterprises such as power plants, cement manufacturers, and other small industrial enterprises. Based on current estimates, approximately 40 percent of all SO_2 emissions in China are related to power production.

In 2000, SO_2 emissions in China reached nearly 20 million tons. Approximately 70 percent of cities in southern China, representing approximately 30 percent of China's landmass, are exposed to acid rain. These figures suggest that China has become one of the three largest acid rain regions in the world. According to estimates from the Chinese Research Academy of Environmental Sciences (CRAES), the total economic loss stemming from SO_2 pollution and acid rain totaled 110 billion yuan (approximately $13.3 billion) in 1995,

close to 2 percent of China's Gross National Product that year.

The Chinese government has attached great importance to the control of SO_2 and has adopted a series of control measures. These measures include the designation of "two control zones" (one focused on high levels of acid precipitation and the other on high ambient SO_2 concentrations) and a pollution levy fee on SO_2 emissions. In addition to these measures, China has formulated a set of technology policies related to SO_2 emissions, such as restricting the use of high sulfur-content coal, requiring coal washing, and employing flue gas desulfurization.

The cornerstone of recent Chinese air quality policy is the Total Emissions Control (TEC) program. The TEC program specifies a national SO_2 emission target and allocates the target to the provincial and municipal levels. China's "Tenth Five-Year Environmental Protection Plan" set the TEC limit at 10 percent below 2000 emissions levels nationwide and 20 percent below 2000 levels in the two control zones. These reductions must be met during the Tenth Five-Year Plan period (2001 to 2005).

The structure of the TEC policy, which includes setting national emissions limits, could form the foundation for a "cap and trade" program. A strictly managed total cap on emissions is a necessary element for an emissions trading program, and an effective cap will ensure that the environmental goal is met. The use of emissions trading helps ensure that emission reductions are made cost effectively, since trading encourages reductions where they are least costly. Experimentation with pilot projects in the 1990s gave China some experience with the potential benefits of emissions trading. The TEC policy, combined with improved management capacity, an evolving market economy, and new environmental requirements suggest China might be ready to formally embrace emissions trading.

The Use of SO_2 Emissions Trading in the U.S.

The U.S. has successfully used a cap and trade program to cost effectively reduce SO_2 emissions from large electricity generating sources. A cap and trade program sets an overall emission limit for power plants (the cap) and harnesses the power of the market (trading) to achieve desired environmental results at lower costs. More than 6 million tons of SO_2 have been reduced from sources affected by the program during a period of rapid economic growth. Cost estimates for achieving the full 8.5 million ton reduction goal have decreased dramatically from original estimates. The success of the U.S. SO_2 trading program has led to the application of cap and trade to reduce emissions of oxides of nitrogen (NO_X) in the Northeastern U.S. states. More recently, the U.S. has proposed using cap and trade to further limit emissions of SO_2, NO_X, and mercury emissions from power plants.

The U.S. experience has shown that a cap and trade system can produce

cost-effective SO_2 emissions reductions. How well future cap and trade programs work in China or other countries will be a function of the underlying design elements of the program and the strength of the infrastructure supporting them. Key lessons learned in the U.S. that might be transferable to China include:

- *Design*. Several overarching principles—simplicity, accountability, transparency, predictability, and consistency—should guide the development of a cap and trade program. Adhering to these principles can promote compliance and an efficient emissions trading market.
- *Infrastructure*. Institutions and incentives needed for the trading market to function include a system of private contracts and property rights, at least a partially profit-driven private sector or cost-minimizing enterprises, and respect for the rule of law.
- *Data accuracy*. It is critical to have accurate, consistent, complete, and transparent emissions information. This ensures both environmental credibility and economic efficiency.
- *Data tracking*. An efficient system for managing and tracking emissions and allowance data will facilitate administration of the program, enhance market operations, and reduce errors.
- *Compliance and enforcement*. As with all environmental programs, a cap and trade program requires effective enforcement to ensure that environmental and cost-savings objectives are met. For an emissions market to develop, there must be confidence that emissions will be correctly measured and reported, that compliance will be verified, and if there is noncompliance, that a penalty significantly greater than the cost of compliance will be assessed.

There are, of course, some noteworthy differences between China and the U.S. China's economic, political, and policymaking systems differ in many ways from those in the U.S. China and the U.S. also differ in their use of pollution control technologies, environmental management techniques, and experience with private markets. Such differences must be taken into consideration when introducing SO_2 emissions trading in China.

Key Findings

The use of emissions trading to achieve SO_2 reductions in China is feasible. Several factors lead to this conclusion. The environmental nature of the problem, the potential cost savings from trading, and the current improvements in infrastructure all provide optimistic signs for the use of emissions trading in China. However, significant existing barriers still need to be addressed before emissions trading could be effectively used on a large scale in China. These issues are explored below.

Cap and Trade Structure: an Appropriate Solution to Address China's SO_2 Problem

Acid rain and SO_2 problems in China are regional in nature. Cap and trade allows some flexibility in where emissions occur; therefore, it is an appropriate policy tool. Cap and trade mechanisms are most effective when they address emission reductions over a large geographic area.

A Range of Marginal Control Costs for Sources

There are a wide variety of marginal control costs among SO_2 emitting sources in China (i.e., different costs for different enterprises.). Marginal control cost differences result from the age of the facility, technology availability, location, fuel use, and other factors. Since a wide range in marginal control costs exists in China, an emissions trading program can help find the least cost approach for the participating sources. Sources with low compliance costs typically over-comply and sell their excess reductions to sources with higher compliance costs. From the perspective of the power industry, establishing a national market for emissions trading is feasible because it should help level disparities between different thermal power plants in pollution abatement costs.

Infrastructure for Cap and Trade Forming in China

While still far from complete, the infrastructure necessary to support a cap and trade program is beginning to emerge in China. China has already begun experimenting with pilot emissions trading projects. In 2000, China revised its Air Pollution Control Law to provide legal authority for the TEC policy, which establishes an emission target (like a cap) for SO_2. SEPA is currently developing administrative regulations to implement the TEC policy that will include language on emissions trading. Provisions in related strengthen the fundamentals for emissions trading through the creation of pollution permits. In 1997, a law was implemented that requires the installation of continuous emissions monitors (CEMs) for SO_2 on new or modified thermal power plants in the two control zones.

A Cap and Trade Program is Compatible with the Existing Pollution Levy System

Developing an SO_2 emissions trading program is a systematic process involving a complex array of regulatory, program design, and program management issues. One of the key issues is to blend an emissions trading program with existing traditional regulations and economic instruments. If China is to use emissions trading to reduce SO_2 emissions, the relationship between the trading program and the pollution levy system needs to be addressed. The pollution levy system is among the oldest and most important

components of China's regulatory structure for controlling SO_2 emissions. The levy system is also used to help fund the local environmental protection bureaus.

An expert economic analysis from the Massachusetts Institute of Technology was commissioned for this study to examine the interaction between an emissions trading system and China's pollution levy system. The analysis concludes that, if carefully constructed, an emissions trading program could be designed to interact smoothly with the existing pollution levy program, with the cap and trade system as the main economic instrument. In the U.S., for example, permit fees on power plants seamlessly coexist with the SO_2 cap and trade program (permit fees are collected to cover the administrative cost of the permit program).

Barriers to Cap and Trade in China

After analyzing the current infrastructure and policies for SO_2 control in China, the study team identified the following issues in need of attention prior to the widespread introduction of SO_2 emissions trading in China.

- *Emissions monitoring, verification, and reporting*: An SO_2 emissions trading program requires the accurate and consistent measurement of all emissions. At present, China has in place an emissions declaration (self-reporting mechanism) and a system to verify emissions data on an annual basis. However, a significant gap still exists between current practice and an adequate emissions monitoring and reporting plan that could support a cap and trade program in China.

  Calculating emissions is a fundamental area in need of examination. The vast majority of enterprises in the power sector have not installed automated monitoring devices. The only exception to this rule are ten newly constructed power plants with automated monitoring capabilities, but even among these enterprises, monitoring systems are not being effectively operated. Consistent norms for installing and operating monitoring equipment are essential.

  The U.S. experience suggests that employing CEMS at pollution sources participating in a trading program promotes confidence in the program. Due to the large number of SO_2 emissions sources in China and the cost of installing such equipment, it will be difficult for China to install CEMs for all large sources in the near future. A transition phase will likely occur with regard to emissions measurement, in which some sources will use mass balance estimation methods while others will use CEMs. Facilities that use combustion or post-combustion controls should be the first priority for deploying CEMs because the sulfur content of the fuel is not a good indicator of total SO_2 emitted. The most important aspect of emissions measurement is that the method is as accurate and consistent across sources as possible.
- *The Power Sector*: Though currently undergoing reform, the Chinese power industry

is primarily a state-owned industry. Currently, sources cannot pass the costs for pollution controls onto consumers. If electricity pricing policies are not adjusted, the electricity industry will lack revenue channels and the flexibility necessary to operate in a market-driven trading environment, making it difficult to adopt effective measures. Presently, China is conducting research on electricity pricing reforms.

- *Economic Reforms*: Cap and trade programs use market forces to reduce overall compliance costs. However, at present China still has largely a planned economy. Additional market reforms that further link enterprise-level decision making to market forces rather than planning mandates might be needed to support the use of emissions trading in China.
- *Legal Support*: China's current air pollution prevention and control law supports the use of TEC; however, it does not yet directly support the use of emissions trading. It indirectly suggests using economic and technical measures to control air pollution, which implies that it is possible to employ emissions trading. However, there is a lack of explicit legal provisions regarding emissions trading in the new law. Without explicit legal and regulatory authority, it is doubtful that emissions trading can be successfully applied.

Recommendations

In summary, China is developing the necessary infrastructure for application of SO_2 emissions trading, but there is still a considerable amount of work to be done. Infrastructure improvements are needed in the areas identified below. Recommendations are also offered regarding the initial framework for an emissions trading program.

Infrastructure Improvements

The study team recommends the following key infrastructure improvements to support the future use of emissions trading in China.

- Establish clear legal authority to enable emissions trading. A legal basis for emissions trading should be developed by SEPA through "Administrative Regulations." These regulations should then be approved and enacted by the State Council. The regulations should cover criteria for including sources in the trading program, protocols for emissions monitoring and verification, procedures for compliance determination, and consistent practices for charging enforcement penalties.
- Strengthen emissions monitoring and reporting practices. Promote the use of CEMs for SO_2 monitoring wherever that is economically feasible and develop more consistent and accurate emissions estimation measurement protocols for

sources not using CEMs. The use of CEMs is particularly important where combustion or post-combustion controls are used.

- Establish a consistent and comprehensive emissions verification procedure.
- Establish emissions tracking and allowance tracking systems. The emissions tracking system will help manage the large volume of emissions data collected and will ultimately need to be highly automated with sources using CEMs. Allowance tracking will be critical for verifying "ownership" of allowances and for determining compliance at the end of each year. The tracking system should be designed to enable regulators, stakeholders, and the public to have access to the data.
- Continue training programs. Extensive training programs should be developed and used to educate facility operators and program administrators about the theory and practice of emissions trading.

Framework for Implementation

Similar to other new policy initiatives in China, continued experimentation and capacity building at the local level with emissions trading is likely to proceed a large regional program. Once China moves forward in adopting a broad emissions trading program, it should be aimed at combating acid rain in the regions where the problem is most severe, focused initially on major pollution sources, and phased in gradually to cover more area and more sources. With additional legal stature, the current TEC program in the five-year planning cycle provides a foundation for setting the SO_2 emissions cap on both a national and regional scale (for the two control zones).

Based on the regional nature of the SO_2 problem and China's current SO_2 policy and management framework, the scope of the tradable permit program should be first implemented in the two control zones with the first stage of the project focusing on large-scale power plants in the two control zones. Power plants are recommended because they contribute over 30 percent of the total SO_2 emissions in China and are projected to continue growing as electricity spreads into more rural areas across the country. Large plants are also more easily monitored and controlled at this time in China. The current five-year planning cycle could be a convenient platform for allowance allocations and program evaluations.

One possible option for the incremental establishment of an SO_2 emissions trading program would be to structure program development in four phases, as follows:

- Stage One: During the introductory pilot stage the scope of emissions trading should be limited to large scale power plants (annual SO_2 emissions exceeding 5,000 tons per year) in the "two control zones";
- Stage Two: On the basis of the pilot results, the trading program should be

extended to all large power plants in the “two control zones”;

- Stage Three: The trading program could then be extended to all large power plants in China; and
- Stage Four: Eventually trading can cover other types of large boilers, potentially including industrial sources.

Summary

Although China does not yet have all of the needed institutional capacity in place to support a broad regional emissions trading program, it is feasible to develop that infrastructure and to use emissions trading to achieve SO_2 reductions in China. Infrastructure needs to support a cap and trade program include: accurate, consistent, and complete mass-based emissions monitoring as well as consistent and objective enforcement practices. Further development of these fundamental capabilities will greatly enhance China’s ability to use economic instruments such as cap and trade. The development of this infrastructure will also improve the efficacy of all of China’s current and future air quality management policies.

Building the supporting infrastructure and using emissions trading in China will require considerable time, resources, and effort. However, once established, such a system will enable better emissions management and overall cost reductions in achieving the desired environmental goal. This will be particularly important as China’s economy grows and reliance on electric power increases.

INTRODUCTION

Air Pollution's Effect on the Environment and Human Health

The 1990s was a decade of great transformation for China. China's population grew to 1.27 billion in 2000, and with it, increases in urbanization and economic growth have been extraordinary. The average annual rate of growth of gross domestic product over the past two decades has been 9.6 percent. The tremendous economic expansion and all the ensuing changes exerted significant stress on China's natural environment. The growth in population, industrialization, and urbanization has led to a severe air pollution problem in many of China's cities, with very large economic and quality of life costs. China has realized that the rate at which these changes have occurred has outpaced its current policies, especially regarding air quality.

Coal is China's most abundant fossil energy resource. Air pollution from the burning of coal and other fossil fuels is the most prominent urban environmental problem in China. It is both an ecological and human health problem. Particulate matter and SO_2 are China's most significant air pollutants. Epidemiological studies have shown that an exposure-response relationship exists between particulate and SO_2 concentrations and several adverse health effects leading to increased hospital visits, such as loss of pulmonary function, chronic respiratory illness, bronchitis, and premature death. In China, these health and productivity losses associated with urban air pollution are estimated at more than $20 billion a year (World Bank, 1997). As of 2000, two-thirds of China's cities that are monitored were out of compliance with the nation's ambient air quality criteria, which indicates a serious air quality problem.

Sulfur oxides are released when fossil fuels are burned. They mix with other hydrocarbons in the atmosphere and form sulfuric acid. These gaseous emissions can remain in the atmosphere for several days where they can be transported long distances by wind, or they can be scavenged from the atmosphere by rain, snow, or fog and deposited to the earth's surface. This phenomenon is referred to as acid rain or, more accurately as acid deposition. At the beginning of this century about one-third of China was affected by acid deposition, which has been shown to reduce forest and crop growth as well as harm aquatic life. Certain ecosystems are more sensitive to the damaging effects of acid deposition. Those sensitive regions in China are the subtropical evergreen

forests of southern China, the high-altitude tundra of Tibet and parts of Qinghai Province, the coniferous forests in northeastern China, and parts of southwestern and eastern China where acid deposition is expected to be extremely high in the future. Model estimates put current crop and forest losses at $5 billion a year (World Bank, 1997).

Building a Policy Solution

As China continues to develop, its demand for energy will grow, as will its reliance on coal to meet those energy demands. New strategies are needed to ensure that air pollution does not increase unchecked with the increasing use of electricity. A variety of policy options are available for reducing SO_2 and a combination of such policies will be needed before China can meet its air quality standards. Due to the U.S.'s success in reducing SO_2 emissions during a period of economic growth, emissions trading is a policy option that is of particular interest to China. The U.S. now has over ten years of experience in all the components needed to establish a successful trading program such as setting an emissions cap, allocating emissions, monitoring and tracking of emissions and trades, and enforcement. When China expressed an interest in exploring the use of an emissions trading program for SO_2, a natural collaboration between China and the U.S. was formed.

China-U.S. Bilateral Cooperation on Emissions Trading

The first step in the cooperative effort was a joint workshop hosted by the U.S. EPA and SEPA held in Beijing in November 1999. The workshop was structured to facilitate information exchange among Chinese and U.S. experts on SO_2-related issues. Participants included experts from the government, power sector, academia and environmental organizations of both countries. Current SO_2 related policies were discussed along with the use of emissions trading in the U.S. and results of pilot emissions trading projects in China.

After developing working papers, U.S. EPA and SEPA held a second joint workshop and training session in Washington, DC, in October 2000. The one-day training session featured an in-depth discussion of the science and policy debate leading up to passage of the U.S. SO_2 cap and trade program legislation. A tour and demonstration of the emissions and allowance tracking systems at U.S. EPA was also included. The workshop itself showcased presentations by U.S. and Chinese experts working collaboratively to address the various issues associated with developing an emissions trading framework tailored to the specific needs and resources in China. This study embodies years of work by Chinese and U.S. experts to examine the feasibility of using emissions trading to reduce SO_2 emissions in China.

Similarities and Differences between the U.S. and China

The starting point for emissions trading in the U.S. came at a different time during the country's development than it will for China. By the time emissions trading was introduced in the1990s, the U.S. had already eliminated the use of coal from its residential sector and railroads, leaving one dominant source of SO_2 emissions—electric utilities—which accounted for over 70 percent of all SO_2 emissions in the 1980s. China's distribution of SO_2 emissions sources is different, with 40 percent of emissions stemming from electric utilities. Other major sources of SO_2 emissions include residential (cooking and heating) and industrial coal combustion. The 40 percent from electric utilities is a significant portion of emissions that could be addressed cost effectively with a cap and trade program.

The obvious differences between the U.S. and China mask some very interesting similarities related to planning an emissions trading program. Both countries are of an equivalent landmass with a westerly wind pattern and a more populated East. Both have a sufficient number of sources emitting SO_2, and within those sources, there are varying abatement costs to reducing emissions, which is a key component to a successful trading program. In China, environmental policy is developed at the national level and implemented and enforced at the local level. This is similar to some air quality policies in the U.S. where standards for criteria pollutants are established at the national level by U.S. EPA but individual states are required to ensure compliance with the standards. Other policies, including the SO_2 emissions trading program, are administered by EPA at the federal level. The similarities in policy environments tend to diverge at this point, with China delegating much more authority to the local level than the U.S. Regardless of the differences, the U.S. trading program can serve as a model for designing a trading program that will be effective in China.

Pilot Programs

The national authorities in China encourage experimentation at the local level with new policy tools, usually in the form of pilot programs. In China, pilot programs are currently the mode by which emissions trading is being introduced to the nation. Much useful information and experience is being gained through these pilot efforts to help determine effective measures that can be adopted on a national level.

Report Contents

Chapter I outlines the use of SO_2 emissions trading in the U.S. and discusses the different elements that constitute the program. A thorough technical description of the

design and operation of the U.S. SO_2 emissions trading program is included. The economic and environmental results of the program are also highlighted.

Chapter II reviews the current policies to address SO_2 emissions in China, along with insights into how such policies could interface with an emissions trading system. The formulation of program elements that could collectively support an SO_2 emissions trading framework in China are discussed. Lessons learned from emissions trading pilot projects in China are highlighted in Chapter III.

Three expert technical analyses were commissioned to help illuminate key issues. These analyses are presented Chapter IV and they include:

- *Designing a Tradable Permit System for the Control of SO_2 Emissions in China* explores the interaction between China's existing pollution levy system and a future emissions trading program. The analysis was developed by A. Denny Ellerman at the Massachusetts Institute of Technology.
- *Using Science to Set Environmental Goals and Understand Environmental Implications in China* describes analytical tools useful in policy making that help characterize the relationship between emissions and environmental impacts. The analysis was developed by Paulette Middleton, from the RAND Corporation and Meng Fan from the Chinese Academy of Environmental Sciences.
- *SO_2 Emission Control Technologies and Associated Costs for the Chinese Power Sector* discusses SO_2 emission control technologies available to the Chinese power sector and their costs. The analysis was compiled by Hongjun Kan and Noreen Clancy of the RAND Corporation.

PART ONE: EMISSIONS TRADING EXPERIENCE IN THE UNITED STATES

Stephanie Benkovic, Katia Karousakis, Joe Kruger, Melanie LaCount, Jennifer Macedonia, Beth Murray, Jeremy Schreifels, Janice Wagner, Chad Whiteman

1. Background

This section provides an overview of the history of environmental issues and regulatory responses to SO_2 in the US.

1.1 History of SO_2 Emissions in the U.S.

Emissions of SO_2 in the U.S. have varied considerably in the last century. As illustrated in Figure 1, between 1900 and 1970 total annual emissions in the U.S. more than tripled, increasing from 10.0 to 31.1 million tons. Since SO_2 emissions are directly related to fuel use, particularly the burning of coal, emissions tend to mirror the use of coal in the economy.

Prior to 1955, coal was used extensively as a fuel in many sectors of the economy. Particularly notable is the use of coal in the category of “Fuel Combustion – Other”, which includes residential heating. After that point the U.S. transitioned to using natural gas for residential hearing and cooking needs. Another large portion of the inventory in the 1940s and 1950s is from non-road engines, including the railroads an industry primarily fueled by coal at that time. In the above figure, the early increases in emissions (1900 to 1930) can be attributed to the country's industrialization. A decrease in emissions is seen at the time of the “Great Depression”, a period of severe economic decline. As the economy rebounded, emissions climbed again, peaking around the time of World War II. Over time, rail transport declined, and railroads switched over to diesel-powered locomotives. At the same time, home heating and industrial uses shifted to other, cleaner fuels such as natural gas. Meanwhile, the use of coal increased significantly in the electric utility sector. By 1970, more than half of the SO_2 emissions in the U.S. came from fuel combustion in the electric utility sector. In the 1970s, when emissions were at their highest, annual ambient SO_2

concentrations were above 0.02 parts per million (ppm) at some sites near the vicinity of large industrial facilities.

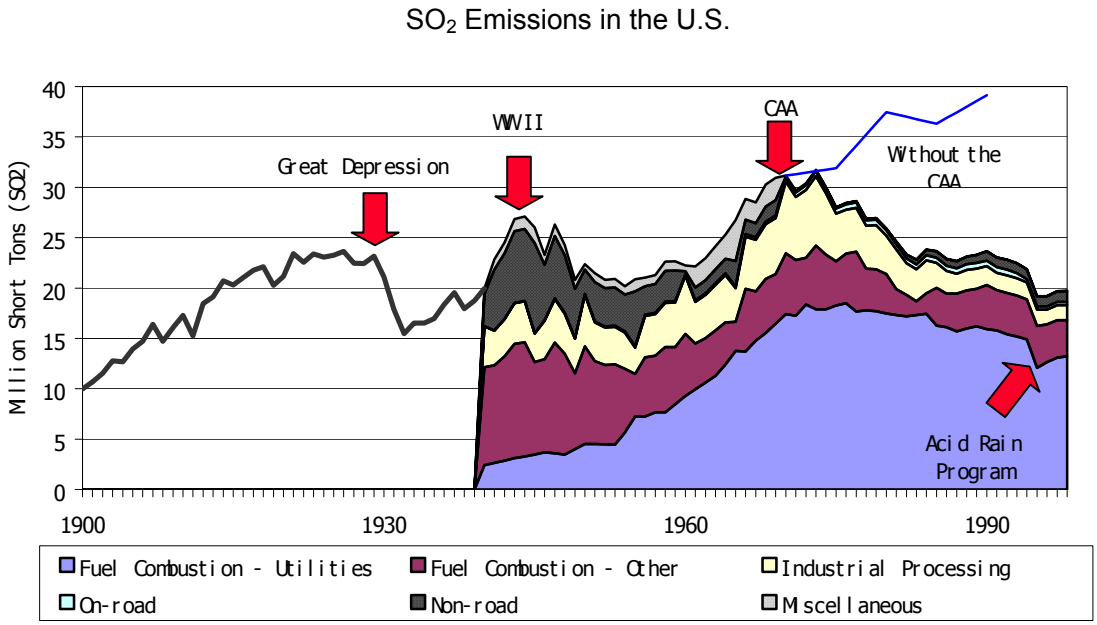

Figure 1 Historical Trends in SO_2 Emissions from 1900 to 2000 (Source: USEPA)

Between 1970 and 1980, nearly all non-utility sectors had decreasing SO_2 emissions while the utility sector's emissions remained stable, resulting in an increasingly large contribution to total SO_2 emissions in the country. Forecasts done in the 1980s showed SO_2 emissions increasing in the utility sector through the 1990s as demand for electricity increased and the industry continued to rely on coal-fired generation. Along with the influx of SO_2 emissions came the emerging realization that these emissions cause health and environmental impacts.

1.1.1 Building the Foundation for Emissions Reductions: Establishing a National Acid Precipitation Assessment Program

In the late 1970s, the President's Council on Environmental Quality asked scientists to initiate a long-term, interagency research and assessment program to study acid rain. With Administration support and congressional action, the Acid Precipitation Act of 1980 became law. During its first 10 years, the research conducted by the National Acid Precipitation Assessment Program (NAPAP) furthered understanding of the scientific processes and effects of acid deposition. Peer reviews, workshops, and annual reports throughout the 1980s culminated in the NAPAP State of Science and Technology Reports

published in 1991 and the NAPAP 1990 Integrated Assessment Report (NAPAP, 1991). The monitoring and research conducted in the 1980s and the subsequent integrated assessment provided a significant part of the scientific knowledge base.

NAPAP was coordinated by an Interagency Task Force consisting of representatives from 12 Federal agencies, four National Laboratories, and four Presidential appointees. More focused program direction was provided by a Joint Chairs Council, which was made up of executive officers of the U.S. EPA, the National Oceanic and Atmospheric Administration, the Departments of Agriculture, Energy, and the Interior, and the President's Council of Environmental Quality. Additional participating agencies included the National Aeronautics and Space Administration, Tennessee Valley Authority, the National Science Foundation, and the Departments of Health and Human Services, Commerce, and State.

The Joint Chairs Council established a program management structure that involved appointing a Director of NAPAP and setting up two interagency committees. The NAPAP Director was the executive manager of all research and assessment activities. The two committees were responsible for the scientific quality and the policy relevance of NAPAP research and assessment activities; hence, the Interagency Science Committee and the Interagency Policy Committee were formed. These committees were made up of senior representatives of the six agencies that comprise the Joint Chairs Council.

NAPAP Budget

NAPAP began in 1980 with a budget of $10 million dollars a year. The budget continued to climb for the next five years and peaked at $65 million dollars a year. During those first 10 years, a total of more than $500 million dollars was spent by the U.S. government to study and better understand the scientific and technological aspects of acid deposition and its control. Approximately 300 scientists and 100 peer reviewers participated in conducting and evaluating the research and its subsequent scientific reports.

NAPAP Process and Deliverables

At the outset, NAPAP expended much effort in identifying the list of scientific, technical, and economic questions that needed to be addressed. Based on these questions, NAPAP formed task groups in the following areas to address the questions: emissions and controls, atmospheric processes, atmospheric transport and modeling, atmospheric deposition and air quality Monitoring, terrestrial effects, aquatic effects, and effects on materials and cultural resources. The task groups members were scientists and experts from the participating NAPAP agencies. The task group leaders were responsible for the coordination of research and assessment activities in their particular subject areas. The task group leaders reported to both the NAPAP Director and their respective agencies.

In 1988, NAPAP organized three assessment working groups for the purpose of assessment development based on the science. These working groups were in the subject areas of atmospheric visibility, human health effects, and economic valuation. NAPAP's assessment at the end of 10 years consisted of two parts. The first was a series of 27 reports titled *State of Science and Technology Reports* commissioned by the task groups that documented the scientific and technical information covering the range of acid deposition causes, effects, and control options. The reports were subject to several levels and phases of review—interagency review by the NAPAP Task Force agencies, peer review by independent experts, and open public review by interested persons. The information in these reports served as the basis for the second part, NAPAP's *Integrated Assessment Report*.

The integrated assessment was an interdisciplinary activity where findings from the various disciplines were coordinated to produce a better understanding of the cumulative impacts of acid deposition. Developing the integrated assessment involved evaluating data, models, illustrative future scenarios, and control technology information for the purpose of analyzing the effects of various control options, thereby linking assessment to the underlying technical information. The integrated assessment also involved much interpretation of the science and the goal of communicating the results in policy-relevant terms.

NAPAP did not wait until the end of the 10 years to begin communicating its progress and results to policymakers and the public. NAPAP produced annual progress reports to Congress and was frequently requested to testify before Congress on its current status (in the first five years alone, the NAPAP Director testified before Congress 12 times). Therefore, by the time the Clean Air Act was reauthorized in 1990, the general level of knowledge on acid deposition and its effects had been moved forward to help inform the debate.

1.1.2 Results of NAPAP: The 1990 Report

NAPAP developed an integrated analytical assessment to examine the relationship between acidic deposition/air pollutant concentrations and aquatic effects, terrestrial effects, effects on materials and cultural resources, human health effects, and visibility effects. The assessment characterized how acidic deposition or air pollutant concentrations affect these specific resources. The scientific findings describing the environmental impacts, and in some cases quantifying those impacts, helped to inform the debate leading up to passage of the 1990 Clean Air Act Amendments. A more thorough discussion of the modeling and quantification tools used in the integrated assessment can be found in NAPAP, 1991. A summary of the findings is presented below:

Aquatic Effects

Aquatic effects of acid deposition are both chemical and biological. Surface water chemistry can change and become more acidic when exposed to acidic deposition. The underlying geology plays a big role in how sensitive surface waters are to chemical changes from acidic deposition. In the U.S. most of the sensitive surface waters are surrounded by soils with low capacity to buffer acids and tend to be located in the Northeast. Once a water body becomes more acidic, additional acid cations entering the water create an environment that can be toxic to biota. This is largely due to the mobilization of aluminum. Some water bodies are naturally more acidic than others and tend to be sensitive to additional acidification from deposition.

It can be challenging to fully study and account for changes in surface water chemistry. The full chemical composition of the water body can provide analytical clues to the causes of acidification. The spatial relationship of water bodies and pollution sources provides additional clues. Historical records of surface water chemistry over time provide a rich source of information, but long-term records are not available at many sites. Laboratory tests on surface waters also provide another layer of information. NAPAP used data from all of these sources to the extent available to conclude that increased damage would occur in sensitive ecosystems if pre-1990 emissions trends were not reduced.

Terrestrial Effects

Damage to forests from acidic deposition and high air pollution concentrations was also examined in the NAPAP Integrated Assessment. Certain species of forest trees in North America and Europe had experienced declines in growth rates, foliage loss, and mortality. Localized areas of forest decline (mainly high-elevation red spruce) were found as a result of high acidic deposition combined with other stress factors. Though the effects of forest soil nutrient disruption were found at both high and low elevations, high elevation effects tended to be more severe—this being due to greater deposition at high elevations and the impact of acidic cloud water. Again, due to the underlying soil characteristics, most of the sensitive forests were found in the East.

Effects on Materials and Cultural Resources

Materials exposed to the elements will degrade from natural weathering processes. The presence of air pollution and acidic deposition can accelerate the rate of deterioration of certain materials. Materials susceptible to damage include monuments, historic buildings, outdoor structures (such as bridges), and automotive paints and finishes. For some materials, such as carbonate, steel, or nickel, the effects are apparent after about one year of exposure. For other materials, including copper and paints, effects may appear after about four years. Research suggests that materials containing calcium carbonate, such as limestone and marble, and galvanized steel are particularly sensitive to the effects of acid deposition.

Visibility Impairment

Links between SO_2 and sulfate aerosols and visibility are indirect, but quite strong. Small particles, such as sulfate aerosols, tend to scatter light and reduce atmospheric visibility. Though this link is well established, there are many other factors that have a pronounced influence on visibility, like relative humidity. The NAPAP study examined visibility data (primarily from historical airport records) and the role of sulfates in visibility impairment. The study found that variation in visibility reported at airports was closely correlated with variation in regional SO_2 emissions. In addition to affecting airport travel, reduced visibility can also degrade scenic vistas in National Parks and other areas. Data from the monitoring network in National Parks (Interagency Monitoring of Protected Visual Environments) have been collected and are used to track changes in visibility at National Parks.

Human Health Impacts

High concentrations of SO_2 can result in temporary breathing impairment for asthmatic children and adults who are active outdoors. Short-term exposures of asthmatic individuals to elevated SO_2 levels while at moderate exertion may result in breathing difficulties that may be accompanied by such symptoms as wheezing, chest tightness, or shortness of breath.

Other effects that have been associated with longer-term exposures to high concentrations of SO_2 in conjunction with high levels of particulates, include respiratory illness, alterations in the lungs' defenses, and aggravation of existing cardiovascular disease.

Emissions of SO_2 are transformed in the atmosphere to particulates of various sizes. Both large and small particles (less than 2.5 microns in diameter) can cause health impacts. A large body of epidemiological literature examines the relationship between ambient concentrations of particulates and health effects. Fine particles (less 2.5 microns) are particularly important because they easily penetrate the deepest portions of the lungs. Studies have found an association between exposure to fine particles and increased health problems, including premature death, cardiac and respiratory-related hospital admissions and emergency room visits, aggravated asthma, and acute respiratory symptoms (such as aggravated coughing and difficult or painful breathing).

Periodically, NAPAP studies the costs, benefits, and effectiveness of the U.S. SO_2 cap and trade program and develops a report to Congress. A description of NAPAP's continued role in program assessment appears in Appendix A.

1.2 Controlling SO_2 Emissions

1.2.1 Milestones in SO_2 Emissions Control

As environmental and human health concerns grew, policies aimed at reducing SO_2 and improving control technologies increased. The EPA was created in 1970 to start addressing these problems with the first set of environmental policy instruments for controlling emissions of SO_2. The Clean Air Act (CAA), established in 1970, was amended by Congress in 1977 and then again in 1990 to add new provisions for greater environmental protection. Some key air quality milestones include:

- National Ambient Air Quality Standards (NAAQS) and State air quality implementation plans (SIPs): An air quality management approach that establishes maximum ambient concentrations for criteria pollutants and requires states and local governments to develop plans to implement policies and measures to meet those standards (1970 CAA).
- Technology and performance standards: Emission and technological standards that set minimum performance thresholds for major stationary sources (1970 CAA).
- Review of major new and modified sources to prevent deterioration of air quality, particularly in national parks (1977 amendments).
- New policy to cap SO_2 emissions of electricity generating units and allow for emissions trading—known as the U.S. SO_2 cap and trade program (1990 amendments).

A discussion of these regulatory efforts and their interaction with the U.S. SO_2 cap and trade program is included in Section II.

1.2.2 How Changing Stack Heights Change Environmental Impacts

When the effects of local emissions were first encountered, engineers and policy analysts thought that increasing a facility's stack height would effectively eliminate the environmental problem. In fact, the emissions just settle out farther down wind. The 1990 NAPAP analyses of emissions by stack height suggest that, since 1945 more SO_2 emissions have been released in the atmosphere from stacks taller than 73 meters (230 feet) than from shorter stacks. By 1980, approximately 30 percent of the SO_2 emissions were emitted above 146 meters (480 feet), compared with only 5 percent in 1950 as shown in Figure 2. The percentage of the total SO_2 emissions released below 37 meters (120 feet) has generally decreased over the study period.

The height at which emissions begin to interact with their surroundings is usually higher than the physical stack height. The temperature and volume flow rate of the plume emitted from a stack affect how high the plume rises before it mixes with its surroundings. The higher the temperature and/or the greater the volume flow rate of the effluent at the top of the stack, the higher the plume rises the greater the "effective stack height" (physical stack height plus plume rise). Depending on stack and meteorological conditions, the effective stack height may be tens to hundreds of meters higher than the physical stack height. (The figure addresses only the physical stack height, not effective height.) The trend toward merging several stacks into one stack and toward higher temperatures and volume flow rates makes the percentage of pollutants emitted at higher effective heights even greater than shown in the figure.

Long-Term Annual SO_2 Emission Trend from Point Sources by Release Height

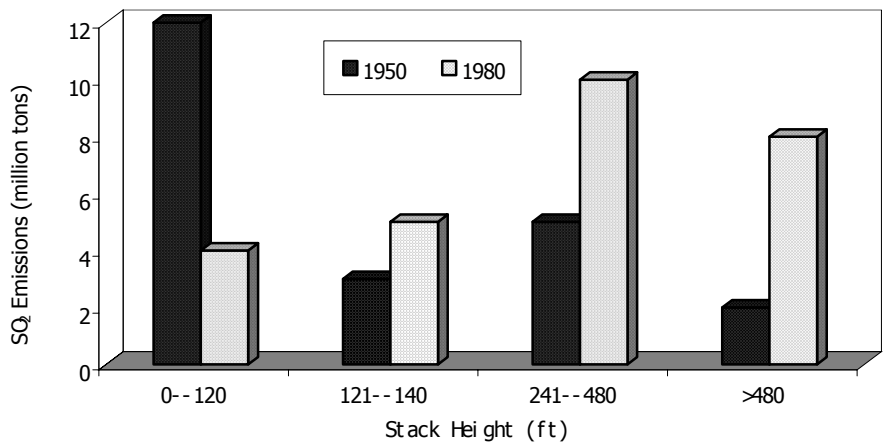

Figure 2 Comparison of Stack Heights of Large Point Sources in the U.S. (Source NAPAP 1991)

The effective height at which emissions are released into the atmosphere affects the efficiency with which emissions are transported and removed from the vicinity of the source. Hence, higher effective stack heights increase the long-range transport of pollutants because wind speeds generally increase with altitude. Greater effective stack heights also increase the time required for pollutants in the plume to be transported back to ground level by turbulence. High effective stack heights reduce the air concentrations and the dry deposition of emissions in the vicinity of a source by causing the pollutants to be more widely dispersed before they reach the surface. Thus, the trend toward release of emissions at higher levels results in a more distant transport of pollutants and more far-reaching environmental effects.

2. Theory and Practice of SO_2 Emissions Trading in the US

This section describes the beginnings of emissions trading practices in the U.S. Several different forms of trading have been used for a variety of situations, all with varying degrees of environmental and economic efficacy. Lessons learned from these early programs led to the evolution of the current cap and trade policy used to control SO_2 in the U.S. Some of these earlier forms of trading are still used today, though on a limited scale.

2.1 Offsets, Bubbles, and Credit Trading in the US

2.1.1 Early Forms of Emissions Trading

U.S. EPA first applied the concept of marketable emission permits in the mid-1970s as a means for new sources of emissions to locate in areas with poor air quality without causing additional air quality problems. New sources and existing sources that wanted to expand their facilities were required to offset their emissions by acquiring emission reduction credits from existing sources. This important but modest beginning was based on an interpretation of the CAA, rather than on a specific statutory authority. U.S. EPA's offset policy was included in the 1977 amendments to the CAA statute.

2.1.2 Foundations of Air Emissions Trading

U.S. EPA gradually broadened the offset policy to include emission bubbles, and netting which are described in the following paragraphs. While many of the achievements are modest, U.S. EPA's early efforts in emissions trading are important because they provided a foundation and valuable practical experience for the development of more effective trading programs such as the Acid Rain Program.

2.1.3 Offset Program

In the mid-1970s, the U.S. EPA proposed (and still uses) the "offset" policy that permits new sources to locate in areas not meeting air quality standards, provided that the new sources install air pollution control equipment which meets Lowest Achievable Emission Rate (LAER) standards. These sources also have to offset any remaining emissions (after application of LAER). The offsets must come from emission reductions made by other sources in the area. Through this process, growth can be accommodated

while maintaining progress toward attaining national ambient air quality standards.

Of more than 10,000 offset trades (a few of which are described later in this section), over 90 percent have been in California. Nationwide, about 10 percent of offset trades are between firms; the remainder are between sources owned by the same firm. Most offset credits are created as a result of all or part of a facility being closed.

The offset policy, which was included in the 1977 amendments to the CAA, created three related programs: bubbles, banking, and netting. The common element in these programs is the Emission Reduction Credit (ERC), which is generated when sources reduce actual emissions below their permitted emissions and apply to the state for certification of the reduction. For a source to receive an ERC the state must determine that the reduction meets the following criteria: (1) that the reduction is surplus in the sense of not being required by current regulations in the State Implementation Plan (SIP); (2) that it is enforceable; (3) that it is permanent; and (4) that it is quantifiable. ERCs are normally denominated in terms of the quantity of pollutant in tons released over one year. By far the most common method of generating ERCs is closing the source or reducing its output. However, ERCs also can be earned by modifying production processes and installing pollution control equipment. Trades of ERCs most often involve stationary sources, although trades involving mobile sources are permitted. States have approved a variety of activities that sources may use to generate offset credits.

2.1.4 Offsets and the Regulating Authority

Under project-based trades, like offsets, the regulating authority must verify and validate emissions reductions on a case-by-case basis. Stringent review must be undertaken to ensure that the emissions reductions reported for each individual project are real, additional, and long-term (i.e., that permanence and leakage are properly addressed). To do this, a review body must be established either within the regulating agency or, if adequate safeguards are in place[1], using outside experts who are accountable to the regulating authority. The project participants must submit to the review body documentation supporting the request for creating emissions offsets, including information on the emissions baseline, monitoring of actual emissions, and crediting lifetime of the project. A baseline is an estimate of the level of emissions that are expected in the absence of the emissions reducing activity. Establishing a baseline can be controversial because the future is difficult to know with certainty and the amount of reduction credit is heavily dependent on this determination. Protocols for baselines as well as for monitoring and verification need to be established by the regulating authority to ensure that the

[1] Adequate safeguards include: sufficient direction and oversight from the regulating authority, accreditation of competency, and protection from conflicts of interest.

offsets created are consistent, real, and long-term.

To provide certainty to project participants, the project-based mechanism could be established such that a project's emissions baseline and emissions monitoring plan is submitted, reviewed, and approved prior to initiation of the reduction project. In this way, once the baseline has been approved, it remains valid for the crediting lifetime of the project. The emissions reductions are calculated as the difference between the approved emissions baseline and the source's actual emissions after mitigation measures have been implemented. Participants could then apply for offsets by submitting documentation to the review body, demonstrating that real reductions have been achieved. The review body would need to verify the reductions before issuing the offsets, which, assuming no problems had been identified, could then be used by the regulated sources to meet their emissions limitation.

In a recent draft study on project-based offset trading systems, the Environmental Law Institute (ELI) concludes that such programs in the U.S. "have generally failed to generate considerable trades and retrospective reviews have tended to blame their shortcomings on high transaction costs, uncertainty and risk in obtaining needed government approvals, as well as lack of clear legal authority and clearly specified objectives." (ELI, 2001)

2.1.5 Bubble Policy

The bubble policy, established in 1979, allows sources to meet emission limits by treating multiple emission points within a facility as if they face a single aggregate emission limit. The term bubble was used to connote an imaginary bubble over a source such as a refinery or a steel mill that had several emission points, each with its own emission limit. Within the "bubble," a source could propose to meet all of its emission control requirements for a criteria pollutant with a mix of controls that is different from those mandated by regulations as long as total emissions within the bubble met the limit for all sources within the bubble. A bubble can include more than one facility owned by one firm or it can include facilities owned by different firms. However, all of the emission points must be within the same attainment or non-attainment area.

Bubbles must be approved as a revision to an applicable State Implementation Plan (SIP), a factor that has discouraged their use. Prior to the 1986 final policy, U.S. EPA approved or proposed to approve approximately 50 source-specific bubbles. U.S. EPA approved 34 additional bubbles under U.S. EPA-authorized generic bubble rules. The U.S. EPA-approved, pre-1986 bubbles were estimated to have saved $300 million over conventional control approaches. State-approved, pre-1986 bubbles saved an estimated $135 million (U.S. EPA, 2001). No estimates are reported for the number of, or savings from, post-1986 bubbles. By design, bubbles are intended to be neutral in terms of

environmental impact.

2.1.6 Evaluation of Early Emissions Trading Activities

Several factors seem to have limited the appeal of the ERC trading policy. To assure that air quality did not deteriorate, state environmental administrators often required expensive air quality modeling prior to accepting proposed trades between geographically separated parties. Deposits to emission banks typically were “taxed” by the air quality management authority to meet state SIP requirements or to generate a surplus that the area could, for instance, use to attract new firms. Offset ratios greater than one to one further depressed the value of ERCs. In many areas, it appears that ERCs had an economic value less than the transaction costs of completing a sale to another party. In other respects, the emissions trading program revealed the myriad possibilities for emissions trading and many of the features that would be necessary to make trading viable. It served as the foundation for the lead credit trading program.

2.2 Differences between ERC and Cap and Trade Systems

There are some important distinctions between credit-based emissions trading and cap and trade or allowance-based emissions trading. The differences lie not only in the distinction between credits and allowances, but also within the programs that use them. Initially, air pollution regulation in the U.S. specified *what* control technologies needed to be installed, *where* the control technologies were to be installed, and *when* installation was to be completed. Compliance was assured through verification of equipment installation and performance testing. The performance testing was typically based on pollution rates (e.g., pounds per quantity of heat input), not total emissions (tons).

Credit-based trading programs, like bubbles and offsets, provide some flexibility in *how* an individual source complies with the traditional “command and control” approach. Because there is no limit to the amount of aggregate emissions under this approach (just the rate at which they are emitted) government oversight needs to be rather significant so that environmental integrity can be insured (i.e., no emissions increases).

Credit-based programs allow emission reductions beyond legal requirements to be certified as tradable credits. The baseline for determining the credits is usually based on pre-existing technology-based standards. If a source uses its legal allowable limit as its baseline rather than actual emissions, it is possible that some “paper credits” will be generated. These paper credits are the difference between what a source is allowed to emit and what a source actually emitted in practice. Credits should always represent real emission reductions, and part of the government oversight that is needed for credit programs is for the purpose of preventing “paper credits” from being awarded.

Another common problem to be aware of when considering emission reduction credits is a reduction that occurs through some motivation other than an environmental improvement. For example, a facility may make a process change for economic reasons that has an ancillary effect of reducing emissions. Because the facility would likely have made this change anyway, credit should not be given for this reduction. If credits are granted, sold, and used to increase emissions elsewhere, there has actually been a net increase in emissions since the process change would have occurred anyway and an emission increase has occurred through use of the credit. These types of reductions are often referred to as “anyway tons.”

Guarding against paper credits and anyway tons in a credit-based program can require significant government oversight and resources and can be subjective. In the end, these credit-based trading programs may provide little or no environmental benefit, just flexibility for sources which usually results in some modest cost savings.

While credit based programs can impart flexibility to existing systems, allowance-based trading programs establish *what* needs to be done by setting an emissions cap at a level that reduces emissions. They are flexible, cost-effective control programs in themselves, rather than a more effective reallocation of costs of a traditional control program (Stavins, 2000).

One particular distinction between credit trading and allowance trading is the capacity for allowance trading to take account of discrete emission reductions. That is, in credit trading schemes, emissions reductions are usually required to be permanent. An allowance trading system allows facilities to take advantage of real emission reductions that are either permanent or temporary. This is possible because an allowance-based system relies on the overall emissions cap. The cap, once distributed in the form of allowances, is finite. Only through the authorization to emit more through the issuance of additional allowances can there be more pollution. In general, if the cap amount is determined in advance (or changed periodically in accordance with a specified schedule), facilities can make reasonable decisions about compliance planning (Tietenberg, undated).

Costs of allowance programs tend to be lower than credit-based programs for several reasons. Allowance-based programs rely on complete and consistent accounting of total emissions and require that allowances be surrendered in proportion to emissions. Beyond that, transactions do not need government approval (a cost savings) and sources have total flexibility in how they comply and when they undertake compliance measures (an additional cost savings). Figure 3 illustrates the emergence of the different emissions trading forms in the U.S.

In conclusion, although credit-based mechanisms can reduce the costs of attaining an environmental target, the administrative and transaction costs associated with a per-unit reduction of emissions are higher than for cap and trade programs. There is greater

uncertainty and risk associated with an offset than with an allowance (e.g., due to baselines, permanence, and leakage issues). Also, extensive involvement and oversight by the regulating authority and its review body are required with project-based mechanisms to ensure environmental integrity. These transaction complexities vary depending upon project type. The cap and trade approach is the preferred approach, where feasible, for achieving and maintaining an environmental target. Because the integrity of a cap and trade program relies on the rigorous measurement/estimation of each ton emitted, it is currently more appropriate for large stationary sources of emissions.

Emissions Trading Development

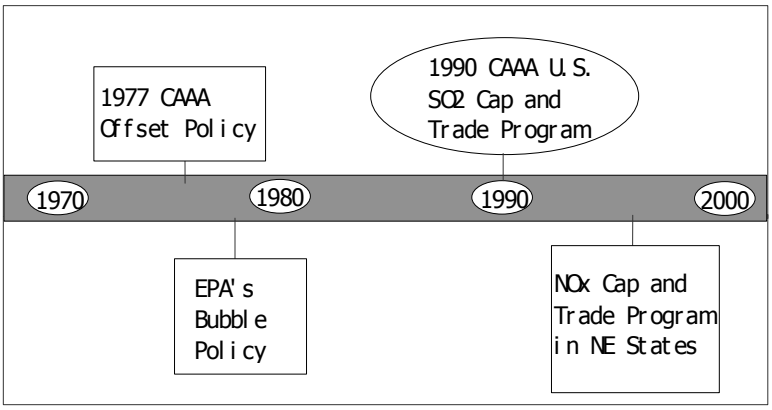

Figure 3 Timeline of emissions trading developments in the U.S.

2.3 Options for Reducing SO_2 Emissions

SO_2 from power plants can be reduced in several ways, including coal washing, switching to lower sulfur coal or natural gas, flue gas desulfurization, coal washing, and increasing energy efficiency. All of these options have different marginal costs. A brief discussion of these emission reduction options follows.

2.3.1 Coal Washing

After coal is mined, it typically goes through a preparation process called coal cleaning before being transported to electric utility plants for burning. The majority of coal cleaning processes used in the U.S. use physical cleaning processes as opposed to chemical cleaning processes. Physical cleaning processes remove impurities in the coal such as floor rock, clay shale partings, and other mineral matter. Removing these impurities increases the utility boiler efficiency and availability, reduces transportation costs, and reduces emissions of air pollutants.

Air emissions of SO_2 can be reduced through physical coal cleaning processes by the

removal of the inorganic sulfur in the coal before combustion. Inorganic sulfur (primarily pyrite) and organic sulfur are the two basic types of sulfur found in coal. Organic sulfur is chemically bound to the coal preventing its removal using physical cleaning processes. The amount of sulfur removal from a coal using a physical cleaning process depends on the proportion of each type of sulfur in the coal and increases with increases inorganic sulfur content. Generally, 40-50 percent of the inorganic sulfur can be removed from a coal yielding an overall sulfur reduction of 10-40 percent.

Advanced coal cleaning technologies which are able to achieve much higher sulfur reductions by removing both the organic and inorganic sulfur from coal are being developed. Currently, 70 percent of all coal produced in the U.S. is cleaned using a physical cleaning process (Kempnich, 2000). Physical coal cleaning technologies are cost effective as they yield environmental benefits as well as increased energy from the coal. The removal of sulfur from coal using advanced coal cleaning technologies has had limited application due in part to competition with more efficient post combustion control technologies such as flue gas desulfurization (FGD).

2.3.2 Fuel Switching to Low-sulfur Coal

In 1990, most large power plants were located in and around the East with a clear concentration in the Ohio River Valley (see Figure 4). Power plants were also scattered around the western states, with much lower spatial density. Historically, power plants purchased coal from nearby sources since the cost of transporting coal, which is heavy and bulky, was expensive. In the U.S., there are three major areas of prevalent coal mining in the Northwest, Midwest, and the East (see Figure 4). Coal found in close proximity to the majority of large power plants near the Appalachian mountain range has an average sulfur content between 1 and 3 percent , while coal in the Midwest (also close to a concentration of power plants) has a very high sulfur content, typically greater than 3 percent. The northwest coal, known as Powder River Basin (PRB), is extremely low sulfur coal, with an average coal content less than 1 percent.

Power Plants and Coal Deposits in the U.S.

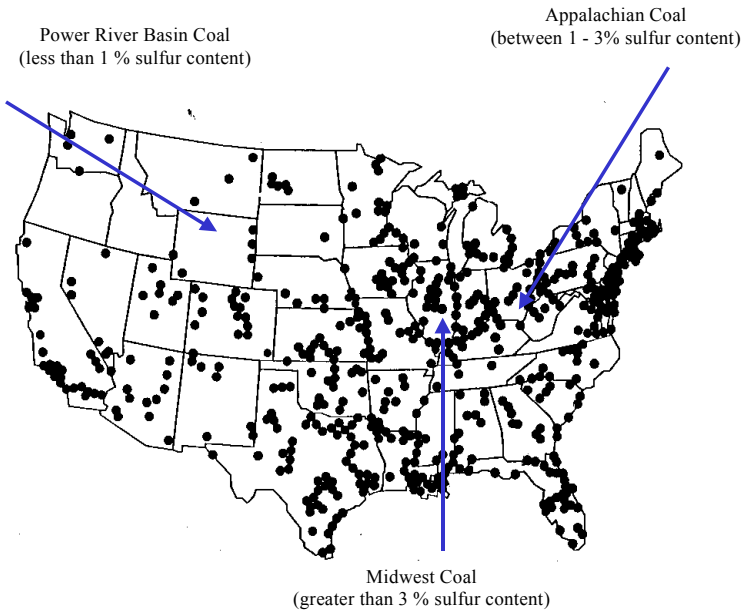

Figure 4 Location of power plants and major coal seams in the U.S.
(Sources: US EPA and Ellerman et al., 2000)

Some changes in boiler configuration are needed to change from using high to low sulfur coal, depending on whether the coal types are bituminous or subbitminous. In practice, fewer modifications are needed if different coal types are blended. However, before the de-regulation of the railroad industry in the 1980s, it was very expensive for power plants located in the Midwest or East to purchase low sulfur coal from the northwest. Following deregulation of the railroad, the use of PRB coal turned out to be a favorable compliance option in the SO_2 trading program, as discussed in Section III.

Flue gas desulfurization (FGD)

In addition to the ability to lower SO_2 emissions through the combustion of coals with lower sulfur content, coal-fired units have the option to install flue gas desulfurization (FGD) technology (commonly called scrubbers). Scrubbers were first demonstrated at a power plant in London in 1936. Early scrubbers had serious reliability problems and therefore were often avoided. Beginning in the 1970s, however, when competition for dominance in European and Japanese pollution control technology markets was high, scrubbers became both more reliable and more effective at removing sulfur. The cost of scrubbers has also decreased substantially. Today's scrubbers are highly reliable, capable of achieving routine emissions reductions of over 95 percent, and equipped to generate useful by-products, such as gypsum, instead of waste.

FGD post-combustion control devices are installed to scrub the pollutants from the exhaust gases produced from the burning of coal in the boiler. Scrubbers use a sorbent to

control SO_2 formation in either a wet or dry process. Plants are more commonly retrofitted with either of two types of wet FGD processes or a dry FGD process. The wet FGD processes are limestone forced oxidation (LSFO) and magnesium enhanced lime (MEL) and the dry FGD process is lime spray drying (LSD). LSFO is the more commonly used wet FGD technology since the sorbent is less expensive. In this process, water is combined with limestone to form an alkaline slurry that is sprayed downwards from spray nozzles in a direction counter to the flow of the exhausted flue gas. By this countercurrent method, SO_2 is removed from the flue gas by absorption and through chemical reactions with the limestone. In the MEL process, magnesium is added to the lime, which makes the sorbent more reactive than the limestone used in FGD and LSFO. Both of these processes are designed to achieve approximately 95 percent SO_2 removal but are able to achieve up to 98 percent SO_2 removal rates. For the dry FGD technologies, LSD mixes a small quantity of water with lime to form a slurry that is then sprayed on the hot flue gas in a spray dryer which reacts with SO_2 in a moist and then a dry phase. Some of the reaction products are captured at the bottom of the spray dryer, while the remainder are removed in the particulate control device. LSD technologies achieve a removal efficiency of approximately 90 percent. LSD technologies are more suitable for regions where water is in short supply.

A thorough discussion of existing FGD technologies and an analysis of their relative performance and costs is presented in Appendix B.

Fuel Switching to Natural Gas

Switching fuel sources from coal to natural gas requires extensive modifications to the boiler and can be a fairly expensive control strategy. However, the environmental benefits from switching to natural gas are multiple. Significant reductions in SO_2, NO_X, and mercury as well as smaller reductions in carbon dioxide emissions are achieved from switching to natural gas.

Increased Energy Efficiency

Increases in energy efficiency can also lead to reduction in SO_2 emissions by burning less fuel to produce the same amount of electricity. Efficiency improvements can be employed at the boiler level or on the demand side. Some improvements increase the heat exchange in the boiler by decreasing the mineral deposits on the boiler walls. Preventative maintenance and repair of leaking values can also increase energy efficiency. Computer systems can be installed on the boiler to control the operating parameters on a real time basis, which tends to increase boiler efficiency.

Demand Side Management

Demand side management (DSM) is the practice of encouraging energy consumers to consume less, thereby reducing emissions associated with power generation. Another

form of DSM can be promotion of energy efficient products that consume less energy when used. For example, the U.S. has labeling programs that help consumers identify which products are most energy efficient. These products typically cost consumers less to own and operate over the lifetime of the product.

2.4 Designing the Solution

2.4.1 Legislation as Foundation for Emissions Trading

A particular feature of the Acid Rain Program design that has likely played a significant role in making the program successful is the design of the legislation that authorized the program. In 1990, the U.S. Congress made significant amendments to the CAA. A large portion of the amendments authorized and defined the U.S. SO_2 cap and trade program. The program set an ambitious, but realistic, environmental goal that required substantial emission reductions from the electric power industry.

2.4.2 Title IV of the Clean Air Act Amendments

Title IV of the 1990 CAA Amendments established the Acid Rain Program and defined much of the detail of the program's operation. Much of the program terminology was defined in the legislation, including: affected source, allowance, baseline, and new unit. Trading parameters were established and tracking systems defined. One of the most important provisions in the legislation was the establishment of the initial allowance allocations for the group of sources that were affected during the first phase of the program (Phase I units). Each unit and its allocation were listed in the legislation, leaving no room for uncertainty as the program was implemented. It was very clear which units were affected by the program and what allocation they could expect, which allowed them to immediately begin to formulate compliance plans. The legislation clearly articulated the consequences of noncompliance, which include the forfeiture of future allowances as well as a financial penalty. This feature has enhanced the market for allowances by making it clear that it is far more cost effective to comply with the program than it is to have fewer allowances than required at the end of the compliance period and pay not only an allowance penalty, but a large financial penalty as well.

An important part of the program also included in the legislation were provisions for a reserve of allowances for distribution to sources that could demonstrate conservation measures or the use of renewable energy prior to the onset of compliance requirements. The purpose of this incentive program was to encourage the use of conservation and renewable energy as emission reducing practices.

As with all major legislation, a significant amount of debate and political maneuvering ensued before the passage of Title IV and the 1990 CAA Amendments. Many dynamics were at play, only a few will be discussed here. For a more thorough discussion of the legislative history see Ellerman et. al., 2001.

Due to a combination of sensitive ecosystems, sulfate transport, and active community groups, Northeast States were supportive of further restrictions on SO_2 emissions across the country. Some of the Northwestern States were also in favor of further limits on SO_2 emissions, since large deposits of low sulfur coal were located in that region. Other interest groups including the environmental community and Canada were vocally in favor of SO_2 emission reductions.

On the other hand, Midwestern States, home to many high sulfur coalmines, were opposed to additional SO_2 emissions controls. Utility companies were also generally opposed to further controls, particularly those companies located near high-sulfur coal sources.

Some resistance to further reductions in SO_2 was alleviated by the unique cap and trade proposal. Due to the trading aspect of the program, the proposal was not seen as explicitly limiting the use of coal since low sulfur coal could be used and high sulfur coal could still be used in conjunction with a scrubber to meet allowance limits. Since the trading features were designed to help reduce costs, some opposition to further regulation was softened. The use of bonus allowance allocations is also said to have swayed some states. Further bolstering the chances of the bill, was the support of the White House. President George Bush was fully behind the bill aiding in its support and passage. Thus, enough votes in Congress were generated to pass Title IV and the rest of the amendments and the President quickly signed it into law.

2.5 Theoretical Explanation of Cap and Trade

2.5.1Features of Cap and Trading

Cap and trade programs differ from more traditional command-and-control approaches for environmental regulation because the environmental target, established via the cap, is achieved at a minimum economic cost, via trading the allowances. The regulating authority determines the total allowable level of emissions and issues allowances for this amount. The allowances are then allocated to the regulated sources, which are able to trade them amongst each other on the allowance market. In this way, firms with high marginal costs of abatement will opt to purchase additional allowances from the market whereas firms with low marginal costs of abatement will opt to reduce their emissions beyond their initial allocation and sell the excess allowances at the going

market price. Thus, marginal abatement costs across all sources are equalized, and hence, by definition, the costs of attaining the environmental target are minimized.

2.5.2 Why Trading and not Taxes in the U.S.?

There are several reasons why the U.S. government adopted allowance trading as a policy tool to address SO_2 emissions rather than using environmental taxes. First, allowance trading provides greater environmental certainty compared to taxes. This is because the regulating authority determines what the environmental target should be, and the prices in the allowance market will adjust to reflect this. With taxation, the regulating authority must establish a tax per unit of emissions. However, due to imperfect information (i.e. regarding control costs and damage functions), setting the tax at the level required to attain the environmental target becomes difficult.

Second, under a regime of environmental taxes, new entrants into the polluting activity will lead to increased emissions. In the case with allowance trading, new entrants can either be required to purchase allowances directly from the market, or the regulating authority can set-aside allowances that are within the aggregate allowable level of emissions or cap. Thus, the environmental target is always maintained.

Third, if there is inflation in the economy, the real value of environmental taxes will decrease, thereby reducing their effectiveness. With allowance trading, the price of the allowances responds automatically to supply and demand in the allowance market, and no regulatory adjustments are therefore necessary to maintain the stringency/level of the cap.

Finally, in the U.S., there were strong political reasons to opt for allowance trading as opposed to environmental taxes. Sources prefer a system in which allowances are allocated without charge to the regulated sources, rather than a system of environmental taxes. The *initial* allocation of allowances reflects an asset that is scarce and therefore has economic value, and is provided without cost to the regulated sources. Recognizing this, affected sources are more supportive of this economic-incentive mechanism. It should also be noted that both policies, taxes and cap and trade systems, could be designed to collect revenue. In the cap and trade example, if some portion of available allowances is auctioned to sources, those proceeds could be used as revenue much like taxes.

This section describes issues that were specific to the U.S., for a discussion of the economic considerations for choosing between taxes and emissions trading, see Baumol and Oates, 1998.

2.6 Framework of the U.S. Sulfur Dioxide Cap and Trade Program

This section outlines the basic building blocks of the U.S. SO_2 emissions cap and trade program. Fundamental components of the program, including legal authority,

determining the cap level, applicability, allocations, and monitoring and reporting are described. In some cases, the options used to form the U.S. program are described along with other options that could also be considered in constructing a trading program under alternative circumstances.

2.6.1 Legal Authority

Legal authority to use emissions trading in the U.S. to reduce SO_2 was granted by Congress through Title IV of the 1990 CAA Amendments. The first step in establishing legal authority to use emissions trading is to examine how the overall regulatory and market systems are structured and to examine the status of the existing system for pollution control. Most likely, the introduction of an emissions trading program will require appropriate amendments in a country's legislation. For example, one needs to establish whether there are fundamental legal issues (e.g., existing technological standards, taxes) that may hinder the development of an emissions market.

Another legal issue that needs to be addressed is that of property rights. In the case of the SO_2 program, it was decided that the U.S. legislation should specify that allowances are not property rights. This provision was inserted to obviate a challenge of an unconstitutional "taking" should the government decide to alter the emissions cap (i.e., to reduce the number of available allowances.) For all practical purposes however, these allowances are property *de facto*. The granting of an exclusive right to a person creates an interest in using that right well and in getting as much out of it as possible, whether the right is in labor, capital, or environmental inputs (Ellerman, 1998).

Another important aspect is to establish an appropriate enforcement authority. In order for an emissions cap and trade program to work effectively, a strict and credible penalty for non-compliance must be established, and these must be enforced without exception. The most effective approach is to have an automatic penalty equal to two or three times the current market price of the permit. Generally, the less robust the monitoring procedures, the higher the multiplicative factor on the market price should be. Under Title IV of the CAA Amendments, Congress authorized the U.S. EPA to impose penalties of $2,000 per excess ton of SO_2 (indexed annually with inflation, the 2001 penalty is $2,778), along with a requirement that any unit that does not have sufficient allowances to cover its emissions must offset the excess by equal tonnage in the following year. Additional civil and criminal penalties may also be applied.

2.6.2 Determining the Cap Level

The allowance trading program was established to address the acidic deposition, human health, and visibility effects as well as the materials damages associated with SO_2

emissions. Based on available scientific information, it was determined that an emissions target to reduce total national SO_2 emissions by 8-12 million tons below the 1980 level would yield the environmental benefits desired. A 10 million ton target was selected (equivalent to 40 percent below 1980 levels). Emissions from electric power generation represented about 70 percent of total national emissions and were to be reduced by about 50 percent (or by 8.5 million tons) from 1980 levels using an allowance trading system with emission reductions beginning in 1995 and full reductions expected by the year 2010. The program was established to take effect in two phases: Phase I began in 1995 and affected 263 units at 110 mostly coal-burning electric utility plants located in 21 Eastern and Midwestern states[2]. Phase II, which began in the year 2000, tightened the annual emissions limits imposed on the Phase I plants and also set restrictions on smaller, cleaner plants fired by coal, oil, and gas, encompassing over 2,000 units in all. Hence, with regard to *affected sources,* the SO_2 provisions are confined to large stationary sources. Large utilities were targeted because they contributed the largest portion of national SO_2 emissions, as shown in Figure 5.

Emissions of SO_2 in 1985 by Major Source Sectors

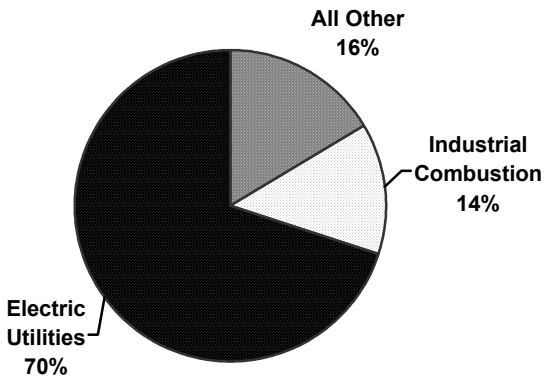

Figure 5 SO_2 Emissions in the U.S. by Major Source Sectors (Source: U.S. EPA)

2.6.3 Applicability

In general, any facility that burns fossil fuel (coal, oil, natural gas, or any fuel derived from these fuels), produces electricity, and sells electricity is affected by the U.S. SO_2 cap and trade program. There are some exceptions for example: simple combustion turbines and units under 25 MW which were operating before November 1990, cogeneration units that do not sell more than a certain threshold of electricity, and “qualifying facilities” and independent power producers with existing power purchase agreements, so long as those

[2] An additional 182 units joined Phase I of the program as substitution or compensating units, bringing the total of Phase I affected units to 445.

agreements remain in effect. Small new units (commencing commercial operation after the CAA Amendments passed in November 1990) are exempt from extensive monitoring requirements if they are less than 25 MW and burn a clean fuel, that is one with a sulfur content less than 0.05 percent by weight.

Once a unit is affected by the U.S. SO_2 cap and trade program, it is always affected. The only "escape" is to retire the unit. New units are required to notify U.S. EPA before they begin operating.

2.6.4 Permitting

Every affected plant must have an acid rain permit. The simple permit includes: identification of the plant by name, state, and ID code; identification of the units at the plant that are affected; statement that each unit plans to comply by holding sufficient allowances to cover emissions; and for new units, the date they plan to begin operating and the date by which their monitors must be certified.

2.6.5 Scope

The *geographic scope* of the program is determined by the environmental problem being addressed by that program. The SO_2 program is designed to solve the problem of long-range acid deposition, and has therefore been set up as a nationwide program covering 48 continental U.S. states (Alaska and Hawaii are excluded).

2.6.6 Distribution of Allowances (Allocations)

Allowance Allocations

The majority of allowances in the SO_2 program are allocated (i.e. distributed for free) to the sources based on selected emission rates and each unit's representative fuel utilization level. In Phase I, the specified emission rate was 2.5 pounds of SO_2 per million British thermal units (mmBtu). This rate was applied to units that had existing rates greater than 2.5 pounds per mmBtu. It was then multiplied by the unit's average fuel use from 1985 through 1987. In Phase II, the limits imposed on Phase I plants were tightened, and emission limits were imposed on smaller, cleaner units that were previously not included in Phase I. In general, U.S. EPA allocated allowances to each source at the lesser of its existing emission rate or 1.2 pounds of SO_2/mmBtu, multiplied by the unit's historic fuel consumption. There were numerous special provisions recognizing special circumstances; however, the total number of allowances allocated was not allowed to exceed the cap level (see *Equity*).

Equity

Additional special provisions were included in the CAA Amendments to address equity concerns raised by some states. For example, in some cases, states that had already reduced the emissions of their electric utilities well below the national average were given extra allowances. Similarly, a state with high population growth in the 1980s was given bonus allowances for its electric utilities to compensate for this growth. In all cases, these redistributions were undertaken without increasing the aggregate allowable level of national emissions. Hence, the increases in allowances allocated to certain states were offset by a decrease in the number of allowances allocated to other states or emission sources.

Auctions

U.S. EPA also holds an annual allowance auction. To supply the auction with allowances, U.S. EPA sets aside a Special Allowance Reserve of approximately 2.8 percent of the total annual allowances allocated to all units. The allowances are sold on the basis of bid price, starting with the highest priced bid and continuing until all allowances have been sold or the number of bids is exhausted. The auction sends market price signals for the allowances and furnishes existing utilities and new sources with an additional avenue for purchasing needed allowances Proceeds from the auction and unsold allowances are recycled back to the units on a pro rata basis.

Private allowance holders, such as utilities or brokers, also may offer their allowances for sale at U.S. EPA auctions, provided that the allowances are dated for the year in which they are offered, for any previous year, or for 7 years in the future. Authorized account representatives must notify the administrator of U.S. EPA auctions of their intent to sell at least 15 business days prior to the auctions. The account representatives must specify the number of allowances they are offering and their minimum price requirements.

Who Administers the EPA Auctions?

The Chicago Board of Trade (CBOT) currently conducts the auctions for U.S. EPA. This authorization is made possible by the CAA Amendments that gave U.S. EPA the authority to delegate the administration of the auctions. After an objective selection process, U.S. EPA chose CBOT to run the auctions because of its demonstrated ability in handling and processing financial instruments and using transactional information systems.

Because U.S. EPA delegates to CBOT (as opposed to contracting with CBOT) to administer the auctions, CBOT is not compensated by U.S. EPA for its services nor allowed to charge fees. CBOT is not allowed to bid for allowances in the auctions nor transfer allowances in the U.S. EPA Allowance Tracking System. Only the administrative functions of the auction have been delegated to CBOT; all other aspects of the auctions

remain with U.S. EPA, as do all allowance transfer functions.

How Are the Auctions Conducted?

The auctions began in 1993 and are held annually, usually on the last Monday of March. Auctions are divided into two segments: (1) a spot allowance auction in which allowances are sold that can be used in that same year for compliance purposes, and (2) an advance auction for the sale of allowances that will become usable for compliance 7 years after the transaction date, although they can be traded earlier. Bidders must send sealed offers containing information on the number and type (spot or advance) of allowances desired and the purchase price to CBOT, no later than 3 business days prior to the auctions. Each bid must also include a certified check or letter of credit for the total bid cost.

The auctions sell allowances from the Special Allowance Reserve on the basis of bid price, starting with the highest priced bid and continuing until all allowances have been sold or the number of bids is exhausted. U.S. EPA may not set a minimum price for allowances from the Special Allowance Reserve.

Allowances are sold from the Special Allowance Reserve before allowances offered by private holders are sold. Offered allowances are sold in ascending order, starting with the allowances for which private holders have set the lowest minimum price requirements. Offered allowances are sold until the allowance supply is depleted, bids are used up, or the minimum price for the next set of offered allowances exceeds the purchase price of the next bid.

U.S. EPA returns proceeds and unsold allowances from the auctioning of reserve allowances on a pro rata basis to those units from which U.S. EPA originally withheld allowances to create the Special Allowance Reserve. Proceeds from the sale of offered allowances are returned to private allowance holders that contributed the allowances to the auctions. U.S. EPA likewise returns payment from unsuccessful bids and allowances from unsuccessful offers.

Direct Sales

To ensure that some allowances were available at a fixed price, a direct sale provision was introduced that provided for allowances to be offered at a fixed price of $1,500 (adjusted for inflation). The provision was set up such that anyone could purchase allowances in the direct sale, but independent power producers (IPPs) could obtain written guarantees from U.S. EPA stating that they had first priority. These guarantees, which were awarded on a first-come, first-served basis, secured the option for qualified IPPs to purchase a yearly amount of allowances over a 30 year span. This provision was aimed at enabling IPPs to assure lenders that they would have access to the allowances they needed to build and operate new units. However, the direct sale was eliminated in 1997 because no sources used the direct sale guarantees. Allowances were available on the

market at prices lower than expected and significantly lower than $1,500 per allowance, thus the provision proved to be unnecessary.

Banking

Banking enables participants to store their excess allowances to help them comply in later years. This reduces compliance costs by allowing utilities more flexibility in the timing of their pollution control investments. Furthermore, the ability to bank allowances provides an additional financial incentive to make reductions earlier in the program and removes the pressure to use allowances immediately before they expire. This has had positive effects on environmental quality and reduced compliance costs. In any case, no matter how many allowances a unit holds, it is never entitled to exceed the source-specific limits set under Title I of the CAA to protect public health.

Voluntary Opt-in

The U.S. SO_2 cap and trade program includes opt-in provisions that expand the program to include additional SO_2 emission sources, such as those in the industrial sector. The opt-in provisions (section 410 of the CAA Amendments of 1990) allow sources that are not required to participate in the cap and trade program the opportunity to enter the program on a voluntary basis, reduce their SO_2 emissions, and receive their own allowances.

The participation of these additional sources reduces the cost of achieving the 10 million ton reduction in SO_2 emissions mandated under the CAA Amendments. As participating sources reduce their SO_2 emissions at a relatively low cost, their reductions—in the form of allowances—can be transferred to electric utilities where emission reductions may be more expensive.

The opt-in provisions offer a combustion source a financial incentive to voluntarily reduce SO_2 emissions. By reducing emissions below its allowance allocation, an opt-in source will create unused allowances that it can sell in the SO_2 allowance market. Opting in is profitable if the revenue from allowances exceeds the combined cost of the emissions reduction and the cost of participating. Only a few sources have applied to opt into the U.S. SO_2 cap and trade program, and the processing of each opt-in application has proved to be administratively cumbersome.

The Conservation and Renewable Energy Reserve

An additional incentive was the Conservation and Renewable Energy Reserve (CRER). The Reserve was in essence, a form of early crediting, and created a pool of 300,000 SO_2 allowances that were made available to affected sources that employed energy efficient or renewable energy measures prior to compliance deadlines. Utilities covered in Phase I of the program were eligible to earn Reserve allowances for such measures employed from January 1, 1992 to their compliance date of January 1, 1995.

Phase II utilities were eligible for such measures employed from January 1, 1992 until their compliance date of January 1, 2000. Under the Reserve program, a utility could earn one allowance for every 500 megawatt hours of energy saved through demand-side energy efficient measures or renewable energy generation.

In retrospect, the CRER was not used to its full potential (as of mid-2001, only 15 percent of the allowances in the reserve have been awarded) due to the fact that the incentives may not have been sufficient and that applicability requirements may have limited participation. U.S. EPA also found that processing of the applications for CRER allowances was administratively burdensome. However, early crediting *can* provide a number of important benefits as part of a cap and trade program. These include allowing sources greater flexibility that reduces their costs, and the achievement of environmental benefits in advance of when the program actually commences. As such, several lessons can be derived from the experience with the CRER in the U.S. SO_2 program. First and foremost, all credits for early action should come from within the aggregate emissions cap. This maintains the environmental integrity of the system by eliminating the creation of questionable credits. Other lessons include that the incentives for participation need to be adequate, the goal of early credit programs needs to be clear, and the criteria for qualifying for credits should not be too complicated. In the U.S. SO_2 cap and trade program, the goal of CRER was to include incentives for energy-efficiency measures, renewable energy, and least-cost planning, the incentive was only equal to the emissions avoided which did not appear large enough to encourage significant investments.

2.6.7 Monitoring, Reporting and Verification

One of the most important requirements of any emissions trading system is that mass emissions be measured as accurately and consistently as possible. This enables a high level of confidence in the value of allowances and enables them to be treated as commodities. The more accurate and complete the method of emissions measurement, the less risk and uncertainty there is associated with an allowance, and hence the more efficient the market. Under the U.S. SO_2 cap and trade program, each affected unit must continuously measure and record its emissions of SO_2, NO_X, and CO_2, as well as volumetric stack flow and opacity. For coal fired boilers, a continuous emission monitoring (CEM) system must be used. Some exceptions are available for oil and gas fired units. There are provisions for initial equipment certification procedures, periodic quality assurance and quality control procedures, record keeping and reporting, and procedures for filling in missing data periods. Where possible, incentives are provided to improve and maintain the quality of the monitoring. For example, units must periodically undertake relative accuracy tests on their CEMs, which entail a financial cost to the firm. The more accurate the CEM, the less frequently it must undertake this test. A discussion of CEMs

and alternative measurement techniques is presented in Appendix C. It is important to note that simply requiring the most accurate monitors will not ensure an effective trading system. Effective implementation is critical; it is essential that the monitoring solution used is standardized and commonly applied to program participants as well as validated in its installation and operation on-site.

In the U.S. SO_2 cap and trade program, affected units are required to report hourly mass emissions data to U.S. EPA on a quarterly basis. The hourly emissions provide a more representative average of emissions, whereas the quarterly reporting (as opposed to, for example, annual reporting) eases the administrative burden for U.S. EPA of receiving and reviewing the data and allows the sources and U.S. EPA to correct problems during the year (rather than after the year is over). The data are then recorded in U.S. EPA's Emissions Tracking System (ETS), which serves as a repository of emissions data for the utility industry. The ETS is software, and all sources must obtain an account and a password from the U.S. EPA in order to submit their files. The emissions monitoring and reporting systems are critical to the program. They instill confidence in allowance transactions by certifying the existence and quantity of the commodity being traded. Monitoring also ensures, through accurate accounting, that the SO_2 emissions reduction goals are met.

Alternative Approaches

Experience indicates that CEMs are the most accurate and proven method available for determining SO_2 mass emissions, they were therefore the preferred choice in the U.S. However, circumstances may be different in China and these differences might lead to selection of different monitoring solutions. Due to the large number of SO_2 emission sources in China, the cost of installing such equipment, and the currently limited capacity to operate and maintain the equipment, it will be difficult for China to install CEMs for all large sources in a short period of time.

The sulfur mass-balance emissions estimation approach is one alternative to CEMs (See appendix C for a discussion of the mass-balance approach). With effective standardization and validation of testing methods, alternative methods to CEMs (like mass-balance) could be used to estimate SO_2 emissions to a degree of accuracy that may be sufficient, depending on the goals of the program. CEMs would be necessary, however, for any units with SO_2 controls (e.g. scrubbers). U.S. EPA's experience indicates that emissions reductions resulting from use of post-combustion controls (scrubbers) can be verified only through use of CEMs after the point of control.

Using a combination of CEMs on new sources and sources installing control equipment and mass-balance for other participating sources could be a viable transition plan until more sources in China are able to install and operate CEMs. During this transition, a "standardization method" or discount ratio may be applied to the emissions estimates that use a mass-balance approach to provide a more conservative estimate where the less accurate methods are used. A discount ratio would also provide an incentive for firms to make the investments to install CEMs.

To track the allowance transactions and the status of allowance accounts, the U.S. EPA has instituted an electronic record-keeping and notification system called the

Allowance Tracking System (ATS). The primary role of the ATS is to provide an efficient, automated means of monitoring compliance with the SO_2 program. It also provides the allowance market with a record of who is holding allowances, the date of allowance transfers, and the allowances transferred. All ATS information is available on the Internet. Any party interested in participating in the trading system may open an ATS account by submitting an application to U.S. EPA. ATS is computerized to expedite the flow of data and to assist in the development of a viable market for allowances.

Finally, to verify that each source has sufficient allowances to match its emissions, U.S. EPA performs the task of annual reconciliation (i.e., a comparison of the data from the ETS and the ATS.) At the end of the year, utilities are granted a 60-day true-up or grace period, during which SO_2 allowances may be purchased, if necessary, to cover each unit's emissions for the year. At the end of the grace period, the allowances a unit holds in its compliance account must equal or exceed the annual SO_2 emissions recorded by the unit's monitoring system. Any remaining allowances may be sold or banked for use in future years.

2.7 The Interaction of the Acid Rain Program with Other Programs for Reducing Sulfur Dioxide

The U.S. SO_2 cap and trade program is not the only SO_2 related policy that the U.S. EPA implements. In fact there are layers of regulations relating to SO_2 control, and often there are layers of requirements for pollution sources. This system helps ensure that the environment is protected and that the public health and environmental standards are met. Here we explain the larger set of environmental policies in the U.S. that focus on SO_2 and describe their interactions.

This section reviews the basic principles of each of these programs, describes how the U.S. SO_2 cap and trade program integrates with the other policy instruments, and identifies some “lessons learned” from implementing multiple policy instruments for a single pollutant.

2.7.1 Other Policy Instruments

In addition to the electric utilities covered under the cap and trade program, the U.S. has implemented a variety of regulations to limit emissions of SO_2. For example, diesel fuel refining has been regulated so that fuels for automobiles and trucks contain less sulfur. In addition to the mobile source reductions, a variety of other programs exist and will be discussed in this section.

National Ambient Air Quality Standards and State Implementation Plans

The National Ambient Air Quality Standards (NAAQS), initially established in response

to the 1970 CAA, set maximum allowable concentrations for pollutants in the ambient air. The purpose of the NAAQS program is to protect human health and welfare from the effects of criteria air pollutants (criteria pollutants include sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), lead (Pb), and particulate matter (PM)) Unlike the U.S. SO_2 cap and trade program, the NAAQS are not targeted at individual sources. NAAQS focus on ambient air quality and require state regulatory agencies to prepare and implement air quality management programs. The centerpiece of this program is the State Implementation Plan (SIP), which is a strategy developed by a state for attaining and maintaining the NAAQS. In addition to federal requirements, the SIPs may include state-specific policies and measures to control emissions from individual sources or sectors, including those sources or sectors that are regulated through national programs (e.g., electric power plants regulated through the Acid Rain Program.)

SIPs are used by States to ensure that local air quality is protected. SIPs must be reviewed and approved by the EPA, and are required to include the following:

- Emission limits—expressed as a quantity, rate or concentration—for individual source types or sectors;
- Timetables for compliance by sources;
- Systems for monitoring air quality;
- Policies and procedures for enforcement; and
- Evidence that the state has the necessary administrative and legal capacities.

Responsibilities under the U.S. SO_2 Cap and Trade Program

Sources

- Develop and implement a compliance strategy.
- Install, operate and maintain continuous emissions monitors to measure emissions of SO_2, NO_X, and CO_2.
- Report hourly emissions data to U.S. EPA.
- Hold sufficient allowances to cover annual emissions.

Government

- Establish emission caps and allocate allowances.
- Collect, verify, and publish emissions data.
- Record and publish allowance transfers and account balances.
- Conduct annual compliance checks (reconciliation of allowances and emissions).
- Inspect emissions monitors.
- Enforce penalties for noncompliance.

Responsibilities under Other Policy Instruments

Major Stationary Sources

- Apply to the state regulatory agency for an operating permit.
- Report emissions data to relevant state agencies.
- Fulfill the requirements outlined in the operating permit, including any monitoring and technology or

performance requirements.

Government

State

- Develop and implement a state implementation plan (SIP).
- Monitor air quality.
- Operate a permit program for major sources, including fee collection.
- Inspect sources to ensure compliance.
- Enforce penalties for noncompliance.

Federal

- Establish and revise NAAQS as appropriate based on scientific and public health data.
- Establish and revise technology standards for categories of new and modified sources.
- Review and approve SIPs.
- Ensure states implement and enforce SIPs.
- Develop a federal implementation plan (FIP) for states that fail to submit an acceptable SIP.

States are afforded some freedom to determine which sources and sectors should be covered by what state-specific regulation and to what extent. In other words, states can decide which sources and/or sectors to regulate and what means of regulation to use, including technology standards and market-based instruments. However, state-specific regulations cannot exempt a sector from applicable federal requirements; the regulations can only serve to make rules more stringent than existing federal requirements or address sources or sectors that are not subject to federal requirements. To receive SIP approval from the U.S. EPA, the state must demonstrate that the programs implemented under the SIP will ensure the NAAQS are met.

Prevention of Significant Deterioration

As an added protection for areas where air quality is better than required by the NAAQS, the CAA provides for the prevention of significant deterioration (PSD) of air quality. This program sets an allowable increment for a pollutant above an area's baseline air quality. This increment is "consumed" as new or modified sources begin emitting in the area. This added level of protection preserves clean air in NAAQS attainment areas, provides an added margin to protect human health, and reduces opportunities for sources to gain competitive advantage by relocating to areas with good air quality to increase their ability to emit.

NAAQS attainment areas are grouped into one of three categories that specify the allowable increment. The categories are:

- Class 1: Very little additional pollution is allowed.
- Class 2: Moderate additional pollution is allowed.
- Class 3: Pollution concentrations approaching but not surpassing NAAQS are allowed.

Federal lands and parks are designated Class 1 and states designate the remaining areas.

Permits and Fees

Under Title V of the CAA, each major stationary source[3] is required to obtain an operating permit from the state and to pay emissions fees to cover the administrative cost of the permit program. The fee must be at least $33 per ton[4] for the first 4,000 tons of each regulated pollutant emitted by the source. However, a state can charge a lower emission fee if it can demonstrate that the lesser fee will cover the development and administrative costs of the permit program. Although these fees are intended to support the state permitting program, they also provide a modest economic incentive for sources to reduce pollution.

The permitting process requires more than just payment of permitting fees. The state-issued permits include source-specific emission limitations, compliance schedules, monitoring requirements, and other applicable obligations from the CAA and relevant SIP, including technology or performance standards. Sources that participate in the Title IV SO_2 cap and trade program must also file a five-page permit that obligates the source to comply with the rules of the program.

Technology and Performance Standards

The CAA includes technology and performance standards for new and modified sources, some of which are based on the NAAQS attainment designation of the area in which they operate (see Table 1). New and modified[5] sources, regardless of where they are located, must, at a minimum, comply with New Source Performance Standards (NSPS)[6] that establish maximum emission levels for specific sectors. Within NAAQS attainment areas, new sources must also meet emission levels based on the best available control technology (BACT) that has been adequately demonstrated and that takes into account the costs of the technology. The BACT is determined on a case-by-case basis and may result in emission limits that are more stringent than NSPS. In NAAQS non-attainment areas, new and modified sources must meet more stringent requirements and limit emissions to the lowest achievable emission rate (LAER), which is the lowest emission rate achieved by any similar source without regard to cost (Boubel et. al., 1994). In addition to requiring the LAER, new and modified sources in non-attainment

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[3] A major stationary source is defined as any facility which directly emits, or has the potential to emit, one hundred tons or more of a pollutant per year.

[4] The fee is statutorily set at a minimum of $25 per ton (indexed for inflation) for the first 4,000 tons. States have the option of charging for all emissions greater than 4,000 tons but they are not required to do so.

[5] Modifications that trigger the New Source Performance Standards include any physical or process change that results in an increase in the quantity of emissions.

[6] NSPS is set by the U.S. EPA for certain source categories (e.g., utility boilers) but BACT and LAER are

areas are required to offset emissions. In other words, for each ton of emissions from the new or modified source, an equivalent or greater quantity of pollution must be reduced from other sources in the vicinity.

Table 1: Technology Standards for Pollution Sources

	New or Modified Source	Existing Source
Attainment Area	Best available control technology (BACT)	None
Non-Attainment Area	Lowest achievable emission rate (LAER) Emission offsets	Reasonably available control technology (RACT)

In addition to federal requirements, states may establish supplemental technology or performance requirements as part of the SIP program. These additional requirements are detailed in the SIP and source operating permits.

Penalties

If a regulated source violates any provision of the CAA, SIP, or its operating permit, the U.S. EPA may seek civil penalties of up to $25,000 per day[7] for each violation. In addition, in cases where a regulated source knowingly violates the provisions, criminal penalties can be assessed.

Results

By 1990 most areas of the U.S. were meeting the SO_2 NAAQS and few additional reductions were expected as a result of the NAAQS, SIP, and NSPS programs. However, between 1990 and 1998, due in part to the reductions from the Acid Rain Program, national concentrations of SO_2 in the ambient air decreased by 35 percent and SO_2 emissions decreased by 17 percent (U.S. EPA, 2000).

2.7.2 Integration and Interaction

The U.S. cap and trade program plays a significant role within the overall policy portfolio for controlling emissions of SO_2. However, the program is not a replacement for existing policy instruments. Instead the program complements existing programs to protect local air quality that have remained intact.

In evaluating the integration of emissions trading and other environmental policy instruments, it is useful to look at aspects of the programs relating to:

- The points of *interaction* between the emissions trading program and the other

determined on a case-by-case basis (often by the states).

[7] The fine is statutorily set at a maximum of $25,000 per day. The actual fine is often set through litigation or negotiation. As a result, the penalty process is often lengthy and expensive and the penalty amount is difficult to predict.

policies and

- The extent of the *compatibility* of the emissions trading program with the other policies.

There are few points of interaction between the U.S. SO_2 cap and trade program and the more traditional command-and-control programs (e.g., the technology and performance standards.) Even the administration of the programs is separated—a different division within U.S. EPA has responsibility for each of the programs. In addition, the source obligations under each of the programs are separate and distinct so compliance with one program does not guarantee compliance with the other. For example, if an electric power plant participating in the SO_2 cap and trade program holds sufficient allowances to cover annual SO_2 emissions from its combustion unit(s) it is determined to be in compliance with the U.S. SO_2 cap and trade program. However, the electric power plant must also meet the additional requirements detailed in its operating permit or it may be determined out of compliance with other provisions of the CAA.

2.7.3 Compatibility

The U.S. SO_2 cap and trade program is fully compatible with the other programs aimed at reducing emissions or concentrations of SO_2. The key aspects that have led to the integration of the various instruments to control SO_2 include:

- The U.S. SO_2 cap and trade program *creates an incentive to innovate and develop new technologies and processes to reduce emissions*. Traditional command-and-control programs set a uniform standard for categories of similar sources (e.g., based on regional NAAQS attainment and the status of the facility). These programs tend to treat all sources within a category the same and prescribe a single common solution. As a result, traditional command-and-control programs often miss opportunities for further low-cost emission control at some facilities or impose high costs at other facilities. Emissions trading creates the incentive for sources to pursue low-cost opportunities and capitalize on differences among emission sources and control strategies.

  The flexibility afforded to electric power plants in the U.S. SO_2 cap and trade program has led to the development of new and efficient control options with decreasing costs. As an example, since the inception of the program the cost of scrubber technology has fallen by more than half while scrubber efficiency has increased (Ellerman et al., 1997).
- *The portfolio of policy instruments protects against increases in regional pollutant concentrations resulting from trading (e.g., "hot spots").* The regulatory tiering approach—the application of more than one regulatory regime—prevents unhealthy levels of SO_2 in the vicinity of sources (Tietenberg, 1999, Stamford and

Tietenberg, 1995). Since the ambient (NAAQS) and source-specific standards ensure that SO_2 emissions are limited to levels that do not endanger human health and welfare, trading need not be restricted by geographic considerations and regulators need not review trades on a case-by-case basis. Since sources subject to the U.S. SO_2 cap and trade program are also subject to state and national regulations protecting local air quality (e.g., SIP) hot spots will not occur, provided the ambient and source-specific standards are sufficient.

A recent study conducted by the Environmental Law Institute found that trading under the U.S. SO_2 cap and trade program did not lead to hot spots (Swift, 2000). According to the study, many of the largest electric power plants participating in Phase I of the Acid Rain Program reduced emissions well below their allocated limit and to a level below the overall average. The results indicate that emissions trading can actually reduce the effects of hot spots, not create them.

As an added safeguard against hot spots, states can set source-specific emission limits that are lower than the quantity of U.S. SO_2 cap and trade program allowances allocated to sources in their state. The sources must meet the lower emission limits established by the state but are free to trade the excess allowances in the marketplace. Although in these cases in-state sources must adhere to more stringent emission requirements, they receive financial remuneration through the sale of the excess allowances to sources in regions not bound by the tighter restrictions.

The “safety net” created by ambient and source-specific standards eliminates the need for regulators to approve each trade. Because the standards cannot be circumvented by electric power plants, any changes in emissions due to trading must still be at or below the standards that protect human health and welfare in the vicinity of the plant. Since regulators do not need to approve each trade, the transaction costs and processing time for trades under the U.S. SO_2 cap and trade program is greatly reduced.

- *Fee collection is independent of State Implementation Plans, technology standards, and emissions trading.* The fees collected by state permit programs are an important source of revenue to offset program development and administrative costs.These fees are collectedfrom all major sources, irrespective of compliance with or participation in other programs.
- *The goals of each of the programs are different but complementary.* The aim of each program is essentially the same: the reduction of atmospheric SO_2 emissions. The goals of each program are as follows:
  - The U.S. SO_2 cap and trade program seeks to reduce the long-range effects of acid rain on human health, property, and the environment by reducing SO_2 emissions from electric power plants nationwide.

- The NAAQS aim to protect human health and welfare by limiting ambient concentrations of SO_2.
- The facility permitting programs strive to create a single document for each major source that details the source's emission and operating obligations, as well as any permit fee requirements.
- Technology and performance standards seek to control the emission rate or concentration from major sources and facilitate the attainment of NAAQS by establishing uniform standards for categories of sources.

It is important to examine the full range of integration issues, particularly when using more than one economic instrument, like emissions fees and emissions trading. In the China case, where an SO_2 emissions levy currently exists, careful thought is needed when combining this policy with a framework for emissions trading. However, these two policies can be designed to be fully compatible (Ellerman, 2001). A thorough discussion of this issue is offered in an expert technical report in Section IV.

2.7.4 Information Systems

Of the many valuable lessons learned from the U.S. SO_2 cap and trade program, perhaps one of the most important lessons is the need for comprehensive, accurate, transparent, and timely information about emissions and tradable allowances. The information is essential to the U.S. EPA for ascertaining compliance and evaluating program effectiveness. But the U.S. EPA not only processes the information, it also makes information about emissions and tradable allowances accessible to the public. Information transparency facilitates an efficient tradable allowance market and builds confidence and credibility in the emissions trading approach (Kruger et al., 2000).

The operation of the U.S. SO_2 cap and trade program consists largely of collecting, verifying, maintaining, and disseminating vast amounts of data. The most effective method available today to process and disseminate these data is an integrated information system. Recent advances in information technology are making it possible to provide relevant data to interested parties in real time and in a variety of useful forms. For dissemination of emissions and tradable allowance data, the Internet has become critical over the last several years.

The advantages of using information systems go well beyond their ability to handle large amounts of data. Using a flexible, comprehensive information system to collect and manage data can provide numerous benefits, including:

Increased data accuracy – tools such as electronic reporting and automated data quality checks reduce errors and eliminate redundant data entry.

Reduced time and costs – electronic reporting and automated data quality checks also reduce the time and costs required to complete, process, and review paper forms. In

addition, the electronic storage of data can significantly reduce, or even eliminate, the costs associated with the collection, transport, storage, and dissemination of paper forms.

Enhanced access –electronic data storage makes it easier and faster to retrieve, analyze, and evaluate relevant data on demand. Improved access to data can also promote confidence in the trading program by permitting program participants and interested members of the public to retrieve data to ascertain compliance, evaluate a program's effectiveness, and make informed decisions. Data transparency can also facilitate efficient markets, build public acceptance, and foster credibility (Kruger et al., 2000).

Improved consistency and comparability – electronic reporting and electronic data storage encourage consistency by requiring all program participants to report the same information in a common reporting format. This consistency promotes comparability across time and between program participants.

The U.S. SO_2 cap and trade program's information system was developed through an iterative process. As the program evolved, so did the information system. Using feedback from operations staff, software developers, and customers (affected sources, brokers, states, etc.), U.S. EPA has improved the information system to meet the needs of the program.

In the early stages of an emissions trading program, the data system may be as simple as a spreadsheet with manual audit procedures. As an interim measure, this approach can be reliable if the volume of data is low but might also provide an opportunity to assess whether automation is necessary and to what extent (Price, 1997). As resources become available and the program evolves, the information system can be modified, expanded, and, if appropriate, automated to address the needs of the program.

Tracking Emissions

Perhaps the most data intensive component of an information system is the emissions tracking system or ETS. The purpose of the ETS is to collect, review, and maintain relevant emissions-related data from each program participant. The type and quantity of data collected will depend on the measurement and monitoring requirements for the trading program. For example, a trading program that relies on emission factors to calculate emissions from stationary combustion sources might require participants to report data on the type and amount of fuel consumed, the combustion technologies installed, and the emission factors used. A trading program utilizing continuous emissions monitors might require data on measured emissions and the results of periodic quality assurance testing. The frequency of reporting will depend upon the calculation method, the length of the compliance period, and administrative decisions, but it should be frequent enough to supply program participants and interested parties with timely information about emissions and facilitate compliance determination. Regardless of the methods used to

calculate emissions, the data must be consistent, accurate, and objective if market participants and the public are to have confidence in the program.

The ETS of the U.S. SO_2 cap and trade program is a comprehensive system for collecting, reviewing, and maintaining emissions data. Due to the large volume of data[8], the U.S. EPA requires all sources to submit emissions-related data electronically. As the submissions are received, they are processed and audited by the ETS. If any errors or omissions are discovered, the ETS sends an electronic report to the source that details the errors or omissions. Electronic submissions improve accuracy and reduce the burden on participants and administrators by eliminating the need for redundant data entry, facilitating automated data quality checks, and providing immediate feedback about data quality.

After the quarterly emissions data is submitted by the source and audited by the ETS, U.S. EPA disseminates summary data in print and over the Internet. Sources, administrators, and other interested parties can query the database to find information about emissions of SO_2, NO_X, and CO_2 by source or by state.

Tracking Allowances

The Allowance Tracking System, or ATS, is the accounting system for the cap and trade program. The ATS of the U.S. SO_2 cap and trade program is a comprehensive system for collecting, validating, and maintaining account data, tradable allowance holdings, and transaction records. Due to the large volume of transactions in the program, the ATS allows traders to submit transfer requests either by written communication or electronic submission.

The ATS plays a critical role in all tradable allowance transactions, including the issuance, transfer, and retirement of allowances. The U.S. EPA uses the ATS to issue and distribute allowances to sources according to auction purchases or prescribed allocation formulas. The ATS also verifies transfers between accounts to insure their validity. When a transfer is entered into the system, the ATS confirms the allowances being transferred are valid and held in the transferor's account. If the transaction passes the validity check, the ATS deducts the transferred allowances from the transferor's account and adds them to the recipient's account.

U.S. EPA publishes all official allowance transactions on the Internet. Account holders and other interested parties can query the database to find information about accounts, allowance holdings, and allowances transactions.

Ascertaining Compliance

The Allowance Reconciliation System or ARS is the vital link that ties the ETS and

[8] Each quarter, the more than 2,300 sources in the U.S. SO_2 cap and trade program report hourly emissions data for SO_2, NO_x, and CO_2. Processing the data requires ETS to collect and check approximately 40 million data entries every quarter.

ATS together to determine compliance. At the end of each compliance period, the ARS compares each source's allowance holdings against the source's total emissions for the year. If the source's emissions are equal to or less than their holdings of current allowances, the source is in compliance.

After the U.S. SO_2 cap and trade program's ARS accesses the allowance holdings and emissions data, the ARS instructs the ATS to withdraw the appropriate number of allowances—one allowance for each ton of SO_2 emitted during the year—from each compliance account.

Tracking Systems Summary

A credible emissions trading program must be based on a foundation of comprehensive, accurate, transparent, and timely information. Public acceptance of an emissions trading program will largely be influenced by the degree to which the public trusts and understands the results of the program. The most effective and efficient way to communicate the information and results is with an integrated information system. The system plays a critical role by collecting, reviewing, maintaining, and verifying data on emissions and tradable allowances. The benefits can also include increased efficiency, decreased costs, environmental accountability, and reduced errors. Each of these benefits facilitates efficient markets.

When planning or building an integrated emissions trading information system, it is important to remember that it is never too early to begin. The more that the implementation of the information system is thought about in the development of the program, the easier it will be to carry through the program requirements into the actual structure of the information system.

2.8 Implementing and Managing the Sulfur Dioxide Cap and Trade Program

This section provides a brief overview of operational components of the SO_2 cap and trade program. U.S. EPA headquarters in Washington, DC is responsible for the day-to-day operations of the trading program. Ten regional U.S. EPA offices around the country deal with enforcement issues of all kinds, and are responsible for tracking states' progress in issuing permits. States are responsible for issuing permits and certifying emissions monitors. Day-to-day operations of the U.S. SO_2 cap and trade program include assessing emissions data that the sources submit, recording allowance transfers, and running the ATS. In addition, staff analyze data trends to assess how the environment is responding to the program. Some of these functions are described in more detail below.

2.8.1 Designated Representatives

Under the U.S. SO_2 cap and trade program, a single individual at a utility plant is responsible for ensuring the plant's compliance with program regulations. This person, called the Designated Representative (DR), is legally responsible for submitting emissions data, allowance transfers, compliance information, and permit applications. A second person, the Alternate Designated Representative (ADR), may perform all the same functions as the DR, but the DR is held responsible for all the actions of the ADR. Interaction between U.S. EPA and the sources is often through the DRs of the sources.

2.8.2 Emissions Data

Each quarter, 2,300 sources electronically submit files containing hourly emissions values for SO_2, NO_X, CO_2, and heat input directly to U.S. EPA's computer system. U.S. EPA provides software for the utilities to use for this purpose. Once the file is submitted, U.S. EPA's ETS evaluates the file for completeness, runs some quality checks, and automatically sends a feedback report. This feedback report contains a status code, indicating whether it passed the quality checks. If a report has formatting errors or critical data quality errors, it is rejected and must be resubmitted. The emissions data contained in the quarterly reports are used to determine compliance at the end of each year. The files must be submitted within 30 days after the end of each quarter.

2.8.3 Allowance Transfers

U.S. EPA establishes a compliance account in the ATS for each affected unit. For those units that were allocated allowances, ATS assigns serial numbers to the allowances in the accounts. Additionally, any person can open a general account in ATS that they can use to participate in the allowance trading program. Only transfers of allowances that will be used for compliance must be recorded in ATS. We have heard anecdotally that only about half the activity in the SO_2 allowance market is recorded in ATS.

To submit a transfer, the Designated Representative (or, for general accounts, the Authorized Account Representative) for the company transferring the allowances from their account completes an allowance transfer form, identifying the account numbers of the accounts involved and the serial numbers of the allowances to be transferred. If the recipient of the allowances has submitted a letter to U.S. EPA indicating that they will accept transfers into their accounts, their signature on the transfer form is not required. U.S. EPA records the transfer in ATS, usually within one or two business days, although the regulations allow five days, and sends a confirmation notice to both account representatives. In addition, each afternoon U.S. EPA updates its web site with that day's

transactions.

U.S. EPA recently added an on-line allowance transfer option, allowing those who wish to transfer allowances to do so over the Internet, either by submitting a file containing the transfer information or by entering the data on the screen. This on-line capability lowers transaction costs even further and allows the market participants more control over their transactions.

2.8.4 How Are Allowance Prices Determined?

Allowance prices are largely determined by the costs of meeting a given emissions cap. In an efficient market, the price of allowances should approach the “marginal cost” to reduce a ton of emissions. Marginal costs can be thought of as the cost to reduce “the next ton of emissions.” These costs will depend upon the types of emission control options available and the level of stringency required by a cap. Thus, cap and trade programs for different pollutants will have different marginal costs and different market prices for allowances. For example, prices in the U.S SO_2 and NO_X markets differ because the options available to achieve the SO_2 cap (fuel switching, flue gas desulfurization, etc.) have different costs than the options available to reach the NO_X cap (e.g., selective catalytic reduction, operational improvements, etc.). Other factors that may affect allowance prices include:

Banking provisions: In a program with a banking provision, companies who believe that the marginal costs of emission reduction will rise in the future may control emissions more than is necessary to bank extra allowances for future use. Thus, the current market price of allowances could be affected by expectations about future marginal costs.

Barriers to an efficient market: There are a number of possible barriers to an efficient allowance market that could affect allowance prices. These include government policies that restrict trading and a lack of information about the costs faced by participants.

2.8.5 Annual Reconciliation and Compliance Determination

By March 1, Designated Representatives must submit annual reconciliation forms for the previous year. In addition, by March 1 they must submit allowance transfers for those allowances that they plan to use to cover their emissions. Compliance is determined on a unit-by-unit basis, so each unit’s account must hold enough allowances. If there is a shortfall, but there are extra allowances in accounts for other units at the same plant, 95 percent of the shortfall can be covered by the allowances at other units, with a minimum penalty of 10 tons. The excess emissions penalty is $2,778 per ton, which increases each year with inflation.

Once emissions are finalized, allowances are deducted from accounts to cover

emissions. Utilities may elect to specify which allowances are deducted; otherwise allowances are deducted according to the first-in, first-out method. Generally, annual reconciliation is completed by June.

Between March 1 and the completion of annual reconciliation, compliance accounts in ATS are frozen, meaning that no current or previous year allowances can be transferred in or out of the compliance accounts. Allowance transfer activity can continue unrestricted for future year allowances or for current and previous year allowances transferred between general accounts.

Thoughts from a Utility Company…

"We believe that the market-based compliance concept utilizing emission credits or allowances has been successful due in large part to U.S. EPA by allowing a free market to develop and function and by not placing restrictive caps on the amount of banking allowed or limits on the utilization of the bank. U.S. EPA has acted as a type of clearinghouse for this system and through their annual auction and their compliance verification process has assured those participating in the market that the allowances that they buy, sell, or trade are valid and fungible. In summary, it has also allowed those being regulated to be creative and choose the least-cost compliance strategy for their specific situation."

Gary Hart, Manager, Clean Air/SO_2 Allowances, Southern Company Services, "Southern Company's BUBA Strategy in the SO_2 Allowance Market", in Emissions Trading: Environmental Policy's New Instrument, edited by Richard Kosobud. New York: John Wiley & Sons, Inc., 2000

U.S. EPA produces an annual compliance report containing annual reconciliation summary and detailed information. It is posted on U.S. EPA's web site approximately 60 days after the allowance deductions are made. The last step is to add another year's allowances, so there are 30 future years of allowances in the compliance accounts.

Program Assessment and Communication

The emissions reports generated through the operation of the program are the basis of ongoing program assessment. On a continual basis, U.S. EPA examines trends in emissions, sulfate deposition, surface water chemistry, and other environmental indicators, like visibility and materials damage. This work tracks progress towards environmental goals and analyzes how the environment is responding to the emissions reductions achieved through the cap and trade program. U.S. EPA works with a number of different institutions on assessment including the National Atmospheric Deposition Program (NADP), the National Acid Precipitation Program, and others.

Administrative Costs

Because of the simplicity and automation, government administrative costs for Title IV implementation have been lower than under more traditional approaches. The fundamentally different approach to air pollution control embodied by the allowance trading program can minimize many administrative costs associated with

command-and-control and previous trading programs. For example, Title IV's performance-based approach eliminates the need to devise source-specific emission limits and to review control technologies and detailed compliance schedules. In addition, eliminating case-by–case review and approval of each trade (including determining the "useful life" of equipment, the intent of the sources regarding future emission and activity levels, and "real" emission reductions achieved), greatly reduces the administrative and transaction costs associated with emissions trading programs (McLean, 1996).

The program's administrative costs of approximately $12 million per year translate into a cost of about $1.50 per ton of pollution reduced. Most of these administrative costs are associated with operating the emission monitoring and reporting components of the program. To put these expenditures into context, during the first five years of the program, government spending to set up and operate the SO_2 allowance program totaled less than $60 million out of a total $3.5 billion estimated government expenditure for air pollution control. Thus, the U.S. SO_2 cap and trade program is achieving 40 percent of the emission reductions required under the 1990 CAA Amendments with only about 2 percent of the staff and other resources (McLean, 1996)

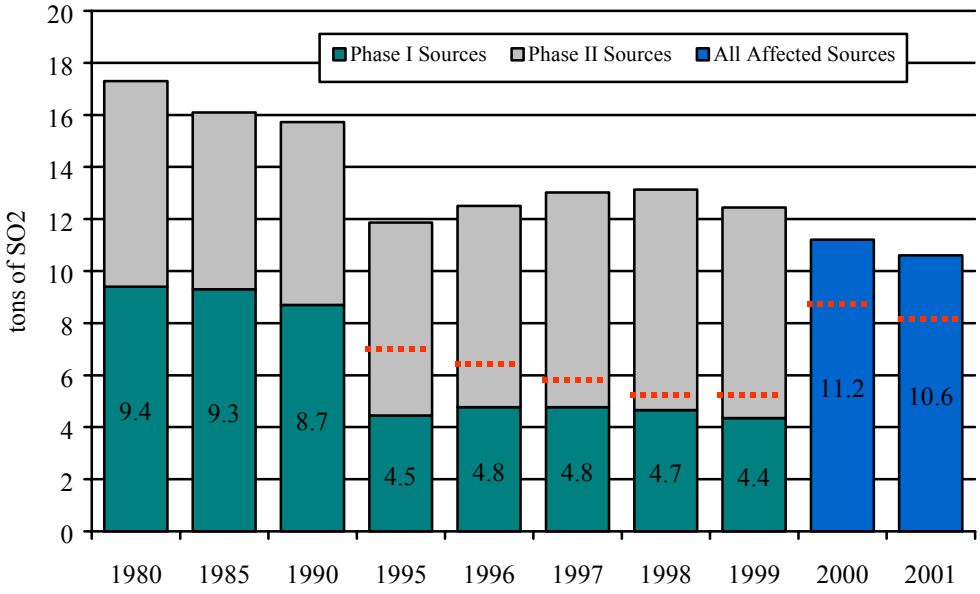
3. Results to Date of Sulfur Dioxide Cap and Trade Program

The U.S. SO_2 cap and trade program has reduced millions of tons of SO_2 annually and environmental indicators including emissions levels, ambient SO_2 levels, sulfate deposition, and surface water chemistry all point towards environmental improvement (Benkovic and Kruger, 2001). This section describes both the environmental results of the program and how this policy has used market forces to achieve desired environmental results at lower costs.

3.1 Environmental Results

One of the benefits of using continuous emissions monitors is having accurate and complete emissions data that can be used to quantify the overall environmental effectiveness of the program. In the first five years of the program, emissions have dropped by over six million tons annually from 1980 levels for sources in the first phase of the program (Figure 6). These deep reductions in emission levels are well below the "allowable" emission levels in Phase I of the program.

SO_2 Emissions from All Affected Facilities



(Dashed red line indicates allowances issued for 263 Phase I sources (1995 to 1999), and for all affected sources in 2000.)

Figure 6 Emissions of SO_2 from Phase I and Phase II sources (Source: U.S. EPA)

During Phase I, emission reductions beyond the required allowable levels were encouraged by the banking provision of the program. Banking allows sources to make earlier, more substantial emissions reductions and then save the additional emissions allowances for future years. These early reductions mean environmental benefits begin to accrue sooner. Phase II began in the year 2000, extending emission limits through allowances to all utilities in the country that are fossil fuel fired and have a capacity greater than 25 MW (an increase of over 1,700 sources). As seen in Figure 6, the allowable limit is higher in Phase II, due to the number of sources participating. Emissions peaked slightly over the allowable limit in 2000 and 2001, as sources took advantage of their flexibility and used banked allowances for compliance. Despite modest use of banked allowances, overall emissions for all facilities were lower in the year 2000 than they have been since the 1960s.

When designing the cap and trade program, concerns were raised that the market-based approach sacrificed some degree of control and predictability. Of particular concern was that some of the highest emitting sources would purchase allowances rather than control their emissions. Experience with the program to date indicates that this fear was unfounded. Figure 7 illustrates the geographic location of emission reductions. The largest emission reductions have occurred in the heaviest emitting States in the Ohio River Valley including Ohio, Pennsylvania, West Virginia and Indiana (NAPAP, 1998). Some of the most sensitive ecosystems in the country are located in the Northeast part of

the US. Therefore, emission reductions in the upwind areas of the Ohio River Valley and the Midwest are of critical importance to protecting those downwind ecosystems.

SO_2 Emission Reductions by State

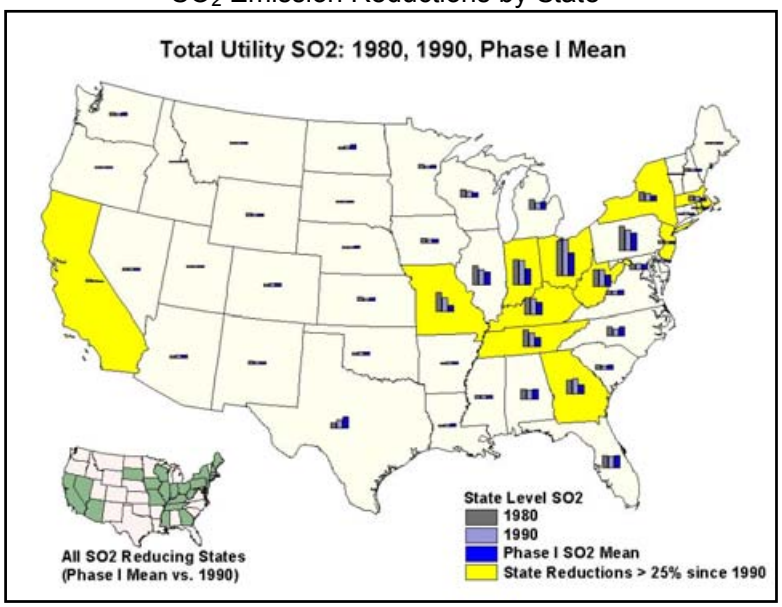


Figure 7 SO_2 Emissions by State for 1980, 1990 and Phase I (1995-1999) mean emission levels. States with shading have reduced emissions greater than 25 percent since 1990 (Source: USEPA)

In addition to the positive environmental results at the regional level, environmental results at the local level have also been very positive. Since the program allows for flexible emissions patterns, there were initial concerns that increases in emissions could occur, creating “hot spots” where local air quality was poor due to increased emissions in a particular area. These concerns persisted despite other layers of requirements under the Clean Air Act that are designed to ensure that ambient air quality goals are met. A recent article examined emissions and allowance trading data from the first four years of the program in order to isolate the effects of trading on emission levels. This analysis found that traded allowances have made little or no difference in the spatial location of emissions overall; and, since most States reduced emissions below their allowable level, the cap and trade system actually helps reduce hot spots by creating incentives for the dirtiest plants to clean up the most (Swift, 2000).

Emissions data are the first tier of environmental indicators showing that the SO_2 cap and trade program is having a positive impact on the environment. Other indicators include ambient air quality measurements, sulfate deposition, pH levels in rainfall and acid neutralizing capacity improvements in Northeastern lakes and streams. These indicators are beginning to provide evidence that the SO_2 cap and trade program is achieving the

intended environmental benefits:

Air Quality: Data collected between 1988 and 1997 (shown in Figure 8) indicate that ambient SO_2 concentrations are declining. In addition, research has shown a correlation in the decline in SO_2 emissions in the Midwestern U.S. with sulfate reductions at two monitoring stations in New York State (Husain, et. al, 1998).

Regional Trends in Ambient SO_2 Concentrations (1988 – 1997)

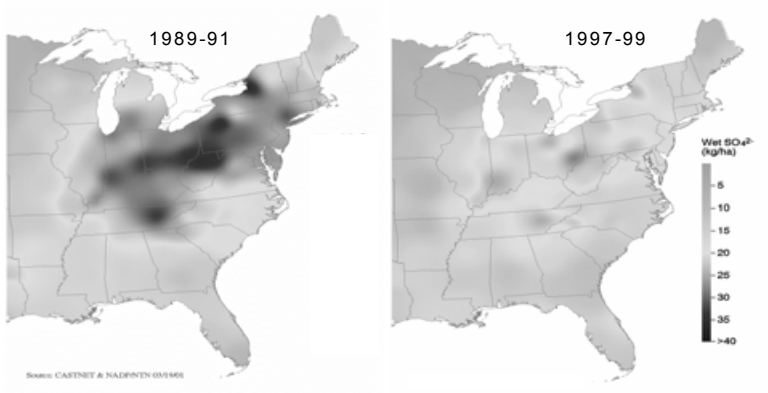


Figure 8 Regional Ambient SO_2 Trends 1988-1997. Percentage is the percent drop in SO_2 concentration in each Region. SO_2 concentrations are decreasing, with most prominent trends in the Northeast and Mid-Atlantic states (Source: USEPA)

Wet Deposition: Field data collected by the National Atmospheric Deposition Program/National Trends Network (NADP/NTN), consisting of more than 200 monitoring sites, show that sulfate levels in precipitation have dropped sharply since the U.S. SO_2 cap and trade program began reducing emissions in 1995 (Lynch et al, 2000). As shown in Figure 9, wet sulfate deposition levels have fallen by up to 25 percent in the Northeast and Mid-Atlantic regions. These ecosystems tend to be more sensitive to acidic deposition partly due to the poor buffering qualities of the underlying geology. Reductions in wet and dry sulfate can help acidified surface waters recover.

Reduction in wet sulfate deposition due to the U.S. SO_2 cap and trade program

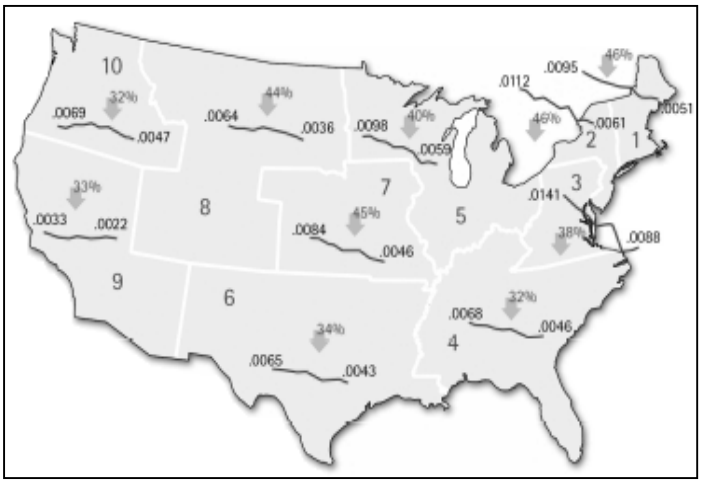


Figure 9 Changes in sulfate deposition in eastern USA following implementation of phase I of title IV of the Clean Air Act Amendments of 1990

(Source: Lynch et. al., 2000) (Units are in kilograms per hectare).

Dry Deposition: The Clean Air Status and Trends Network (CASTNet) measures dry deposition of sulfur and nitrogen at approximately 70 sites. Like wet deposition, dry deposition can cause acidification of surface waters. It is also linked with damage to materials. CASTNet data show that dry deposition sulfate concentration levels also have declined by approximately 30 percent in the Northeastern U.S. and Mid-Atlantic since 1989 (Holland et. al., 1999).

Surface Water Impacts: A recent study examining acidified lakes in the Northeast found that lakes atop thin gravel soils (and thus sensitive to acid deposition) in New England have shown statistical decreases in surface water sulfate concentrations and concurrent increases in acid neutralizing capacity (ANC) (Stoddard et. al., 1998). Rises in ANC provide a positive indicator of ecosystem recovery in the New England area. However, despite the declining surface water sulfate concentrations in the Adirondack Mountains region of New York State, there has been no measurable increase in ANC (Stoddard et. al., 1998). Some scientists postulate that additional reductions of SO_2 and NO_X are needed for recovery of these particularly sensitive ecosystems.

Other Impacts: Although more difficult to measure and quantify, there are also expected to be significant health benefits from the U.S. SO_2 cap and trade program. The estimated mean value (in 1997 dollars) of the health benefits associated with decreased sulfate levels and associated fine particle reductions in the Eastern U.S. is $10 billion for 1997 and $50 billion per year by 2010 when the program is fully implemented. Other potential benefits include improved visibility and reduced materials damages (NAPAP, 1998).

Despite the success of the program and the large reductions in emissions, electric utilities remain the major contributor to SO_2 emissions in the U.S. as seen in Figure 10.

SO_2 Emissions by Source Sector in 1999

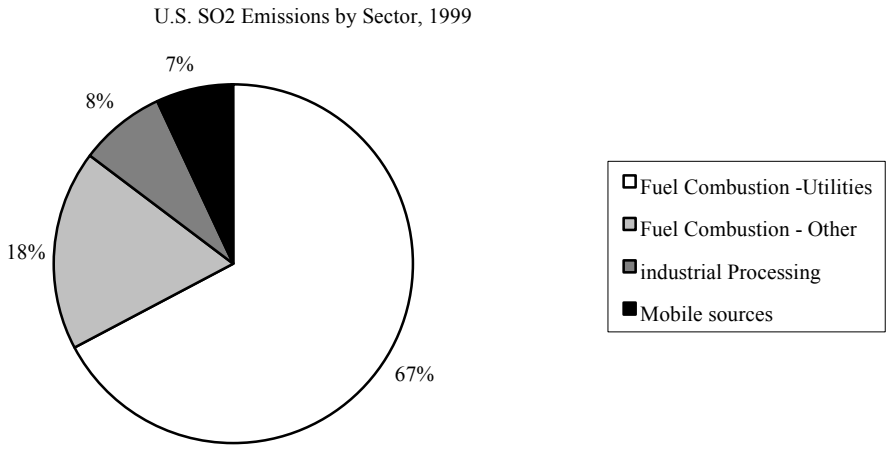


Figure 10 National emissions of SO_2 by source sector, electric utilities remain the largest single SO_2 source sector (Source: USEPA)

3.2 Program Costs

3.2.1 Cost Reduction by Cap and Trading

Estimated costs to attain the Program's emission reduction goal continue to decline as shown in Figure 11. Cost estimates for the SO_2 cap and trade program are significantly lower than the cost estimates to achieve the same reductions without the flexibility of the trading mechanism (Benkovic and Kruger, 2001). In 1989, the Edison Electric Institute estimated annual program costs to affected sources to be greater than $9 billion annually at full implementation in 2010, without the use of emissions trading. U.S. EPA's 1990 estimate, which included assumptions about the effect of emissions trading on costs, was approximately $5.7 billion annually. Subsequent estimates by the U.S. General Accounting Office (GAO) and Electric Power Research Institute (EPRI) are even lower, about $2.3 billion and $2.5 billion per year, respectively. More recent estimates have been as low as about $1 billion per year by 2010 (Carlson et. al., 2000). In addition to reduced costs for participants, administrative costs for the program are significantly less than costs to

administer traditional command-and-control programs.

Estimated Annual Cost of the U.S. SO_2 Cap and Trade Program when Fully Implemented in 2010

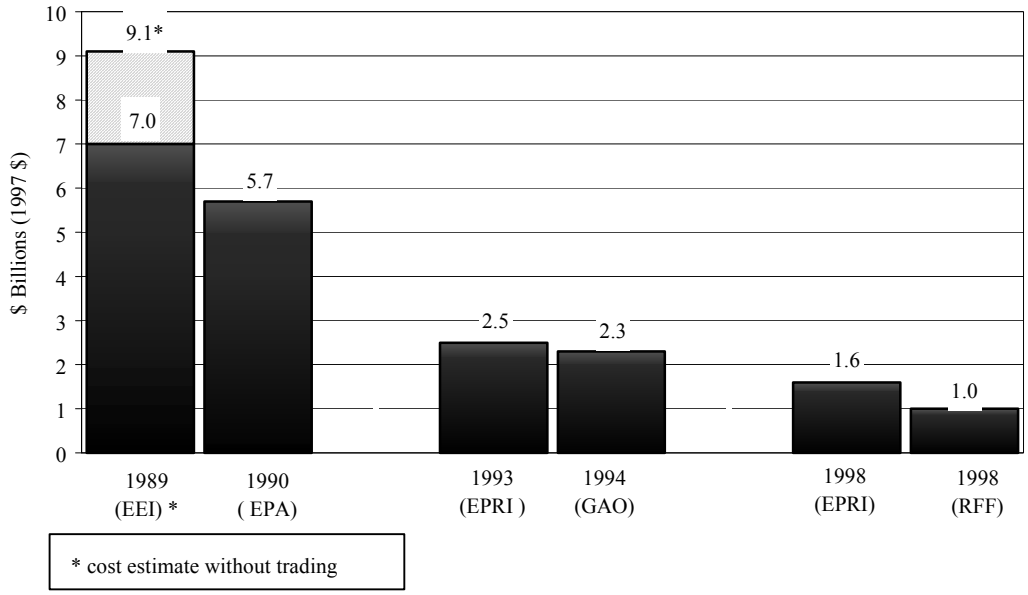


Figure 11 Estimated costs to sources in the Acid Rain Program at full implementation. (Sources: Edison Electric Institute, costs with out trading (EEI), EPA, EPRI, GAO, and Resources for the Future (RFF))

There are several reasons for the significant cost savings realized by the U.S. SO_2 cap and trade program. Flexibility in the program allowed sources to take advantage of new opportunities including the railroad deregulation, which brought low sulfur coal to the East at a lower cost (Burtraw, 1996 and Ellerman et al, 1997). The railroad industry was deregulated in the 1980s, and the next decade saw falling transportation costs, which made Powder River Basin coal and other low sulfur coals more economically feasible in the Midwest. In addition, competition between different types of compliance strategies lowered the cost of compliance. For example, in the 1990s, scrubber costs decreased by approximately 40 percent, and scrubber efficiencies improved from around 90 percent removal of sulfur to up to 95 percent removal (NAPAP 1998).

The significance of these lower costs is twofold. First, they show that it is often difficult to estimate future technological improvements and the more efficient use of existing technologies. Second, these lower costs again illustrate the benefits of a flexible approach to compliance that allows different technologies and fuels to compete against each other, and rewards firms for finding cost-effective measures that exceed emission reduction

targets.

3.2.2 Methods of Compliance

Emission reductions of SO_2 in 1995 were achieved by an almost equal split between scrubbing and fuel switching. Table 2 pairs estimated emission reductions at Phase I units with the method of emission control used; where the method was fuel switching, the table lists the source of the lower-sulfur coal. Slightly more than half of the reduction came from switching to lower-sulfur coals. A significant amount of reduction was also achieved through the installation of scrubbers. Twenty-six units installed scrubbers under Phase I; these units accounted for 45 percent of the reduction accomplished in 1995 (Ellerman et. al., 1997).

Low-sulfur western coal from the Powder River Basin continued to play an important role in reducing SO_2 emissions, but the main contribution to reducing emissions by fuel switching in 1995 came from the bituminous coal-producing regions, mostly in Central Appalachia. Although switching is often seen as changing the source of the coal from a high-sulfur region to a low-sulfur region, much of the reduction occurring in 1995 resulted from fuel switches within a region. This was observed in all regions, including the predominantly high-sulfur coal-producing regions of North Appalachia and the Midwest, where the coal to which units switched was typically mid-sulfur rather than the conventional low-sulfur coal (Ellerman et. al., 1997).

Table 2 SO_2 Emission Reduction Methods at Phase I Units in 1995

Method/Region	Tons of SO_2 Removed (in thousands of tons)	Percent of total
Scrubbing Total	1,754	45.1
New Title IV Scrubbers	1,734	44.6
Other Scrubbers	21	0.5
Switching Total	2,133	54.9
North Appalachia	205	5.3
Central Appalachia	756	19.5
South Appalachia	60	1.5
Midwestern	406	10.4
Powder River Basin	518	13.3
Other Western Coal	146	3.8
Imported Coal	22	0.6
Natural Gas	20	0.5
TOTAL	3,887	100.0

Source: Massachusetts Institute of Technology (Ellerman et. al., 1997)

Associated Costs of Compliance

The observed cost of compliance by scrubbing has been markedly lower than

expected. This experience is influencing today's allowance prices, which are more closely related to marginal compliance costs, rather than average costs that include the capital costs of flue gas desulfurization.

Table 3 compares the expected SO_2 removal cost for a representative retrofitted unit, with actual costs for the scrubbed units that were fully operational in 1995 (Ellerman et. al., 1997). By 1995, Phase I scrubbers were removing sulfur at an average total cost of $282 per ton, or about 40 percent less than what had been predicted by earlier estimates of average total overall cost. The cost savings arise from two factors: lower operating and maintenance costs, particularly fixed costs, and more intensive utilization of generating units with scrubbers (83 percent capacity factor in 1995 versus 65 percent as assumed in most earlier studies) (NAPAP, 1998).

Table 3 Scrubber Costs per Ton of SO_2 Removed (in 1994 dollars)

Types of Costs (per ton of SO_2)	ICF 1990	EPRI 1993 [a]	Actual 1995 [b]
Capital Charge	$285	$262	$206
Fixed Operation & Maintenance	$66	$83	$15
Variable Operation & Maintenance	$104	$129	$65
Total Cost	$455	$474	$286

[a] The representative retrofitted unit used in EPRI 1993 is a 300-megawatt unit with a retrofit difficulty factor of 1.27. The unit is assumed to remove 90 percent of the sulfur from a 3.97-lb coal and to be operating at a 65 percent capacity factor and a gross heat rate of 9,722 Btu/kWh.

[b] Data are from an MIT questionnaire given to affected utilities, as reported in Ellerman et al, 1997, updated in Ellerman et al, 2000.

Source: Massachusetts Institute of Technology

Allowance Prices

The existence of the allowance market has provided constant economic incentives for finding innovative and cost cutting emission reduction strategies. The actual SO_2 allowance prices from 1994 through the second quarter of 2000 are shown in Figure 12. Allowance prices have varied within a range of $60 to $250 dollars per allowance. As of June 2001, they were approximately $200 per ton.

Allowance Prices for SO_2 (1994 – 2000)

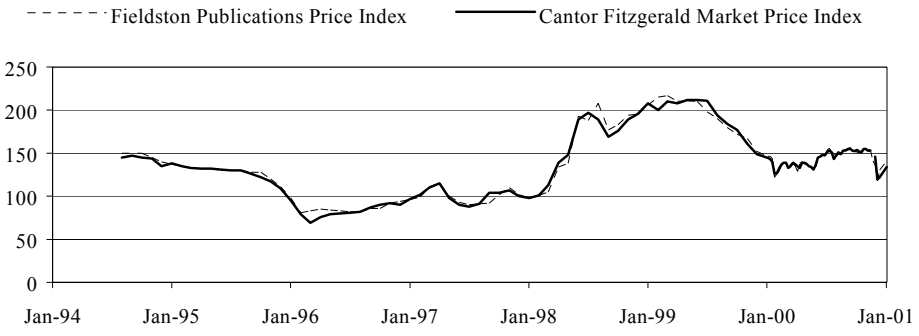


Figure 12 SO_2 allowance prices, 1994 to 2000

(Source: Fieldston Publications Price Index and Cantor Fitzgerald Market Price Index)

The market sophistication for participants and third parties (like brokers) has increased as the program has matured. During the first two years of the program, most trades occurred between units owned by one company. By the third year of the program, trades started occurring more frequently between economically distinct entities as shown in Figure 13 (now measuring about 50 percent). Trades between companies remain a large portion of total trades today.

It is worth noting that the U.S. SO_2 cap and trade program delivered large emission reductions during a time of overall growth in the U.S. economy. Figure 14 illustrates the trends in the U.S. Gross Domestic Product, fuel use and SO_2 emissions.

Allowance Transfers by Year for the US SO_2 Emissions Trading Program

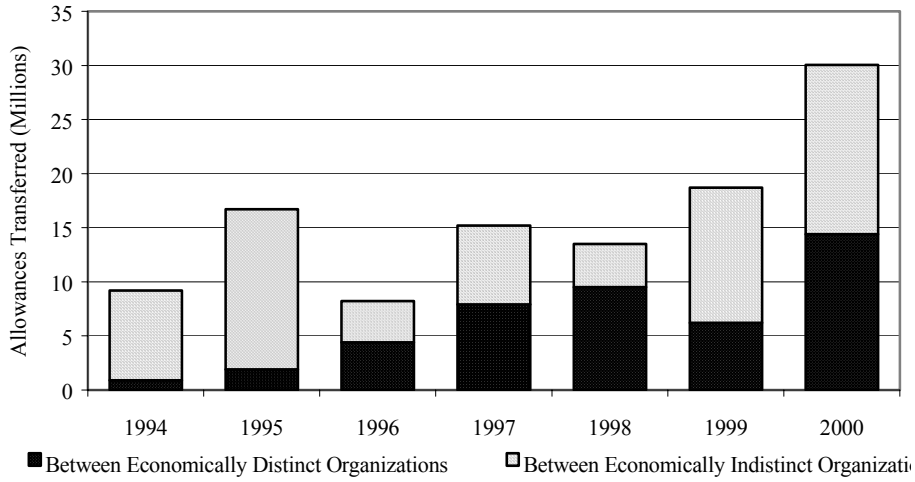


Figure 13 SO_2 Allowance Transfers Between and Within Organizations

SO_2 Emissions Declined while Electricity Production and GDP Increased(Net Percent Changes)

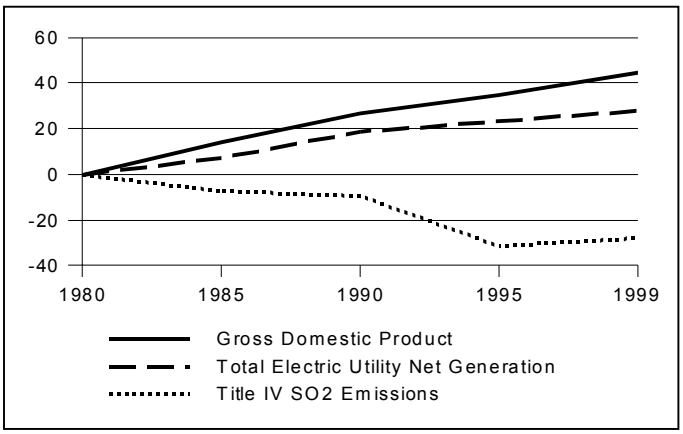


Figure 14 Trends in GDP, electricity generation and SO_2 emissions from the utility sector

(Sources: Bureau of Economic Analysis, Energy Information Administration, and EPA, Clean Air Markets Division)

In summary, results to date show that the use of the cap and trade mechanism has led to significant cost savings. The three main reasons are:

- Competition across all emission reduction strategies
- Markets provide incentives for innovation and reveal true costs
- Banking provides timing flexibility for emission reductions

3.3 Expanding Cap and Trade Policy to Other Environmental Problems

After the first few years of the U.S. SO_2 cap and trade program, its success spurred policy makers to consider using emissions trading as part of the solution to other regional air quality problems in the U.S. A cap and trade program, known as the NO_X Budget Program, was established collectively by States within the Ozone Transport Region (OTR) to help reduce the unhealthful levels of smog, or ground level ozone, that pervade the area during the summer months. They developed a NO_X cap and trade program in cooperation with the U.S. EPA that was largely based on the SO_2 cap and trade program model. Connecticut, Delaware, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, and Rhode Island participated in the NO_X Budget Program in 1999. As a result, over 240,000 tons of NO_X were reduced during the 1999 and 2000 ozone seasons from 1990 levels. This reduction was more than required. Prices for NO_X allowances ranged from a beginning price of over $7,000 per ton to less than $1,000 per ton in September. Allowance prices for NO_X in the last year have varied between $1,000 and $2,000 per ton.

The NO_X Budget Program is a cap and trade program tailored to the participating states with several unique distinctions from the U.S. SO_2 cap and trade program identified in Table 4. Large stationary sources were included in the program (both utilities and industrial plants) since these sources contribute over a third of the total NO_X emissions in the area. The control period was defined as May through September since smog is a seasonal phenomenon. States participating in the program allocate allowances as they choose to the individual utilities and large industrial boilers within their respective states. Participating sources are allowed to buy, sell, or trade allowances to meet their individual needs. These sources may also “bank” allowances. However, restrictions are placed on the use of banked allowances in an attempt to protect against high peaks in NO_X emissions on hot days when conditions for smog formation are most favorable.

From these two cap and trade applications in the US, we have seen that the costs of controlling SO_2 and NO_X have declined significantly and the environmental results have been excellent.

Many countries facing dual pressures of economic growth and environmental improvement find the cap and trade approach attractive since it can achieve significant emission reductions during times of economic growth. Other countries using or considering cap and trade programs to control air pollution include Chile, Slovakia, Poland, and China (Benkovic and Kruger, 2001). Emissions trading is also under international consideration by the Conference of the Parties to the United Nations Framework Convention on Climate Change. The proposed trading system would facilitate multinational greenhouse gas emissions trading among participating countries. Such a system could also be interfaced with domestic greenhouse gas emissions trading programs. Many countries are actively considering both a domestic trading program for greenhouse gases and participation in a multinational emissions trading program.

Table 4 Summary Comparisons of NO_X and SO_2 Cap and Trade Programs Administered by USEPA

	SO_2 Cap and Trade Program	NO_X Budget Program
Participating States (geographic scope)	National	Connecticut, Delaware, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, and Rhode Island participated in the program in 1999 and Maryland participated starting in 2000.
Participating Sources	All electric utilities with a capacity greater than 25 MW	Electrical generating units connected to generators greater than 15 MW, other indirect heat exchangers greater than 250 mmBtu (boilers and turbines, process heaters)

	SO_2 Cap and Trade Program	NO_X Budget Program
Timing of Emission Reductions	Phase I 1995-1999 (largest 263 sources) Phase II 2000 – 2010 (all sources, over 2,000)	Phase I 1999 (over 900 sources) Phase II 2003 *Possible expansion into other States.*
Compliance Period	Annual	May to September, the "ozone season"
Legal Authority	Legislative (1990 Clean Air Act Amendments)	Memorandum of Understanding (OTC MOU) signed by participating states September of 1994
Implementing Agency	USEPA Clean Air Markets Division	Participating States (requires coordination across states)
Administering Agency	USEPA	USEPA The states requested assistance from EPA with tracking emissions and allowances associated with the NO_X Budget Program.
Allocations	Developed by Congress in the 1990 CAAA. EPA allocates directly to sources 30 years in advance.	Developed by participating states. States allocate one to our years' of allowances to sources using independent allocation schemes.
	An annual auction sells 2.8 percent of allowances allocated to sources. Proceeds are returned to the sources for allowances taken.	There is no auctioning of allowances in the NO_X Budget Program.
	Allocations for coal fired boilers are based on historical heat input data and a performance standard of 1.2 lbs per mmBtu or 120% of actual emissions rate if actual rate is less than 1.2 lbs/mmBtu.	States develop independent allocation formulae. Some states allocate based on electricity output, others base allocations on heat input data, and performance standards.
	New sources do not receive allowances and must purchase allowances from the market or the annual auction.	States set aside allowances for new sources.

3.4 Lessons Learned from the SO_2 Program

The U.S. has had experience with a wide variety of regulatory tools for environmental policy. These include the traditional command and control approaches, as well as market-based approaches such as ERC trading and cap and trade programs. With more than six years of operating experience, several lessons can be derived from the U.S. SO_2 cap and trade program when compared with alternative regulatory approaches.

First, traditional operating permits can be greatly simplified. With rigorous emissions monitoring and the flexibility of an allowance system there is no need for setting source-specific emission limits, specifying control technology, or requiring detailed compliance schedules (McLean, 1996).

Second, transaction costs can be made very small because the government involvement in an allowance transfer simply involves recording the transaction, not case-by-case review or approval, and the source has numerous opportunities for transactions. There are hundreds of allowance holders, several allowance brokers, and the annual no-fee government allowance auctions. Furthermore, the decision to trade is not a stand alone one, but part of a company's overall compliance strategy.

Third, the ability to bank allowances can reduce cost and lead to significant early emissions reductions, but it also can extend the time for achieving the ultimate emission reduction target.

Fourth, continuous emissions monitoring can be moderately expensive, particularly for installation of elevators and platforms for tall stacks and for frequent quality assurance. However, accurate monitoring and timely reporting are critical to the credibility of the entire trading program, and their cost is modest when compared to the overall cost savings. The cost of monitoring at over 2,000 sources for SO_2, NO_X, and CO_2 has been estimated at about $200 to $300 million per year, compared to the cost savings for the SO_2 program alone of $3 to $4 billion per year (in 1997 dollars).

Fifth, phasing in the participation of sources can complicate administration and undermine achievement of emission reduction goals and has been perhaps the most serious flaw of the SO_2 allowance program. Two types of problems can occur: a) with interconnected electric utility grids, participating sources can shift electrical load to nonparticipating sources whose emissions can increase and undermine the emission reduction goal; and b) if sources in a particular region are allowed to voluntarily participate while others in the same region can chose not to participate, there is a risk of allowances being earned by the voluntary participants and used by other participants in lieu of reducing emissions, while the non-volunteering sources increase their emissions and cause a net increase in emissions.

Administrative mechanisms to compensate for these problems can be complex and are of limited effectiveness in ensuring the environmental integrity of the program. The “substitution” and “reduced utilization” provisions employed in the U.S. SO_2 cap and trade program have been litigated and revised and have become the most complicated administrative parts of the program. For example, complex allocation formulas had to be developed for substitution units (those Phase II units that volunteered to participate in Phase I) to prevent creation of large numbers of excess allowances. Further, in determining compliance of the Phase I units, it is necessary to review significant amounts of information on most of the 2,000 Phase II units to ensure that load shifting does not

undermine intended emissions reductions. Approximately 75 percent of the cost of developing and implementing the permitting provisions of Title IV and at least one third of the cost of developing and operating the allowance tracking system, or about $6.6 million, can be attributed to the complexity of Phase I. In retrospect, it would have been simpler and environmentally more credible to have all affected sources included from the outset in Phase I with emissions limitations tightened in Phase II to accomplish the goals of the program.

Sixth, capping total emissions coupled with allowance system compliance flexibility are compatible with electric power industry restructuring. The electric industry is the largest source of SO_2 in the United States and one of the largest sources of NO_X, mercury deposition, fine particulates, and CO_2. The industry is also currently undergoing a major restructuring from one dominated by regulated monopolies to one that will be competing nationally on price and availability.

Traditional air pollution control programs regulate emission rates (not tonnage of emissions) and assume stable patterns of electricity production. Because they have no emissions caps, if, as a result of restructuring, production shifts to higher emitting plants with lower pollution control costs, emissions could increase as well as shift geographically. A cap and trade program accommodates a dynamic market situation by ensuring that total emissions will not increase and by allowing costs of emissions control to follow shifts in production and emissions.

Seventh, cost savings can exceed expectations. Since 1990, the projected cost of compliance with the full SO_2 emission reductions has declined from $5 - $7 billion per year to $1.0 – $1.5 billion per year, against an annualized cost of compliance without trading of $7 - $9 billion. Although some of the cost savings can be attributed to the unexpected lack of increase in fuel prices, competitive markets do continuously seek more cost-effective solutions, leading to more rapid innovation and cost savings.

Eighth, government administrative costs can be much lower than traditional programs. By streamlining permitting, eliminating case-by-case review of trades, removing government participation in compliance decisions, and focusing instead on the measurement of emissions produced by affected sources, considerable public resources can be saved. Before deciding on additional provisions that would add complexity to the basic cap and trade program (e.g., reserve funds aimed at meeting goals outside of the basic program or provisions for opting into the program) are adopted, the provisions should be carefully scrutinized to see whether they warrant the increased administrative burden they would create.

One government decision still present in the cap and trade program is determining how to allocate allowances. This usually requires some consideration of historical utilization and emissions information. For traditional programs, historic (and sometimes future) utilization and emissions information are required as each source receives an

emission limit or applies for approval of a trade. For a cap and trade program this activity occurs once at the beginning of the program. Then the methodology applied to allocate allowances among participating sources may be reapplied periodically if allocations are updated. The advantage of this approach is that it provides a more equitable and consistent treatment of sources and elimination of what have often been lengthy delays in the approval of trades.

For the U.S. SO_2 cap and trade program, most of the allocation decisions were made by the Administration and Congress in 1989 and 1990 as part of the legislative process. Initially a few allocation formulas were established to recognize significant differences among existing sources, (e.g., due to different fuels and historic levels of control.) However, this blossomed into 29 formulas in order to give consideration to special situations. The resulting language in some cases was inconsistent and ambiguous, demanded numerous special data requirements, and served neither the environment nor market efficiency. As a result, the allocation process was made unnecessarily costly and long, and it provoked litigation. Approximately one third of the cost of developing and supporting the allowance trading program, or about $1.4 million, can be attributed to this factor. Allowance allocation formulas and data requirements can be kept to a minimum, with requirements defined clearly and consistently. Before allocation formulas are adopted, they should be carefully scrutinized to see whether the administrative burden and delay that they would cause are warranted.

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Appendix A

NAPAP – Continued Assessment of the Program

In the 1990 Clean Air Act Amendments (CAAA), Congress reauthorized NAPAP to continue coordinating acid rain research and monitoring, as it had done during the previous decade, and to report the results to Congress biennially, beginning in 1992. In addition, Congress asked NAPAP to periodically assess all available data and information and answer two questions:

1. What are the costs, benefits, and effectiveness of Title IV?

This question addresses the costs and economic impacts of complying with the U.S. SO_2 cap and trade program as well as benefits associated with the human health effects and the welfare effects (including reduced visibility, damages to materials and cultural resources, and effects on ecosystems).

2. What reductions in deposition rates are needed to prevent adverse ecological effects?

This complex question addresses ecological systems and the deposition levels at which these systems begin to experience harmful effects.

NAPAP assessments provide a path to evaluate how acid deposition control decisions, specifically Title IV, can affect emission and deposition rates, health and environmental benefits, monetary and non-monetary costs and benefits of Title IV, and the reduction in deposition rates needed to prevent adverse ecological effects. This framework serves as an organizing tool to help identify the inputs and outputs between the operational components of the assessment, facilitates communication and information flow, and allows researchers to focus on the connections between, as well as the processes internal to, the individual components.

Environmental Monitoring

Since the passage of the 1990 CAAA, NAPAP has coordinated federal acid rain research and monitoring in fulfillment of its mandate. Emission and deposition monitoring have been continued to characterize human and environmental exposure to acid deposition and its precursors. Human health and environmental monitoring has been extended to perform routine assessments of the effects of acid deposition and its precursors. More resource-intensive levels of data gathering, model construction, and model application have been employed to characterize the cause-and-effect relationships more accurately, including the impacts of Title IV controls.

NAPAP Continuing Assessment Framework: Example Assessment Questions

What is the status of implementation, the effectiveness, and the costs and benefits of Title IV of the 1990 Clean Air Act Amendments?

- What is the status of implementation (compared to the legislated requirements)?
- What emission reductions have been achieved?
- How have air concentrations and levels of deposition been affected by these emission reductions, and how do the new levels compare to the benchmark projections (i.e., with and without Title IV)?
- As measured by compliance costs, how effective is the market-based approach to emission control compared to a command-and-control approach (e.g., benchmark projections)?
- What are the benefits of Title IV within the United States in the following effects areas?
  - Human health, aquatic ecosystems, forest ecosystems, materials and cultural resources, visibility
- Is there a well-identified end point that affects human welfare?
- The following effectiveness questions should be addressed sequentially:
  - What are the current physical, chemical, or biological characteristics/states of the sensitive receptors?
  - What roles do these receptors play in maintaining ecosystems?
  - How have these states changed since 1980, and what are the trends in these changes?
  - What is the role of acid deposition controls in these trends?
  - What is the difference between current conditions (i.e., with implementation of Title IV) and bench-mark scenarios (i.e., with and without Title IV)?
- What have been the values of the benefits of the emission reductions compared to benchmark projections (monetary and nonmonetary)?
  - What are the consequences of emission allowance trading and banking on the environment?
- What are the reductions in deposition rates that are needed in order to prevent adverse ecological effects?
  - What are current deposition rates and what are their variabilities in time?
  - Are there resources whose responses are unique enough to be identified as specific indicators of changes in acid deposition?
- What are the dose-response relationships (observed and modeled for sulfur and nitrogen deposition in the effects areas of interest)?
  - What are the regional extent and magnitude of these responses?

The major goal of NAPAP's integrated assessment activity is to provide structured, technical information in a format that enables decision makers to evaluate the effectiveness of current public policy and provides a sound science base for future policy decisions. It must be credible, open, and communicated fully and responsibly. Secondary goals are to further develop a process for future assessments and to identify the near-term monitoring, research, and modeling needs leading to future assessments.

Scope of the Assessment

Beginning with the two main questions posed by Congress in the Amendments, a list of key policy-relevant questions were developed with input from experts within the NAPAP agencies, academia, the private sector, nonprofit organizations, environmental groups, industry groups, and congressional staff. These policy-relevant questions were given realistic bounds within the time frame of the report. The smaller, specific issues were identified along with the end points, sources of information, and tools needed to address them. All of the issues were expressed as questions that several research synthesis teams were charged with answering and that serve as the structure for this report (see NAPAP Assessment Questions text box).

Communication of Results

The primary method of communicating the results of NAPAP assessments is through publishing the reports to Congress. It is the responsibility of NAPAP, through the Office of the Director, to inform stakeholders of the results of assessments and receive feedback. To expand the availability of the reports beyond those parties that will receive the printed version and to improve dialogue with interested parties, NAPAP will place the reports on the World Wide Web. In addition, the research synthesis teams have been encouraged to publish their individual synthesis and analyses in the open literature.

Appendix B

Controlling Sulfur Dioxide Emissions: An Analysis of Technologies

Ravi Srivastava, Wojciech Jozewicz

SO_2 scrubbers may be used by electricity generating units to meet the requirements of Phase II of the SO_2 cap and trade program. Additionally, the use of scrubbers can result in reduction of mercury and particulate matter emissions. It is timely, therefore, to review the commercially available flue gas desulfurization (FGD) technologies that have an established record of performance.

The review of FGD technologies presented in this report describes these technologies, assesses their applications, and characterizes their performance. Additionally, the report describes some of the advancements that have occurred in FGD technologies. Finally, the report presents an analysis of the costs associated with applications of limestone forced oxidation, lime spray dryer, and magnesium-enhanced lime FGD processes. The information presented in the report should be useful to parties evaluating FGD technology applications.

This summary was developed by the National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title.

Introduction

Coal-fired electric power generating units account for the majority of SO_2 emissions in the U.S. To mitigate SO_2 emissions from electric power generating units, the Acid Rain SO_2 Reduction Program was established under Title IV of the Clean Air Act Amendments of 1990 (CAAA). This two-phase program was designed to reduce SO_2 emissions from the power generating industry. Phase I of the SO_2 cap and trade program began on January 1, 1995, and ended on December 31, 1999. Phase II of the SO_2 cap and trade program began on January 1, 2000. To meet the requirements of this phase, some power generating units may use FGD technologies. Additionally, the use of these technologies can result in the reduction of fine particle precursor emissions and mercury emissions from combustion units. Therefore, it is timely to examine the current status of FGD technologies.

FGD Technologies

Commercially available FGD technologies can conventionally be classified as regenerable and once-through, depending on how sorbent is treated after it has sorbed SO_2. In once-through technologies, the spent sorbent is disposed of as a waste or a by-product. In regenerable technologies, SO_2 is released from the sorbent during regeneration and may be further processed to yield sulfuric acid, elemental sulfur, or liquid SO_2. Both once-through and regenerable technologies can be further classified as either wet or dry. In wet processes, wet slurry waste or by-product is produced and flue gas leaving the absorber is saturated. In dry processes, dry waste material is produced and flue gas leaving the absorber is not saturated.

FGD technology applications were reviewed based on information provided in the CoalPower3 Database, available from the International Energy Agency's Coal Research Centre in London, England. This database lists commercial FGD applications. The review reveals that regenerable FGD processes are being used only marginally, with once-through FGD processes involved in the vast majority of applications. Therefore, for this work, FGD technologies were grouped into three major categories:

- Wet FGD (consisting of once-through wet FGD),
- Dry FGD (consisting of once-through dry FGD), and
- Regenerable FGD (consisting of wet and dry regenerable FGD).

Moreover, as regenerable technologies are used only marginally, their coverage in the report is limited.

The following paragraphs briefly describe commercially available FGD technologies, based on information in the CoalPower3 Database.

Wet FGD Technologies

In these technologies, SO_2-containing flue gas contacts alkaline (lime or limestone) aqueous slurry in an absorber. The most often used absorber application is the counter flow vertically oriented spray tower. In the absorber, SO_2 dissolves in the slurry and initiates a reaction with dissolved alkaline particles. The absorber slurry effluent, containing dissolved SO_2, is held in a reaction tank, which provides retention time for finely ground lime or limestone particles in the slurry to dissolve, and to complete the reaction with the dissolved SO_2. As a result of this reaction, sulfite/sulfate crystallization occurs in the reaction tank and available alkalinity of the slurry is depleted. Fresh slurry is added to the reaction tank to compensate for this depletion and thereby maintain a desired level of alkalinity. The slurry is recirculated from the reaction tank into the absorber. Reaction products from the reaction tank are pumped to the waste handling equipment, which concentrates the waste. From the waste handling equipment, the concentrated waste is sent for disposal (ponding or stacking) or, alternatively, processed to produce a saleable gypsum (calcium sulfate dihydrate) by-product.

Limestone Forced Oxidation

Over the years, limestone forced oxidation (LSFO), which minimizes scaling problems in the absorber, has become the preferred process for wet FGD technology worldwide. Gypsum scale typically forms via natural oxidation when the fraction of calcium sulfate in the slurry (slurry oxidation level) is greater than 15 percent. In LSFO, scaling is prevented by forcing oxidation of calcium sulfite to calcium sulfate by blowing air into the reaction tank (in-situ oxidation), or into an additional hold tank (ex-situ oxidation). The gypsum thus formed is removed as usual and, as a consequence, the concentration of gypsum in the slurry recycled to the absorber decreases. In LSFO systems used to produce saleable gypsum, nearly complete oxidation (over 99 percent) is achieved.

Limestone-Inhibited Oxidation

Another wet limestone process, designed to control oxidation in the absorber, is limestone-inhibited oxidation (LSIO). In LSIO, emulsified sodium thiosulfate ($Na_2S_2O_3$) is added to the limestone slurry feed to prevent the oxidation to gypsum in the absorber by lowering the slurry oxidation level to below 15 percent. In general, solids dewatering is more difficult in LSIO, compared to LSFO, due to the higher level of sulfites. The LSIO chemistry is particularly efficient in applications with high sulfur coals.

Lime and Magnesium-Lime

The lime process uses calcitic lime slurry in a counter flow spray tower. This slurry is more reactive than limestone slurry, but is more expensive. Magnesium-enhanced lime (MEL) is a variation of the lime process in that it uses a special type of lime. MEL is able to achieve high SO_2 removal efficiencies in significantly smaller absorber towers compared to calcitic lime. Additionally, MEL needs less slurry, compared to LSFO, for the same level of SO_2 removal.

Dry FGD Technologies

In these technologies, SO_2-containing flue gas contacts alkaline (most often lime) sorbent. As a result, dry waste is produced that is generally easier to dispose of than waste produced from wet FGD processes. The sorbent can be delivered to flue gas in an aqueous slurry form [lime spray drying (LSD)] or as a dry powder [duct sorbent injection (DSI), furnace sorbent injection (FSI), and circulating fluidized bed (CFB)]. LSD and CFB require dedicated absorber vessels for sorbent to react with SO_2, while in DSI and FSI, new hardware requirements are limited to sorbent delivery equipment. In dry processes, sorbent recirculation may be used to increase its utilization.

Lime Spray Drying

LSD is most often used by sources that burn low-to-medium-sulfur coal. In a spray dryer, simultaneous heat and mass transfer between alkali in a finely dispersed aqueous lime slurry and SO_2 result in a series of reactions and a drying of process waste. Studies indicate that most SO_2 capture in the spray dryer occurs when the sorbent is still moist.

Therefore, deliquescent additives may be used to increase the duration of time in which the sorbent remains moist.

Duct Sorbent Injection

DSI is intended to provide SO_2 control directly in the flue gas duct between the air preheater and the particulate control device. In this process, dry sorbent (most often hydrated lime) is injected into the flue gas downstream of the boiler's air preheater. Water is injected separately from the sorbent. Fly ash, reaction products, and any unreacted sorbent are collected in the particulate control device.

Furnace Sorbent Injection

In FSI, dry sorbent is injected directly into the furnace where temperatures are between 950 and 1,000°. Sorbent particles (most often calcium hydroxide, sometimes calcium carbonate) decompose and become porous solids with high surface area. Calcium sulfate, and any remaining unreacted sorbent, leave the furnace with the flue gas and are captured as solids in a particulate collection device.

Circulating Fluidized Bed

In CFB, dry sorbent (hydrated lime) is contacted with a humidified flue gas in a CFB. The bed provides a long contact time between the sorbent and flue gas because sorbent passes through the bed several times. CFB is characterized by good SO_2 mass transfer conditions from the gas to the solid phase. However, due to a higher particulate matter concentration downstream of the fluidized bed, improvements to the existing electrostatic precipitator may be needed to maintain the required particulate emission levels.

Regenerable FGD Technologies

Regenerable FGD technologies find only marginal application in the U.S. and throughout the world. These processes involve comparatively high operation and maintenance (O&M) costs, relative to other FGD processes, and the return from sale of the product does not offset a significant portion of the increased process cost. Regenerable FGD technologies discussed in the report include four wet processes (sodium sulfite, magnesium oxide, sodium carbonate, and amine) and one dry process (activated carbon). These processes produce a concentrated stream of SO_2 that can be used for sulfuric acid production.

Technology Applications

FGD technology applications were reviewed based on the information in the CoalPower3 Database, available from the International Energy Agency's Coal Research Centre in London, England. Findings of this review are described below.

Table 1 shows statistics describing the installation of FGD systems at fossil-fuel fired electric power plants through 1998. FGD systems were installed to control SO_2 emissions from over 226,000 MWe of generating capacity worldwide. Of this capacity, 86.8 percent utilizes wet FGD technologies, 10.9 percent dry FGD technologies, and the remainder

FGD technologies. A similar pattern of FGD technology application can be seen in the U.S. Through 1998, almost 100,000 MWe of capacity in the U.S. was equipped with FGD technology. Of this capacity, 82.9 percent utilizes wet FGD technologies, 14.2 percent dry FGD technologies, and the remainder regenerable FGD technologies.

Table 1 Electrical Generating Capacity (MW) Equipped with FGD Technologies Through 1998

Technology	United States	Abroad	World
Wet	82,092	114,800	196,892
Dry	14,081	10,654	24,735
Regenerable	2,798	2,798	5,192
Total FGD	98,971	98,971	226,819

Of the U.S. electricity generating capacity equipped with wet FGD technologies, 68.9 percent uses limestone processes. Also 80.4 percent of the U.S. generating capacity, equipped with dry FGD technologies, uses LSD. A similar pattern of FGD technology usage is observed in overseas applications. Limestone processes are used for 93.2 percent of the overseas electric generating capacity equipped with wet FGD technologies. Also 64.8 percent of overseas generating capacity, equipped with dry FGD technologies, uses LSD.

Recent FGD technology selections made by the U.S. electricity generating industry can be further understood by examining recent FGD technology installations in the U.S. Between 1991 and 1995, 19,154 MW of U.S. electric generating capacity was retrofitted with FGD technologies. Of this capacity 75, 17.5, and 7.5 percent were equipped with LSFO, MEL, and LSD, respectively.

Based on the data presented above, FGD processes of choice have been wet limestone FGD, MEL, and LSD. Of the wet limestone processes, LSFO has been used in recent applications.

Performance

An estimate of the SO_2 reduction performance of FGD technologies was obtained by examining the design SO_2 removal efficiencies reported in the CoalPower3 Database. These data reflect that the median design efficiency for all units using wet limestone processes is about 90 percent. However, advanced, state-of-the-art wet scrubbers are capable of achieving SO_2 removal efficiencies of over 95 percent. High velocity LSFO, with state-of-the-art design options, is reportedly capable of removing more than 99.6 percent of SO_2 under test conditions. The data also reflect that the median design efficiency for all units using LSD is 90 percent. However, recent LSD applications, installed between 1991 and 1995, have design SO_2 removal efficiencies between 90 and 95 percent.

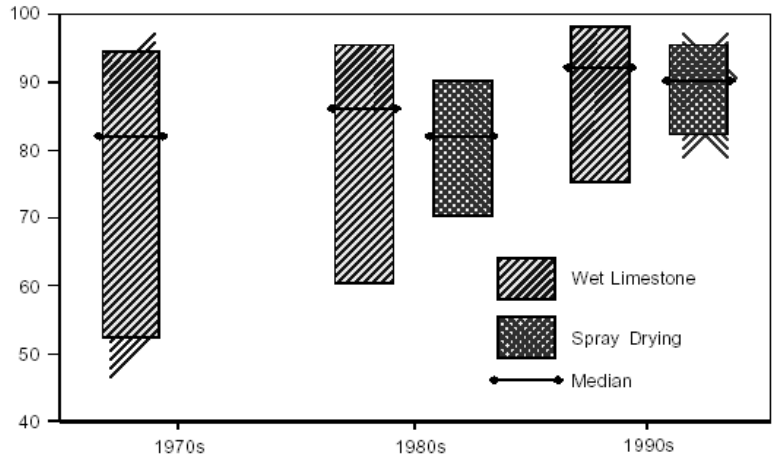

Figure 1 Improvement in design efficiency of FGD Technologies of interest

It is useful to examine the improvement in performance of wet limestone and LSD processes over the period of their application. Figure 1 shows ranges and medians of design SO_2 removal efficiency for the pertinent populations of wet limestone FGD and LSD installations in each of the last three decades. A steady improvement in design SO_2 removal efficiency is evident for these processes. This improvement may be due, in part, to more stringent SO_2 control requirements. However, the trends do reflect that the SO_2 removal efficiencies for the processes considered have improved with time.

Advances

Over the last 30 years, significant improvements have been made in the wet limestone processes. Some of these advances have been aimed at improving the performance and cost-effectiveness of established processes, while others have focused on developing new processes.

Performance Improvements

Several technical options are available for upgrading the SO_2 removal performance of existing wet FGD installations. Some of the important options include increasing the reactivity of the limestone slurry with organic acid addition, installing a perforated tray or other device to increase mass transfer, and reducing the amount of flue gas that is bypassed.

Several advanced design, process, and sorbent options are also available for new wet FGD installations. Some of these include using large capacity modules, increasing flue gas velocity in the absorber, and buffering with organic acid. These advanced options are capable of providing high SO_2 removal and/or increased operational efficiency.

New Process – Ammonia Scrubbing

Over the last few years, a promising wet FGD process has been under development.

This process, wet ammonia FGD, has the potential to improve waste management in conjunction with providing SO_2 removal efficiency in excess of 95 percent. At present, the wet ammonia FGD process offers the unique advantage of an attractive ammonium sulfate by-product that can be used as fertilizer. In addition, this process is also capable of removing other acid gases (e.g., sulfur trioxide and hydrogen chloride).

The attractiveness of the ammonia scrubbing process appears to depend on the ability of the plant to sell ammonium sulfate fertilizer. An evaluation of ammonium sulfate prices over a period of 11 years has indicated a sustained increase. This has been explained by its value as a nutrient for selected crops and its ability to replenish the sulfur deficiency in soils.

FGD Technology Costs

LSFO, LSD, and MEL have been the processes of choice in recent U.S. applications. Therefore, in this work, state-of-the-art cost models were developed for these processes. These state-of-the-art models are collectively called the State-of-the-art Utility Scrubber Cost Model (SUSCM) and are expected to provide budgetary cost estimates for future applications. The following paragraphs briefly describe and provide results for the state-of-the-art LSFO, LSD, and MEL cost models developed in this work.

LSFO and LSD Costs

U.S. EPA's Coal Utility Environmental Cost Workbook (CUECost) provides budgetary cost estimates (+30 percent accuracy) for LSFO and LSD applications based on user-defined design and economic criteria. CUECost provided the starting point for the LSFO and LSD cost models developed in this work. First, sensitivity analyses were conducted with CUECost LSFO and LSD algorithms to identify variables that have a minor impact on cost (i.e., a deviation of less than 5 percent over selected baselines). These sensitivity analyses revealed that, for both LSFO and LSD applications, the majority of cost impacts can be captured with capacity, heat rate, coal sulfur content, and coal heating value. Next, variables other than the last four were fixed at typical values in the corresponding CUECost algorithms to arrive at simplified LSFO and LSD cost models. Then, the simplified LSFO and LSD cost models were validated with published data. Validation results reflect that on average LSFO and LSD simplified cost models predict the published costs within +10.5 and 15.6 percent, respectively.

The simplified LSFO and LSD cost models were then further adjusted with cost-effective design choices to arrive at the respective state-of-the-art models. These design choices were based on information available on commercial applications. For LSFO, these choices included largest absorber size corresponding to 900 MWe, absorber constructed of rubber- lined carbon steel (RLCS) or alloy, use of dibasic acid for pH buffering, and either gypsum stacking waste disposal or wallboard production. Similarly, for LSD the cost-effective design choices included largest absorber size corresponding to

275 MWe and RLCS absorber.

MEL Costs

In MEL, sorbent (magnesium-enhanced lime slurry) is prepared in a similar manner to that used in LSD, and this sorbent is contacted with flue gas in an absorber similar to a typical LSFO absorber. However, because MEL sorbent is more reactive than LSFO sorbent, less flue gas residence time is needed in the MEL absorber. As such, a MEL absorber is smaller than a corresponding LSFO absorber. Further, MEL waste handling equipment operates in a fashion similar to that in LSFO, producing gypsum byproduct. Considering these characteristics of MEL, for costing purposes this process can be considered to be a combination of LSFO and LSD. Therefore, the LSFO and LSD algorithms developed as described above were used appropriately to develop the MEL cost model.

As for LSFO and LSD, cost-effective design choices were made to arrive at a state-of-the-art MEL cost model. These choices included largest absorber size corresponding to 275 MWe, absorber constructed of RLCS or alloy, and wallboard production.

The comparison of capital and O&M costs for three technologies considered here is shown in Table 2. Ranges of costs are given in 1998 constant dollars for units between 100 and 1000 MWe. Table 2 shows that capital cost for LSFO used on a small unit (100 MWe) is higher than that of MEL used on the same unit. For a large unit (1,000 MWe), capital cost is lower for LSFO. Fixed O&M cost is similar for LSFO and MEL over the entire unit size range considered. However, variable O&M cost is lower for LSFO than for MEL, largely due to the difference in the sorbent cost ($15 per ton for LSFO versus $50per ton for MEL).

Table 2. Cost in 1998 Constant Dollars for Selected FGD Technologies

Technology	Capacty Rabge[a] MW_e	Capital Cost $/kW	Fixed O&M $/kW.Yr	Variable O&M mills/kWh
LSFO[b]	100-1000	542-195	18-7	1.80-1.78
LSD[c]	100-1000	363-140	12-4	2.24-2.24
MEL[d]	100-1000	384-238	16-8	2.02-2.01

a Unit has a heat rate of 10,500 Btu/kWh and a capacity factor of 90 percent.
b 4.0 percent sulfur coal application, SO_2 removal of 95 percent.
c 2.0 percent sulfur coal application, SO_2 removal of 90 percent.
d 4.0 percent sulfur coal application, SO_2 removal of 96 percent.

Appendix C

Illustrative List of Emissions Measurement Options

1.Continuous Emissions Monitoring Systems

Experience indicates that an in-stack continuous emissions monitoring system (CEMS) is a highly accurate and proven method for determining mass emissions from stationary source combustion vented through a stack for pollutants such as SO_2, NO_X, and CO_2. A CEMS measures actual emissions on a continuous basis and provides an accurate, reliable, precise, timely, and verifiable measure of true emissions. This method consists of installing a pollutant-specific concentration monitor and a volumetric flow monitor on all flue gas exhaust stacks from the combustion unit (e.g., by installing a probe in the flue gas exhaust stack, which draws a sample and sends it through an umbilical line to the analyzer). Ideally, readings from the measurement equipment should be automatically recorded and stored electronically in order to provide consistency, minimize human error, and maximize the efficiency of data collection and storage. To facilitate this, both the concentration and flow monitors should be connected to a data acquisition and handling system (DAHS), which automatically collects the raw concentration data and volumetric flow data at frequent intervals (e.g., at least once every 15 minutes). The DAHS can then perform a calculation to determine the total mass emissions of the pollutant in question emitted during a specified period of time (i.e., how many tons of the pollutant have exited the stack in that hour, day, or week).

However, as with any measurement technique, implementation is critical. A CEMS will achieve a representative sample only if the probe is located properly in the stack. It should be located an appropriate distance from any upstream obstacles in the stack and from the downstream stack exit and should be situated properly in the exhaust flow, rather than too close to the stack wall or in a “dead spot.” Testing the installed CEMS against an independent test method is critical to ensuring that the CEMS is obtaining a representative sample. Furthermore, the stack environment where the CEMS or its probe will be located is an extreme environment with high temperatures and corrosive gases. Thus, it is also critical that the CEMS be properly designed, maintained, calibrated, and tested frequently to ensure ongoing accuracy.

Use of a CEMS can be costly because of the installation of equipment in each stack and the required maintenance and quality assurance/quality control procedures and

because testing against an independent test method requires a platform on the stack and often an elevator so that testers can reach the platform. However, the cost may be a small percentage of the savings achieved by implementing a cap and trade program versus another form of regulation and the resulting accuracy and confidence in the emissions data may be well worth it. The use of CEMS is particularly important in the following cases:

- For measurement of emissions not directly linked to the fuel burned (e.g., NO_X).
- For episodic problems where accurate data is needed at frequent intervals.
- For measurement of emissions from the combustion of highly variable fuels, especially if frequent fuel sampling is difficult or not accurate (e.g., solid fuels, waste, coal).
- For measurement of emissions where post-combustion emission controls have been applied.

A CEMS is necessary to obtain accurate emissions values for any units with post-combustion control technology (e.g., a wet flue gas desulfurization system or SO_2 scrubber, selective catalytic reduction for NO_X, or a CO_2 capture device) because the resulting emissions reductions can be verified only through direct measurement of emissions after the point where emission control technology is installed. Estimation of emissions reduction from control equipment is not sufficiently accurate because the performance of control equipment can be variable.

2.Mass Balance Estimation Method

Another emissions estimation method is the mass balance approach where inputs and outputs are balanced to calculate the output emissions of the relevant pollutant. This can be applied to combustion emissions that are directly linked to the fuel, such as SO_2 or CO_2, as well as to sources such as cement production (CO_2) and adipic acid (N_2O), which are not linked to combustion. For combustion emissions, the amount of total emissions is calculated by using the total mass of fuel combusted and the percentage of sulfur in the fuel. This assumes that all of the fuel-based pollutant precursor is converted to the pollutant in the atmosphere. For example, if a unit combusted 100 tons of coal in a day, and the coal had an average sulfur content of one percent, then one ton of sulfur is assumed to be released. Simple chemistry equates this to two tons of SO_2 emitted to the atmosphere.

This method can be further refined by adding a provision for determining the amount of pollutant precursor that exits in the ash, and is therefore not emitted out of the stack. This can be accomplished by sampling and weighing the ash and performing chemical analyses of the sulfur content of the ash samples. Under this refinement, the amount of sulfur assumed to be emitted as SO_2 is the difference between the sulfur entering the

boiler in coal, less the sulfur exiting the boiler in ash.

Mass balance methodologies are not appropriate when post-combustion control devices are employed, since these devices may remove variable amounts of a pollutant depending upon how the device is used. It is also important to consider whether any combustion or post-combustion process may affect the pollutant of interest, even if that is not its primary purpose. For instance, one of the byproducts of a limestone scrubber is CO_2. A mass balance approach that focuses solely on fuel-based CO_2 will not account for the extra CO_2 emissions produced by a limestone scrubber or other control processes, such as a fluidized bed boiler, that use sorbent injection.

For combustion emissions, the mass balance approach requires two basic inputs, fuel mass and content of the pollutant precursor (e.g., sulfur or carbon) in the fuel. Methods for determining these two inputs vary for different types of fuel and pollutants, and are discussed below.

The mass balance approach is generally less costly and more accurate for oil and gaseous fuels than for coal because: 1) fuel flow meters, which measure the volume of fuel to be burned, are more cost-effective (and often already in place) than measurement devices of comparable accuracy for as-fired coal quantity; and 2) acquiring a representative sample of gaseous or liquid fuel for fuel sampling and analysis is much easier and more representative with a well-mixed liquid or gaseous fuel than with a heterogeneous solid fuel such as coal. An accurate estimate can be obtained for SO_2 emissions from the combustion of oil or gaseous fuel at a fraction of the cost of a CEMS by using the mass balance approach. For coal, however, the cost of getting an accurate measurement using mass balance can rival the cost of a CEMS, particularly for SO_2 because the high variability in sulfur content requires frequent sampling. In addition, because of the high cost of accurate belt scales for weighing the quantity of coal burned, the mass balance approach is also costly for coal combustion if a frequent measurement of emissions is required.

3.Mass Balance for Coal

Coal Mass Determinations

The appropriate method to determine coal mass will depend on a variety of factors, including the existing infrastructure available to determine coal mass, because significant new investments in additional equipment might cost as much or more than a continuous emissions monitoring systems (CEMS). The most accurate method of determining coal mass is to weigh the coal as it is fed to the boiler (or other combustion unit) using gravimetric coal feeders with accurate belt scales or other similar weighing devices. The cost of accurate belt scales and similar technology rivals the cost of CEMS.

The U.S. requirement to use hourly data for the SO_2 and NO_X trading programs led to the choice of CEMS, since at one hour data reporting intervals, CEMS are much more accurate than coal mass estimations. If a longer reporting period were used (perhaps daily, weekly or monthly), the use of coal mass estimation procedures becomes more feasible.

If coal mass estimation procedures are used, several different protocols are needed for different facilities. For example, at some facilities, it might be possible to employ gravimetric feeders with belt scales, as mentioned above. Other facilities might determine the mass of coal contained in each of several hoppers and use the number of times each hopper is filled in a week to estimate the coal mass combusted. (This would be less accurate than the first approach.) At still other facilities, where coal is delivered by rail, it might only be possible to estimate coal mass by multiplying the number of rail cars delivering coal by the average mass of coal in the rail car. (This would be the least accurate of the three approaches.) As stated before, these protocols would need to be tailored to the actual facilities available at participating sources. In addition, measures might need to be taken to ensure that the trading program is not harmed by disparities in the accuracy among the various protocols in use at different sources; this relates back to the original consistency criteria.

To increase the likelihood that the different coal mass estimation protocols produce acceptable results, check these protocols frequently against the results yielded by independent standard reference methods. Such periodic checks would ensure that each of the different methods resulted in similar estimates of coal mass. Use of these reference methods would be required at each facility to ensure fairness and to increase the consistency of the data received.

Determining Sulfur Content in Coal

A critical pre-condition for determining the sulfur content of coal is to obtain coal samples from locations that are representative of the coal actually burned. A wide variety of options exist for determining the location where coal samples are taken. The basic options are listed below in order of decreasing accuracy based on the convention that the most accurate possible value is that derived from an “as-fired” sample.

Collecting “as-fired” samples of the coal actually combusted at a unit as the coal enters the boiler is the most accurate method for determining coal sulfur content. In particular, the state of Pennsylvania has a protocol for this method, which can be found on the Pennsylvania Department of Environmental Conservation Web site at <http://www.dep.state.pa.us/dep/deputate/airwaste/aq/cemspage/cemshome.htm>.

Samples taken from the coal pile at a source or samples from each delivery are less accurate methods for determining coal sulfur content.

Coal samples taken over time to determine sulfur content of coal from a specific mine.

The use of a generic coal sulfur content number is the least accurate option.

For any of these options, statistically sound sampling techniques should be employed to ensure the representativeness of the coal sample.

Once the sample is collected, internationally accepted chemical analysis procedures should be used to determine the percent sulfur in the coal. Many standards organizations have developed reference methods for determining the sulfur content of a sample of coal. The International Standards Organization (ISO) and American Standard Test Methods (ASTM) are examples of such organizations. The ASTM Standard Volume 05.05 · Gaseous Fuels; Coal and Coke, which includes procedures for evaluating the sulfur content of coal and coke, is referenced at <http://www.normas.com/ASTM/STDS/sections/section05.htm>. In addition the U.S. EPA has also established emission factor techniques that are used for developing emission inventories when these sources are not required to perform more accurate monitoring. These procedures are described in the U.S. EPA's AP-42 series at <http://www.epa.gov/ttn/chief/ap42pdf/c01s01.pdf>.

4.Mass Balance for Oil and Gas

Determining Quantity of Oil or Gas Burned

The mass balance procedure requires a measurement of the quantity of fuel burned, as well as information on the content of the fuel burned. For oil and gas, the quantity of fuel burned can be easily measured with a fuel flow meter. There are several different types of fuel flow meters appropriate for different types of oil and gas. In most cases, they require regular calibration to ensure accurate results. For this measurement option, data should be electronically captured by a data acquisition and handling system. For units that do not have fuel flow meters, an alternative approach that is likely to be less accurate, but may be sufficient, is to take measurements from fuel storage tanks.

Determining Sulfur Content of Oil or Gas

For an accurate estimation of SO_2 emissions from oil-fired units, fuel sampling and analysis should be performed on as-fired oil to determine the following properties of the oil: percentage of sulfur by weight, gross calorific value (GCV), and if necessary, the density. Density would be required if an oil fuel flow meter measures volumetric flow rather than mass flow. This sampling could be performed either every day the unit combusts oil or upon receipt of a shipment of oil. If sampling is performed upon receipt of a shipment of oil, it should be performed after the oil has been added to the storage tank and properly mixed with the oil already in the tank. If the sample is instead taken directly from the delivery vehicle, then the highest value from recent deliveries should be used because it will likely be mixed with fuel already in the tank.

For units that combust "sweetened" pipeline natural gas with low sulfur content and

low variability of sulfur content, a default sulfur content value in lieu of sampling should be sufficient. A conservative default GCV can also be used or monthly sampling can be done to determine the GCV. For gaseous fuels with high variability and sulfur content, fuel sampling for sulfur/carbon content and GCV would be appropriate; frequency of such sampling would depend on the variability and characteristics of the fuel.

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Glossary of Terms

A

Acid deposition The process by which acidic particles, gases, and precipitation leave the atmosphere. More commonly referred to as acid rain, acid deposition has two components: wet and dry deposition.

Acidification Refers to reducing something's pH, making it more acidic; also means the loss of ANC.

Acid rain The result of sulfur dioxide (SO_2) and nitrogen oxides (NO_X) reacting in the atmosphere with water and returning to earth as rain, fog, or snow. Broadly used to include both wet and dry deposition.

Acid Rain Program created under the Clean Air Act to reduce acid rain; employs a cap and trade framework to achieve SO_2 reductions. Also known as the US SO_2 cap and trade program and the US SO_2 emissions trading program.

Allowance An authorization to emit a specific amount of a pollutant under a cap and trade program. For example, in the US SO_2 cap and trade program, one allowance is the authorization to emit one ton of SO_2. Allowances are used for compliance and can be traded among sources participating in the US SO_2 cap and trade program.

Allowance Tracking System (ATS) a computerized system administered by EPA and used to track the allowances and allowance transactions by all market participants

Allowance Transfer Form (ATF) official form used to report allowance transfers to the ATS. The ATF lists the serial numbers of the allowances to be transferred and includes the account information of both the transferor and the transferee

Anyway tons reductions of a pollutant that would have occurred regardless of any environmental motivation. For example, if some technological innovation leads to production processes that are cheaper as well as more energy-efficient and a source applies the innovation to save money, then credits for such efficiency improvement awarded under a project-based trading program could be called “anyway tons.”

B

Banking the ability of sources to carry over unused allowances and/or offsets for use in a later compliance period.

Broker person who acts as an intermediary between a buyer and a seller, usually charging a commission

Bubble a regulatory term which applies to the situation when a company combines a number of its sources in order to control pollution in aggregate; under a bubble facility operators are allowed to choose which sources to control as long as the total amount of emissions from the combined sources is less than the amount each source would have emitted under the conventional requirement

C

Cap and Trade A regulatory program under which the government sets an aggregate emissions cap and distributes rights (allowances) to allow emissions. Allowances are needed for compliance and can be traded among participating sources. Emitting facilities covered by the program are able to tailor their

compliance strategies to reflect their own least-cost approaches and adjust to changes in technology or market conditions by buying or selling allowances as needed in a private market

Clean Air Act Amendments of 1990 reauthorization of the Clean Air Act; passed by the U.S. Congress; strengthened ability of EPA to set and enforce pollution control programs aimed at protecting human health and the environment; included provisions for Acid Rain Program

Credits an authorization to emit a specific quantity of a pollutant (e.g. 1 ton). Credits are generated under a rate-based trading program when an affected source achieves an emissions rate below the specified performance rate. The term is often used interchangeably with "offsets," but a distinction is made here between the authorization to emit a specific quantity of pollutant generated through a rate-based trading program versus that generated through project-based trading program

D

Demand-side a term referring to the need (or demand) for power generation among a utility's customers

Designated Representative for a unit account, the individual who represents the owners and operators of that unit and performs allowance transfer requests and all correspondence with EPA concerning compliance with the Acid Rain Program; for general accounts this refers to the person who is authorized to transact allowances from each account

F

Flue gas desulfurization (FGD) is a post-combustion control device installed to remove pollutants from the exhaust gases produced from the burning of coal in the boiler. FGD units are also known as scrubbers, which use a sorbent to control SO_2 formation in either a wet or dry process.

G

General Accounts accounts in the SO_2 or NO_X ATS's that were created after the initial allocation; general accounts can be opened by any individual and they are not automatically adjusted for compliance

Generation Performance Standard (GPS) Allocation methods under which the government determines sources allowance allocations based on pollution emitted per unit of production (also referred to as output based allocations). For the power sector, GPS would be in the form of emissions per kilowatt hour of energy produced.

Ground-level Ozone the occurrence in the troposphere (at ground level) of a gas that consists of 3 atoms of oxygen (O_3); formed through a chemical reaction involving oxides of nitrogen (NO_X), volatile organic compounds (VOC), heat and light; At ground level, ozone is an air pollutant that damages human health, vegetation, and many common materials and is a key ingredient of urban smog.

H

Historical Allocation Allocation method under which the government gives firms allowances based on their historic heat input (fuel consumption) levels. This is the primary method for allocating allowances for SO_2 Historical allocations could also be based on historic emissions levels.

Hot Spots A increase in local ambient air pollutants.

N

National Ambient Air Quality Standards (NAAQS) health-based standards for a variety of pollutants set by EPA that must be met by states across the country

Nitrogen Oxides (NO_X) gases produced during combustion of fossil fuels in motor vehicles, power plants and industrial furnaces and other sources; is a precursor to acid rain and ground-level ozone

NO_X Budget Program a NO_X cap and trade program adopted by 13 jurisdictions in the Northeast to address ozone transport in that region

O

Offsets an emission reduction of a specific quantity of a pollutant (e.g., 1 ton) verified through a project-based trading program. An offset can be applied to an associated regulatory emissions limit as an authorization to emit that specific quantity of pollutant. See also definition of "credit."

P

Paper credits generated under project-based trading programs if the emissions baseline for a project is set at a level above which the source actually operates. If such a baseline is used to calculate the quantity of offsets generated by the project, then the resulting offsets do not reflect real emissions reductions. Similarly, paper credits could also occur under a rate-based trading program if the performance standard is set at a level above which a source actually operates.

S

Scrubbers a pollution control technology utilized in power plants to remove pollutants from plant emissions

Smog: originally meaning a combination of smoke and fog, smog now generally refers to air pollution; ground level ozone is a major constituent of smog

SO_2 Allowance Auction provided for in the Clean Air Act, the SO_2 auction is held annually by the Chicago Board of Trade for the US EPA. Each year EPA auctions approximately 2.8 percent of available allowances at the auction. The auction is held in March each year and auction results appear on the Clean Air Markets website after each auction. The auctions help to send the market an allowance price signal, as well as furnishing an additional avenue for purchasing needed allowances

State Implementation Plan (SIP) the plan that each state must develop and have approved by the US EPA which indicates how the state will comply with the requirements in the Clean Air Act; each State's SIP is amended as they address requirements to meet the NAAQS.

Sulfur Dioxide **(**SO_2**)** a gaseous pollutant which is primarily released into the atmosphere when as a by-product of fossil fuel combustion; the largest sources of SO_2 tend to be power plants that burn coal and oil to make electricity.

T

Trade An exchange of allowances.

Trader: Anyone who buys or sells allowances.

Two Control Zone Policy A policy in China delineating special zones of pollution control. Two controls zones include an acid rain control zone (where pH of rainfall is less that 4.5 which occurs mainly in southwest China) and an SO_2 control zone (where SO_2 concentrations exceed 60 ug per meter^3), which occurs in many large cities throughout China but generally concentrated on the east coast.

U

Unit Accounts accounts in the SO_2 or NO_X ATS's that hold allowances initially allocated to those sources required to participate in either the acid rain or OTC NO_X programs; EPA adjusts these accounts for compliance each year

V

Vintage year represents the first year in which the allowance can be used for compliance

PART TWO: SULFUR DIOXIDE TRADING PROGRAMS IN CHINA: A FEASIBILITY STUDY

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Introduction

Based on the draft outline jointly prepared by U.S. EPA and SEPA, and the memoranda prepared by U.S. EPA, this chapter, "the Feasibility Study of Implementing SO_2 Emissions Trading in China," consists of two sections assigned to the Chinese Research Academy of Environmental Sciences. The first section focuses on SO_2 control policies in China, and the second section focuses on the following seven areas relating to the development of an SO_2 emissions trading framework in China: scope and applicability of the trading program; collecting and reporting emissions data; integrating the trading program with existing programs; analyzing existing data and making recommendations for the environmental goals of the program; defining allowances; legal authorities and roles; and managing information. The following are brief descriptions of the areas covered in the discussion of China's SO_2 emissions trading framework.

Scope and Applicability of Trading Program. This section describes general research on national data, analyzes affected sources, proposes trading areas and strategy to implement a trading program nationwide, and recommends measures to deal with new sources. Because of budget constraints, existing data are used for this analysis, and no new surveys have been carried out to develop additional data. This section also answers questions such as which sources to include, what areas should be affected, whether the program will be phased in or piloted in certain areas or with certain sources, how to deal with new sources, and how and where the pilot projects will be implemented.

Emissions Data: Collection and Reporting. This section examines current emission measurement, verification, reporting, and management situations in China, outlines gaps between existing capacity and the capacity needed for implementation of a trading program, and proposes ways to solve the problems relating to emission data for a trading

program. This section also explains how emission data are collected and reported, including by whom and to whom, information on verification, compliance checks and quality control procedures. It also answers the question of how the process of emissions quantification, reporting, and verification need to be changed in order to support implementation of a successful emissions trading program.

Interfacing with Existing Programs. This section examines the linkage between a trading program and existing SO_2 control programs and proposes ways to integrate the trading program with existing SO_2 control programs. Existing SO_2 control programs include a total emissions control system, a pollution levy system, and a discharge/emission reporting system. This section also tries to address the question of how to interface with the existing SO_2 pollution control programs, and how to make certain changes for the trading program to be implemented. This section also answers questions such as whether the proposed trading program can co-exist with the existing pollution levy system and examines the relationship between total load control policy and trading programs.

Analyzing Existing Data and Making Recommendations for Environmental Goals of the Program. This analysis sets up both the overall and specific environmental goals for the proposed emissions trading program. The analysis also covers information on available emission control methods and technologies and their costs and any environmental implications of controlling emissions that cause acid rain in China.

Defining Allowances. This section focuses on several issues, including: definition of allowances; allowance distribution options and recommendation (e.g., grandfathering existing plants by basing allocation on historical emissions or heat rates, GPS, or auctions); frequency of allowance distribution; banking of leftover allowances; and a discussion of the use of incentive mechanisms to encourage certain practices.

Legal Authorities and Roles. This section discusses the legal status of SO_2 emissions trading, both at the national and local levels. It highlights any legal deficiencies in the laws that might prevent or inhibit SO_2 trading and puts forward some recommendations that could be used to authorize emissions trading (especially for use at the local level). It includes recommendations for the administrative structure of the program and addresses the issues of compliance and enforcement. The section also summarizes existing compliance and enforcement procedures and recommends changes that could be necessary to implement an emissions trading program.

Analysis of Supporting Information and Tracking Systems. This section analyzes the current status of supporting information systems and recommends modifications of these information systems for use in an emissions trading program.

1.China's Acid Rain and Sulfur Dioxide Pollution Control Policies

China's acid rain and SO_2 pollution problems are very serious. Since the 1980s, these problems have been felt most acutely in China's southwestern minority regions and have since spread south from the Yangtze River and east from the Qinghai-Tibetan plateau. Currently 70 percent of cities in South China—an area that makes up 30 percent of China's total landmass—experience some form of acid rain, receiving precipitation that on average annually falls below 5.6 pH. Starting from 1987, China has been developing regulations, standards, and policies to remedy this problem. The control methods for SO_2 have been changed from a pollution regulatory system that relied on emission concentrations to one that uses total emissions. China's pollution management strategy has also been changed from one that employed narrowly focused administrative tools to one that that integrates a broad mix of legal, rule-based, economic, and administrative mechanisms. Lastly, China has created "two control zones"[9] —regions where acid rain and SO_2 emissions are most severe—that have helped improve management in these key regions.

1.1 China's Total Emissions Control and Emissions Permit System

1.1.1 Totaol Emission Control: An Overview

Beginning with the "Sixth Five-Year Plan", SEPA[10] began to conduct research and launch pilot projects that involved total emissions control. Following the third national environmental protection conference in 1989, the State Council set up total emission control and pollution permit pilot projects in 16 cities. These projects were based on a clause in the State Council's *Decision Concerning the Progress of Strengthening of*

[9] The "two control zones" include the "acid rain control zone" and the "sulfur dioxide control zone." The acid rain control zone is designated as such because it receives precipitation that falls below 4.5 pH, it gets heavier rainfalls than adjoining area, and its sulfur dioxide emissions are relatively high. The sulfur dioxide control zone is designated as such, because in recent years its ambient air quality has been above national class two standards, its daily emissions concentrations surpass national class three standards and its sulfur dioxide emissions are relatively high. While the areas are referred to as zones, for practical purposes, the unit of administration in the zones is the city. Poorer counties are not included in the two control zones.

[10] The original name for China environmental protection administration is National Environmental Protection Agency(NEPA). After 1998, it was upgraded to State Environmental Protection Administration(SEPA)

Environmental Protection Work, which required the "gradual advance[ment] of the total emissions control system and emissions permit system." In its *Decision Concerning Environmental Protection's Key Problems*, the State Council clarified further that "there is a need to implement the total emissions control system, quickly building a system of national standards and within a fixed period publicizing those standards." In 1996, the State Council ratified and agreed in principle to the *National Environmental Protection "Ninth Five-Year Plan" and 2010 Long Term Targets* as well as its two appendices *The "Ninth Five-Year Plan" National Important Pollutants Total Emissions Control Plan* and *The China Trans-Century Green Engineering Project Plan*.

The total emissions control system has great potential. It can encourage pollution-emitting units to strengthen management, conserve resources and reduce emissions. The system can also facilitate the collection of environmental protection funds, buttress urban environmental protection capabilities, improve environmental quality, and promote sustainable development. But because the total emissions control system is a type of administrative tool that has not been clearly codified in Chinese law and has not been integrated with emission permits (due to the lack of a legal basis), there have been considerable difficulties implementing the system. Last year's *Air Pollution Prevention and Control Law* attempted to create a stronger legal basis for the control program's implementation. The new law contains three important clauses defining how the total emission control system and emission permit system is to be used. The first clause states "the country should adopt measures, use planned controls, or create incentives for every region to reduce its total air pollution emissions." The second provides "that the State Council and each provincial, special autonomous region, and municipal people's government can map out *total emissions control* regions for areas that still exceed air pollution standards or areas that fall in the two special control zones (the two control zones will be discussed in greater depth later in the report)." The third clarifies that "the reports filed by units and enterprises that are within a total emissions control plan and have a total emissions control responsibility, according to the principle of disclosure, equity, and fairness, should include the unit's total emissions and the emissions level listed on the unit's permit."

1.1.2 The Total Emissions Control Plan

To support the realization of goals proposed in the "Ninth Five-Year Plan," a "Total Emissions Control Plan" was formulated. SO_2 targets were a significant part of this plan. Based upon each region's 1995 emission levels and level of economic development, the entire national total emissions cap was established and smaller allowances under this cap were then allocated to each province, special autonomous region, and municipality. Thus, a total emission's management plan was implemented from the top down, gradually

moving from the higher levels of administration to lower levels. Over the "Ninth Five-Year Plan," each region was expected to use strict management and the adoption of pertinent measures to ensure that its total emissions fell below those in the planned cap. Early indications suggest the plan is working. As of 2000, the target for total emissions was 24.6 million tons of SO_2 and the actual emissions total was a little less than 19.95 million tons.

1.1.3 Piloting Permits

Employing permits to regulate pollution discharges and emissions gained recognition at the 1989 Third National Environmental Protection Conference. The permit system was initially piloted locally on water pollution discharges in 1988 and was spread nationally in 1989. In 1991, SEPA decided to test the permit concept on air pollution emissions in 16 cities. As of 1994, fueled by three years of hard work, 987 units had received permits controlling 6,646 pollution sources (in 15 of the 16 cities, because Baotou is not included in the following figures). By 2000, in 20 of China's provinces, 36 city governments or people's congresses had approved regulations mandating the implementation of total emission based pollution permits.

After implementing the emissions permit system, polluting entities—based on economic and technical considerations—can select an enterprise-specific pollution abatement plan or turn to a collective pollution abatement plan. The polluting industry can also, through the establishment of a tradable permit program, acquire or sell pollution rights. As such, market institutions can be used to optimally distribute resources within the region and simultaneously ensure continued protection of environmental quality. Based on the total emission targets in the two control zones, the emission permit method can be used to distribute emission totals down to individual polluting units and thereby clarify each unit's total emission target. The system also has the added benefit of making it easier for the local environmental protection department to conduct pollution inspections.

China's acid rain and SO_2 total emissions control efforts began rather late, rendering an organizational structure that is relatively diffuse. Moreover, the human and material resources necessary to implement the SO_2 total emissions control system are somewhat lacking. Considering that these abatement efforts have far-reaching implications, to ensure that the above programs are implemented effectively attention must be placed on creating a stronger, more comprehensive organizational structure.

1.2 Using Market Driven Policies To Control Sulfur Dioxide

Currently, China's primary market-based regulatory methods are emission levies and other policies that use financial incentives to encourage abatement.

1.2.1 Sulfur Dioxide Levy

Based on the "polluter pays principle (PPP)," China has been implementing a pollution levy system since 1978. The levy has played a critical role in pollution abatement. The SO_2 levy has become a central component of the overall levy system, and its introduction marked an important stage in using financially based tools to control air pollution and acid rain.

In 1982, China promulgated pollution levy regulation. Under the regulation, polluters pay levies against the level of concentration exceeding SO_2 standards. The SO_2 levy, based on aggregated emissions of polluters, was not really imposed until September of 1992, with the release of *The Circular Concerning the Pilot Program for the Development of Industrial Combustion of Coal Sulfur Dioxide Emission Levies* (Huanjian [1992]361 Hao). The 1992 circular clarified that two provinces and nine cities, where the acid rain problems were relatively apparent and the intensity of SO_2 were relatively high, were to experiment with levies for emissions that exceeded standards. In 1998, *the State Council's Decision Concerning Problems Related to the Expansion of the Sulfur Dioxide Levy System Pilot* (Guohan [1996]24 Hao) stipulated that the scope of the levy system should be expanded so that levies could be used throughout the two control zones.

China's piloting of a SO_2 levy has already undergone three stages of development. Each stage is clearly depicted in Table 2-1.

Table 2-1 The Development of China's SO_2 Emissions Levy System

	Stage 1	Stage 2	Stage 3		
Period	1982—1993	1993—1997	1997—1999		
Scope	National	Two Provinces and Nine Cities[11]	Two Control Zones	New Rate Schedules (Pilot Cities)[12]	
Pollutant Targeted	Waste Gas	Combustible Fuels	Combustible Fuels	Combustible Fuels and Waste Gas (Total Emission Levies)	
Nature of the Levy	Exceeding Emission Standards	Total Emissions	Total Emissions	Rates for Newly Opened Pollution Sources	Piloted Rates
Levy Rates	0.04 yuan/kg ($4.4/ton)	0.2 yuan/kg ($22/ton)	0.2 yuan/kg ($22/ton)	1.26 yuan/kg ($134/ton)	0.63 yuan/kg ($69/ton)

[11] The two provinces and nine cities are the areas where acid rain is most evident and sulfur dioxide emissions are most intense. The provinces are Guangdong and Guizhou. The cities are Chongqing, Yibing, Nanning, Guilin, Yangzhou, Yichang, Qingdao, Hangzhou.

[12] The new rate schedules were piloted in 1998 in Hangzhou, Zhengzhou, and Jilin.

Based on SEPA figures, levies collected nationally for SO_2 emissions totaled 508 million yuan in 1998, making up 10.3 percent of that year's total emission levies. The SO_2 emission levies have been effective in pushing old industries to clean up their pollution, controlling the production of new pollutants, preventing the spread of SO_2 pollution, and providing a source of abatement revenue. They have also worked as an active stimulus on emissions reduction nationwide. The impact of adopting the levy system and total emission controls is noticeable in recent statistical trends, as total sulfur emissions have been on the decline since 1998 (Figure2-1). Changes in the percentage of cities at different acid rain frequency from 1996 to 1999 can be seen in Figure 2-2.

The current SO_2 emission levy regulation assesses a 0.2 yuan per kg charge on emissions, a rate that is too low (equivalent to about $22 per ton). The regulation does not fully factor in the average marginal social costs of pollution nor does it reflect the average cost of pollution abatement, hence it is not able to completely serve its purpose as a pollution reduction stimulus. Hereafter, the challenge is to conceive of a way to adjust the SO_2 emission levy system so that it can be integrated with a tradable permit program and help realize the objectives of controlling SO_2 pollution.

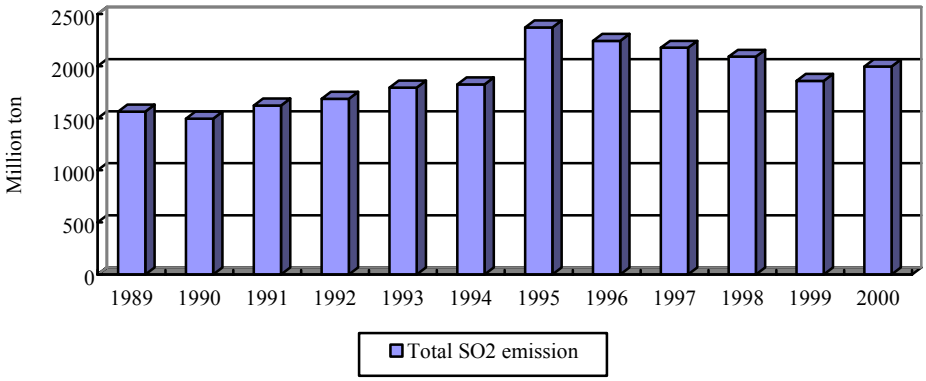

Figure 2-1 The Trend of SO_2 Emission in China from 1989 to 2000

Source: Data from annual Environmental Protection Yearbook, 1990-2001.

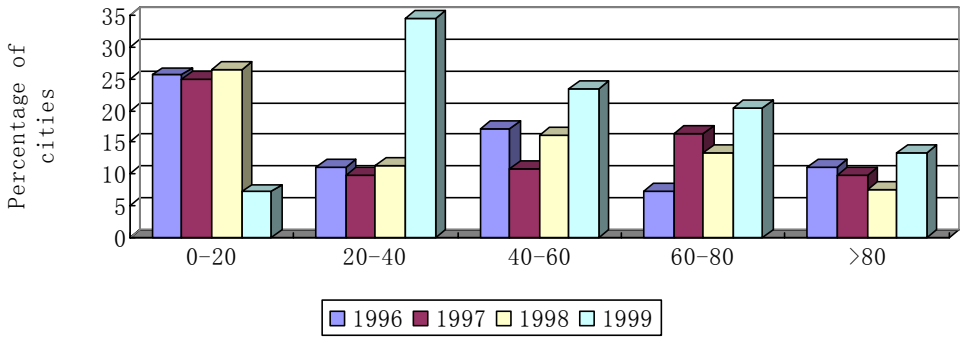

Figure 2-2 Changes of the percentage of cities at different acid rain frequency

Source: China Environmental Monitoring General Station

1.2.2 Piloting Sulfur Dioxide Tradable Permits

In 1994, SEPA, using the 16-city air pollution permit pilot program as a foundation, began experimenting with tradable permits in six cities (Baotou, Kaiyuan, Yangzhou, Pingdingshan, and Yangzhou)[13].

Trades can be executed in at least four ways. Enterprises can purchase pollution rights from the local environmental bureau; industries can invest money in regional pollution clean up to acquire pollution rights; and, enterprises that own emission rights above current emissions can sell the excess to an enterprise in need of additional rights or to a newly opening industry. According to the results of the pilot projects, the tradable permit system has not really employed market mechanisms to execute trading. Rather, local environmental protection bureaus have integrated the tradable permit program with the new construction, expansion, or technical improvement projects. The primary reason for this phenomenon is that the program is still lacking a legal basis and it is founded on the pollution permit system that has yet to be fully implemented nationally.

The most recent revision of the *Air Pollution Control and Prevention Law* clearly makes reference to the establishment of total emissions controls and pollution permits. This legal advancement should create favorable conditions for implementation of permit trading. Another sign of progress is that in 1998 Shanxi Province's People's Congress approved the first regional total emission control regulations, with provisions for the use of tradable pollution rights in Taiyuan City.

1.2.3 Incentive-Based Policies

Policies that use financial incentives or measures that deliver financial benefits to

[13] These experiences are described in detail in Part 3.

reduce sulfur emissions have yet to emerge nationally. In related areas, such as resource conservation, a few incentive-based policies have been crafted. The 1997 *Resource Conservation Law*, by encouraging the application of resource conservation technology, exemplifies one such area. A second illustration can be found in the 1989 State Development Planning Commission's document [1989]973 Haowen *The Core Regulation Concerning the Incentives for Developing Small Scale Thermal Power Plants Linked Production and Strictly Limiting the Construction of Small Scale Power Plants*. This document instructs that "small power plants applying for loans from the national credit plan should receive a preferential interest rate." In 1988, the State Development Planning Commission, in cooperation with four other departments, jointly promulgated the *Core Regulation Concerning Developing Thermal Power Linked Production*. This document specified that newly opened thermal power plants that meet production standards, or plants renovated to increase production capacity, should receive waivers for the fees usually levied to gain power grid access.

1.3 Technology Policies

1.3.1 Limiting the Extraction and Use of High Sulfur Coal

In 1995, the coal from China's key mines could be categorized in the following manner. Approximately 6.4 percent of the coal had a sulfur concentration above three percent; 4.7 percent had a sulfur concentration between two and three percent; 17.8 percent had a sulfur concentration between 2 and one percent; and over 70 percent had a sulfur concentration below one percent.

In the same year, 25 percent of all SO_2 emissions came from the 6.4 percent of high sulfur coal. The majority of this coal is located in the aforementioned two control zones. Many of the regions with high sulfur coal face disadvantages as a result of their natural resource conditions, high demands for power, and daunting production and start up costs. Consequently, a few state-owned coal mines in these areas have been running serious financial deficits. From a purely economic perspective, the extraction of high sulfur coal should be limited and even forbidden. In fact, this approach has been employed effectively in the two control zones.

The State Council Circular Concerning the Acid Rain Control Zone and the Sulfur Dioxide Control Zone (Guohan[1998]5 Hao) requires that "production from mines with coal having a sulfur content over 3 percent be gradually limited or halted." In *the State Council Bulletin Concerning Problems Related to Pressure on Mines in the Coal Industry,* it is furthermore ordered that "all small mines with high sulfur that use inefficient methods of extraction be closed."

1.3.2 Coal Washing

The percentage of washed coal in China is relatively low. In 1995, for instance, only 22 percent of China's coal was washed; whereas, the comparable figure over the same period in the United States was 55 percent. Out of the 380 million tons of coal washing capacity, 65 percent is used for washing coke coal; and out of the 280 million tons of coal that is actually washed, 70 percent is refined. Approximately half of the 9 million or more tons of that is transported via rail is not washed.

There are at least five reasons that coal-washing rates are relatively low. 1) Insufficient importance is attached to investing in coal washing facilities. Currently, investment in state-owned key coal washing facilities comprises six percent of the coal industry's entire investment, or roughly one billion yuan annually. Exacerbating this problem is the fact that there are no channels for local coal mining interests, especially those in township and villages, to procure loans to invest in washing plants. 2) The limits that the railroad system imposes on coal transport makes it difficult to mediate the balance between coal mine construction and overall production. 3) The levies on power plant, industrial boiler, and furnace emissions are still too low. As a consequence, coal users prefer to pay the levy rather than switch over to washed coal. 4) The price ratio of 1:1.2 between raw coal and washed coal is skewed. The last problem is that most construction projects have design plans that are based on raw coal combustion rather than washed coal.

To encourage coal washing, Article 3 of China's *Air Pollution Prevention and Control Law* provides the following regulation: "The country should support the advancement of coal washing, lowering coal's sulfur and ash content, and limiting the extraction of coal with high sulfur and ash content. Newly opening mines with high sulfur or ash coal must construct coal washing facilities so that extracted coal meets national standards. Operating coal mines with high sulfur or high ash coal should, based upon a plan approved by the State Council and within a limited period, construct coal washing facilities." This article provides a legal basis for the development of coal washing facilities.

1.3.3 Desulfurization

Article 30 of the *Air Pollution Prevention and Control Law* clearly stipulates that "if newly opened or recently renovated thermal power plants and other large to mid-sized industries that emit SO_2 exceed regulatory standards or total emissions standards, they must install desulfurization equipment and dust removal equipment or adopt other methods to curb emissions. In the two control zones, if already operating industries surpass limits, they should, in line with Article 48 of this legislation, reduce their emissions within a given period. The country encourages enterprises to use advanced desulfurization

and dust removal technology."

China's desulfurization equipment consists largely of models that can be installed on 1,500 MW coal combustion generators. The vast majority of this equipment is imported. As such, the primary problem is the high cost of installing and operating this equipment. In the two control zones, the pollution levy is still only 0.2 yuan per kg, significantly below the cost of abatement. From an economic efficiency standpoint, it is clear why enterprises opt to pay the levy rather than installing desulfurization equipment. The problem also stems from the fact that the costs of SO_2 reduction are not factored into electricity prices, so the enterprises installing desulfurization equipment cannot make a return on their investment. Such financial disincentives impede progress. Lastly, regardless of whether the desulfurization equipment is domestic or imported, a related issue is whether that equipment can reuse ash residue and sediment.

To develop desulfurization technology, universities, scientific research units, and environmental protection units need to strengthen their connection to ambitiously pursue technology that suits the needs of China. Quickening the pace at which desulfurization technology is commercialized and promptly bringing that technology to market would be beneficial to the construction and environmental protection industries. It would simultaneously open personnel in both industries to this new technology and facilitate the fusing of research and the market.

1.4 Other Related Policies

1.4.1 Adjusting the Natural Resource Sector

The tendency to use coal as a priority among China's natural resources and energy resources sectors is unlikely to change in the short term. Yet to improve environmental quality, particularly to reduce SO_2 emissions, adjustments need to be made in the distribution of resource use in the sector. To a large extent this shift will depend on the development of new resources and renewable resources, such as hydropower, solar power, wind power, and wave power, replacing the incineration of high sulfur coal with clean energy resources.

The principal line of thought guiding these adjustments will be to increase the proportion of hydropower and clean energy. Adjustments will also be necessary in the eastern coast and the northwestern border regions. Since these areas are far from the national power grid but have plentiful wind and solar resources, wind generating power plants and solar generating power stations should be constructed to promote the application of clean energy. By replacing coal and replacing oil, China will be able to conserve resources and preserve its ecological environment.

1.4.2 Adjusting the Commercial Energy Sector

In terms of making changes in the commercial energy sector, the chief alteration involves closing small thermal power plants. Shutting down these plants has been an important measure used in the commercial power sector's reorganization and an important aspect of the effort to curb sulfur emissions.

The average low capacity, single generator power plant is an undeniable problem in China's energy sector. According to 1995 statistics, of China's 2,910 condensing generators with a capacity greater than 6,000 kilowatts, 71.4 percent or 2,078 generators had a capacity below 50,000 kilowatts. Figures from the same year also indicate that national average energy consumption value was 379 calories per kilowatt hour; but, among the small-scale plants the average consumption value was far greater, with some generators even reaching 1,000 calories per kilowatt hour. It would not merely be beneficial to close down these small-scale energy producers to optimize power generation within the industry, it would also be advantageous for resource conservation and sulfur emissions reduction.

In June of 1999, the State Power Company released a document entitled "The Management of Small-Scale Thermal Power Plant Closings," which raised several interesting ideas and regulations regarding the shut down of smaller plants. According to the State Power Company's plan, approximately 12,240 megawatts worth of power will be disabled by the end of 2003 to conform with national requirements.

1.5 Sulfur Dioxide Key Control Zones

1.5.1 Defining the Parameters of the "Two Control Zones"

On January 12, 1998, the State Council ratified a plan designating "two control zones" and approved new regulatory standards and counter measures in line with this plan. In 2000, the National People's Congress revised the *Air Pollution Prevention and Control Law*. Section two, Article 18 of this law clearly stipulates that "the State Council's environmental protection administration working with relevant departments and according to the atmospheric, topographic and land conditions as well as other natural conditions, can with regard to regions that already or might possibly become important acid rain or SO_2 emission areas, pending the approval of the State Council, designate special control zones." This law made significant progress toward establishing a legal standing for the two control zones.

1.5.2 Policy Regulations in the “Two Control Zones”

China’s most recent revision of the *Air Pollution Prevention and Control Law* designates two regions where acid rain and sulfur emissions have been particularly acute. According to the law, special policies and measures are to be implemented within these regions with the hope of mediating and gradually controlling the steadily mounting acid rain and sulfur pollution problems. The following are among the policies.

1.5.3 Increasing Investment within the “Two Control Zones”

Gradually increasing government investment in the two zones will expand environmental monitoring capability, environmental management capacity and strengthen environmental research as well as other public finance projects. Increasing national funding to support desulfurization efforts and gathering funds from local governments, enterprises, and individual investors is also essential for key abatement projects.

1.5.4 Continue to Implement the Total Emissions Control System in the “Two Control Zones”

Nationally, total control SO_2 standards should be divided among each province, municipality, and autonomous region based upon the different stages of total emissions in the two control zones and the basic controls imposed on individual sources of SO_2 emissions. Each province, municipality or autonomous region should then allocate those standards to each city based upon the city’s environmental conditions and the level of economic development. In this way, the implementation of total emissions control would be managed at each regional level of the environmental protection organizational structure.

1.5.5 Extending the Use of Permits

Each level of the environmental protection department, based upon control zones standards, should determine a level of allowable total emissions. From here, the department can take full advantage of the permit system by devolving emission quotas down to each polluting unit and focusing on compliance and inspection.

2. Sulfur Dioxide Tradable Emissions Permits in China

2.1 The Cap of Sulfur Dioxide Total Emissions Control

2.1.1 Sulfur Dioxide Emissions and Acid Rain Problems

The Regional Break Down of the Sulfur Dioxide Emissions and Acid Rain Deposition

Based on SEPA's statistics, as of 2000, total sulfur emissions had reached 19.95 million tons, a figure that was 19.5 percent below 1995 total emissions. The regions with the highest total emissions were natural resource production centers with high sulfur coal or areas with high levels of consumption. In the four provinces, Shandong, Guizhou, Hebei, and Shanxi, the levels of total emissions were 1.83 million tons, 1.5 million tons, 1.3 million tons, and 1.2 million tons respectively. The aggregate emissions from these four provinces made up 31.7 percent of the national total.

Sulfur emissions are clearly attributable to the structure of China's industrial sector. The thermal power industry is responsible for 6.5 million tons or 41 percent of all national SO_2 emissions. Figure 2-3 provides a province by province view of SO_2 emissions.

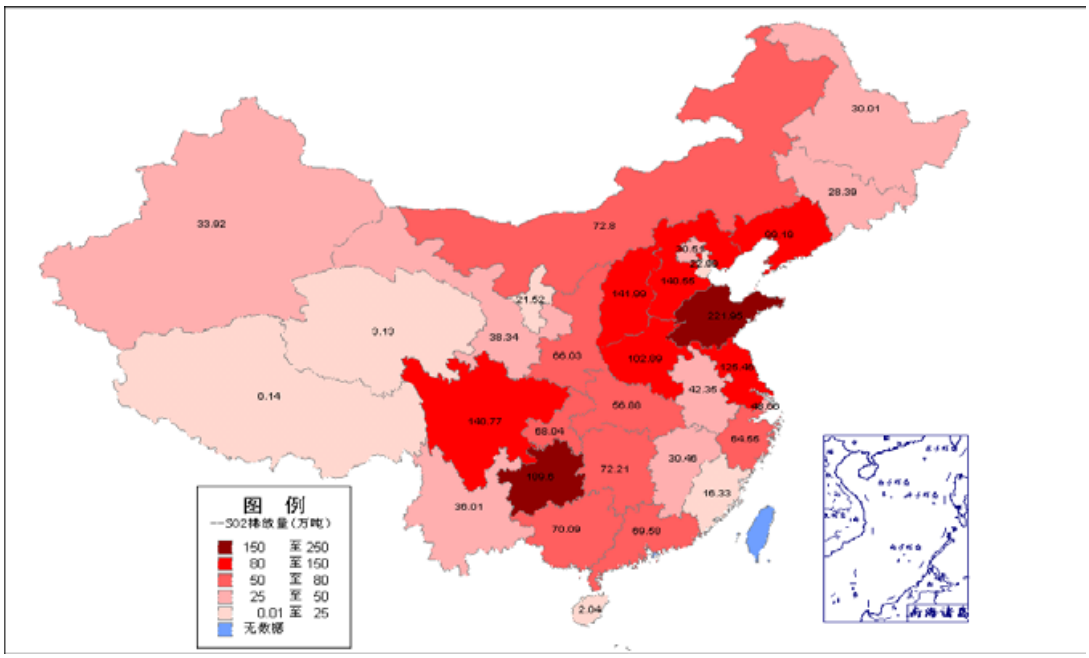

Figure 2-3 1998 National Province by Province Total Emission Distribution[14]

[14] Data source: "1998 Environmental Statistical Yearbook"

Based on monitoring station results from 1999, approximately 33.1 percent of all cities have air quality that exceeds China's class two concentration standards (the average residential area ambient air quality standards of 0.06mg per meter^3); and, among these cities, more than 15 percent exceed class three standards (special industrial area ambient air quality standards 0.10mg per meter^3). There are 109 cities that surpass the World Health Organization's highest air quality standards. The urban areas where air pollution problems are most severe are Guizhou, Sichuan, Guangxi, Shanxi, Hebei, Jiangxi, and Gansu as well as Beijing and Chongqing municipalities. This can be seen clearly in Figure 2-4. Overall in recent years the average concentration of urban SO_2 has decreased, creating a gradual leveling trend.

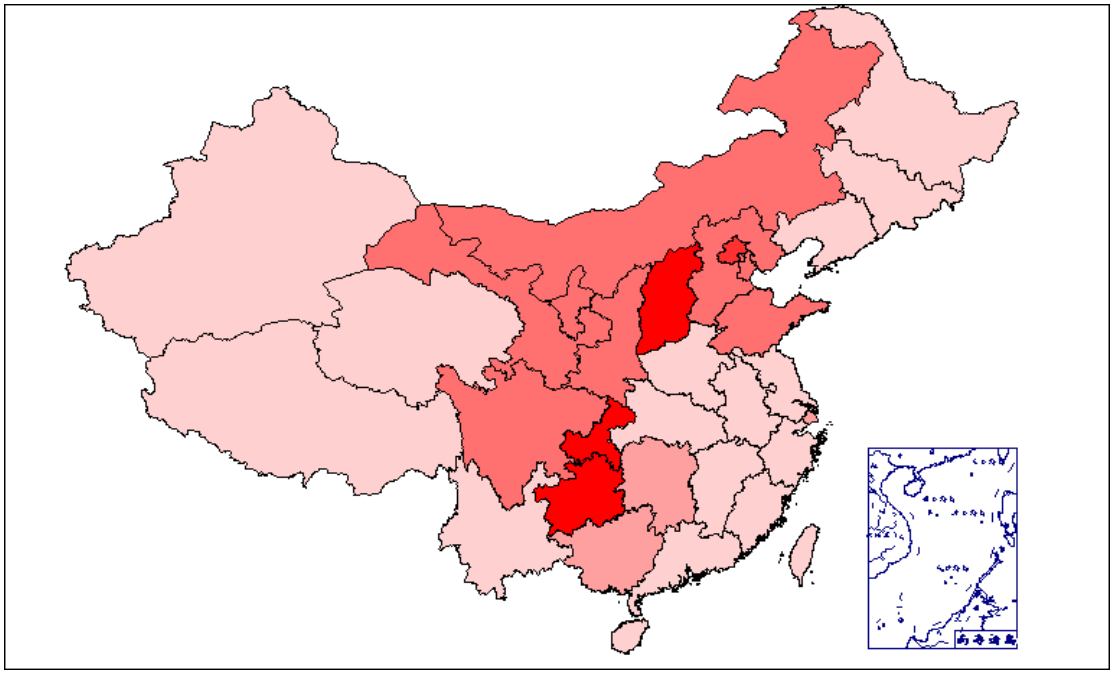

Figure 2-4 Regional Distribution of Sulfur Dioxide Pollution[15]

Over the same period, though, China's acid rain problems have not changed. Acid precipitation still covers about 30 percent of the land areas and it is still primarily distributed south of the Yangtze River and east of the Qinghai-Tibetan plateau as well in the Sichuan basin. North central, southwestern, south central, and east central China are the areas that receive the most serious acid rain. In 1998, the pH of precipitation fell between 4.13 and 7.79 nationally, and 52.8 percent of all cities had a yearly average pH below 5.6. Approximately 73 percent of southern cities received precipitation that fell below 5.6 pH annually on average, with a small number of cities—Zhejiang, Hunan, Guangdong, Guizhou—having acid rain that fell below 4.5 pH. A minority of northern cities

[15] Data source: "1998 Environmental Quality Outline"

fell below the annual 5.6 pH acid precipitation threshold (See Figure 2-5). While the above figures refer to annual averages, nearly every city in the south, and 30 percent of all cities, experience some form of acid precipitation, which means that acid precipitation is sometimes a problem in 76.6 percent of all cities nationally.

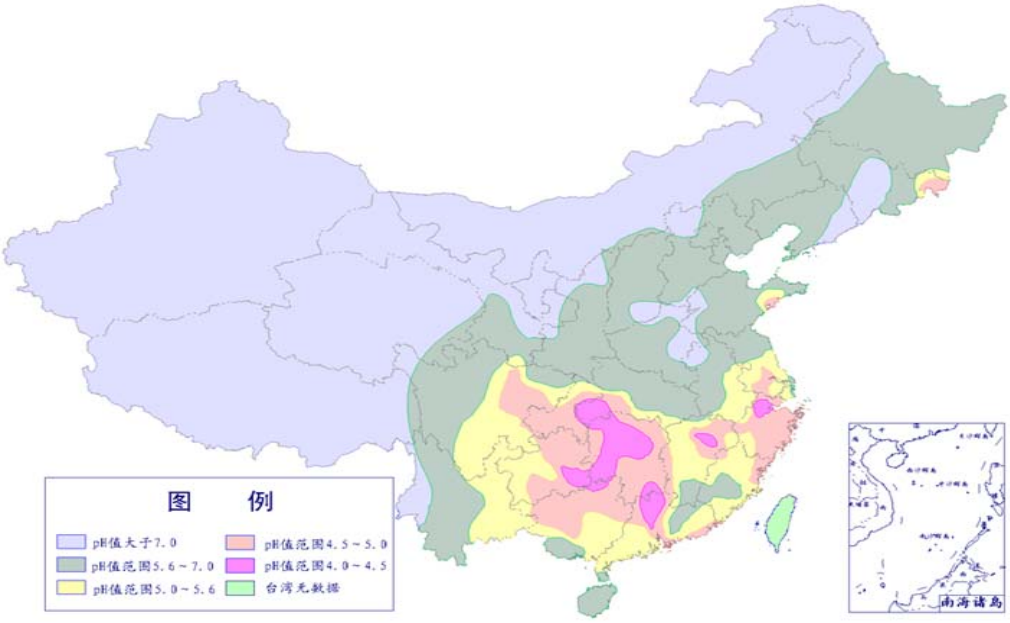

Figure 2-5 Regional Distribution of Annual Average pH levels[16]

2.1.2 The Transport of Sulfur Dioxide and Acid Rain

The Chinese Research Academy of Environmental Science has discovered that the acidification process (involving SO_2 and nitrogen oxides) and the atmospheric transport of acid precipitation in China has several unique characteristics:

In eastern China, north of the 40-degree parallel, prevailing winds flow west or northwest; in the northern half of north central China and northeastern China, currents flow west. At greater heights, the western currents gradually shift to the south. Thus at 1,500 meters, flows are reoriented to the 30-degree parallel. At 2,000 meters above ground level in the eastern regions and on the eastern seaboard, the wind current cuts back toward the west.

In China's southwest below 1,500 meters, most prevailing winds flow southward. The expansive western region and the northwestern regions of China have prevailing winds that stay within China's boundaries. Inside China's boundaries, the most important winds are those that flow between regions, including flows between provinces and flows within

[16] Data source: "1998 Environmental Quality Outline"

provinces. A few of these currents flow in a cyclical whirlpool-like manner.

In the regions north of the 40-degree parallel on the eastern seaboard and domestically between provinces air flows exist that transport precipitation to and away from China. On average, however, more currents flow out from China than into China. In the vicinity of Bandao, Shandong Province, currents that flow into and away from China can be found in the same region. In the regions south of the 35-degree parallel, the key flows are those that move between provinces and move within provincial borders. There are also a few currents in this area that flow cyclically. The province with highest level of acid precipitation is Sichuan followed by Shandong. The region with the lowest level is Tibet.

A careful analysis reveals that in Sichuan and Xinjiang 90 percent of acid precipitation stems from locally based factors. In Guangdong, Guangxi, Shanghai, and Shandong, 80 percent of acid precipitation originates locally. Meanwhile, in Jilin, Anhui, Qinghai, and Tibet a little more than 50 percent of acid precipitation is of local origins. By examining sulfur transport patterns and precipitation levels, most regions within the acid rain control zone deposit more sulfur locally than they transport elsewhere. Conversely, the provinces outside the acid rain control zone transport more sulfur than they deposit locally. The provinces, municipalities, and autonomous regions outside the acid control zone with the greatest influence on those in the zone are the following (in order of magnitude): Shandong, Henan, Shaanxi, Hebei, Tianjin, Gansu, Liaoning, Inner Mongolia, Beijing, Ningxia, Hainan, Xinjiang, Qinghai, Jilin, Heilongjiang, and Xizang. Looking at this interregional transport from the other perspective, the provinces, municipalities, and autonomous regions in the acid rain control zone with the greatest impact on those outside the zone are the following (in order of the magnitude): Jiangsu, Anhui, Hubei, Sichuan (including Chongqing), Hunan, Shanghai, Guizhou, Jiangxi, Guangdong, Guangxi and Fujian.

2.1.3 The Regional Composition of Atmospheric Environmental Resources

A balanced scientific definition of the scope of the trading program must be developed that considers the unique and variable character of the atmosphere as well as the capacity of the environment.

The “Ninth Five-Year Plan” provides programs that are based on regional geographic features, the atmospheric environmental background conditions as well as the atmospheric environmental capacity (i.e., how susceptible, sensitive, and compatible the local environment is to pollution). The plan also divides the country up into 16 different subregions that facilitate environmental quality evaluation and management (Ren Zhenhai, 1998). These subregions include: (1) Qinghai-Tibetan-Sichuan Northern Plateau; (2) Yunan-Guizhou Plateau; (3) Xinjiang Region; (4) Heilongjiang-Gansu-Inner Mongolia

Northern Region; (5) Northeastern Plain; (6) Lanzhou Region; (7) Jiangxi Southern Basin Region; (8) Shanxi Basin Region; (9) Hunan-Hubei Basin Region; (10) Jiangxi Basin Region; (11) Sichuan Basin Region; (12) Jiangsu-Zhejiang Coastal Region; (13) Guangdong-Guangxi Region; (14) The Pearl River Delta and Hangzhou Region; (15) Henan-Anhui Region; (16) Huabei Plain Region (Figure 6).

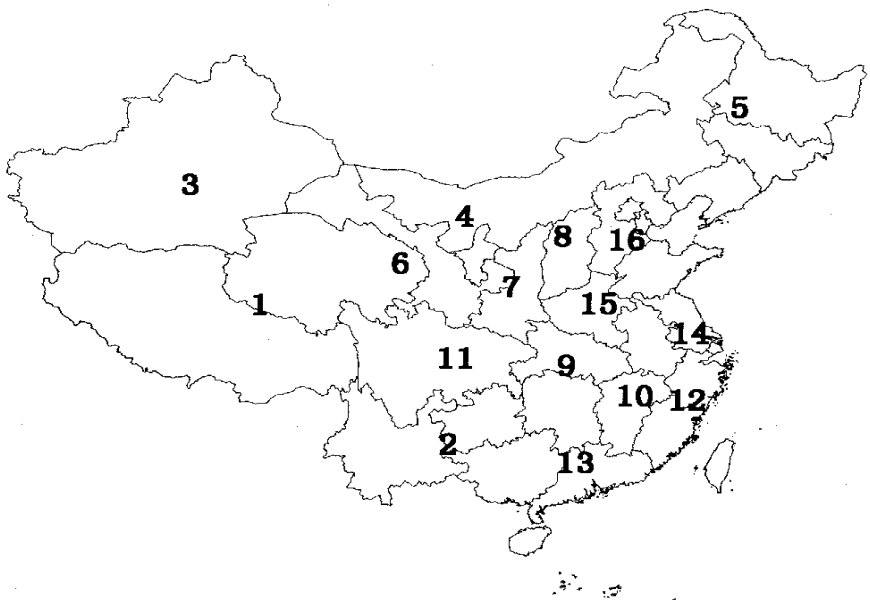

Figure 2-6 Atmospheric Environmental Resource Subregions

2.1.4 Sulfur Dioxide Total Emission Control Targets

SO_2 total emission control long term targets

Based on the Chinese Research Academy of Environmental Sciences' research, if China is able to reduce to SO_2 levels nationwide to 12 million tons (i.e., national control target, which basically equals to the level in the early 1980s when acid rain was not as serious), the entire country will be in compliance with class two of ambient air quality standard. Such a level would be comparable to the emissions level in China at the beginning of the 1980s.

The "Tenth Five-Year Plan's" SO_2 total emission control targets

The "Tenth Five-Year Plan's" SO_2 total emission control targets have already been determined. As of 2005, national sulfur emissions are supposed to be reduced by 10 percent off 2000 emission levels nationwide and 20 percent off the same baseline in the two control zones. Figures illustrating the reduction levels can be found in Table 2-2.

Table 2-2 2005 Sulfur Dioxide Total Emission Control Targets (Million tons)

Year	2000	2005
National	19.95	17.95
The Two Control Zones	11.79	9.40
SO_2 Control Zone	4.60	3.66
Acid Rain Control Zone	7.19	5.73

SO_2 emission pilot trading programs are based on the regulations provided in the *National Environmental Protection "Tenth Five-Year Plan" and 2015 Long-Term Development Targets*. In the future, based upon the chosen region and project scope, concrete targets for emissions trading will be determined under the total emissions control standards.

2.1.5 Allocating Sulfur Dioxide Total Emissions

The allocation of SO_2 total emissions leads to two questions. The first involves allocating national emissions to the provinces and the cities. The second involves allocating provincial emissions to the individual pollution sources and the creation of a SO_2 emission permit system.

In 1998, SEPA put forth a SO_2 emissions control plan that established total emissions control targets and gradually devolved emission levels down to the provinces and cities. However, for technological and management reasons, the "Ninth Five-Year Plan" did not offer a full accounting of allocations to pollution sources.

The "Tenth Five-Year Plan," in its adoption of fully integrated methods that range from top to bottom and from bottom to top, offers clear improvement over the previous five-year plan. Under the principle of "twin compliances," each province and key city submitted total emissions control targets. These targets were based on the region's environmental capacity and level of development. After the targets were aggregated and adjusted, a national total emissions target was formed.

Having arrived at national and regional total emissions targets, the key issues are allocating emission levels down to pollution sources, defining emission rights, providing pollution permits, and, under strict supervision, beginning trading activities.

Fairly and equitably distributing emission levels to the pollution sources is fundamental to encouraging SO_2 reductions by using tradable permit policies. There are three aspects underlying the principal of total emissions allocation. First, allocations from new pollution sources and old pollution sources need to receive different treatment. Second, allocations need to be integrated with regional total emissions plans. Third, allocations need to embody scientific thought, equity and fairness. There are also three ways to consider allocating emission limits that are consistent with China's SO_2 management situation. These are briefly described here and will be discussed in detail in

Section 2.5.

The first technique involves using the current emissions levels as a basis for allocations. In this scenario, a set proportion of the current emission levels would be used to allocate allowable quotas. This method is based primarily on using historical data and is not difficult to implement[17]. The problem is that when this approach is adopted, enterprises with inferior production facilities and substandard clean up facilities are likely to receive disproportionate benefits because they currently have high emissions. As a result, enterprises with advanced technology and efficient abatement facilities are left with an unfair share of the pollution control burden and cannot help but feel cheated.

The second technique involves calculating allocations based on either heat input (coal consumption) or output (electricity production). There are two ways to derive production-based allocations. The first is based on heat input to generate electricity and the second is based on generation performance standards (generation performance standards or GPS allocations are primarily applied to the power industry). Heat generated amounts are premised upon how much of a resource was consumed to create SO_2 emissions. The measurement unit for the total emission, then, is the level of SO_2 emissions per unit of resource consumed. This approach is very common in many countries and is equitable from a scientific perspective, but it ultimately fails to reflect efficient use of resources. Another method, GPS, used chiefly in the power sector, determines the allocation of SO_2 quotas using the amount of power generated. Currently, China is revising its power industry pollution standards to integrate this method and handing a pilot GPS program over to the power industry. If GPS is employed to allocate allowable quotas (primarily in the power sector), it will add far more momentum to the project than other options. The GPS allocation option is equitable and has the additional benefits of promoting overall efficiency increases, developing clean energy, and improving environmental quality.

For newly opening pollution sources, auctions can be used to determine quota allocations.

An Economic Analysis of Sulfur Dioxide Control Technology

At present there are essentially three paths that can be taken to reduce SO_2: (1) fuel switching; (2) clean energy resource use; and (3) desulfurization equipment use. Because of limits on available fuel resources, currently the most common approach is to use clean energy resources or desulfurization. Additional information for such an analysis is provided in Part 4.

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[17] The historical data can be heat input data or emission data. For example, the US SO2 cap and trade program based allocations on a three-year average of heat input data (fuel utilization) and an emission performance standard of (1.2lbs SO2/mmBtu). In China, emission data is easier to obtain compared to heat input. Heat input data can be used to cross check the emission data. However, monitoring or reporting system should be changed accordingly.

2.1.6 Sulfur Dioxide Control Technology

At present the desulfurization technologies China has adopted include desulfurization prior to combustion (e.g., raw coal dressing by coal washing), desulfurization during combustion (e.g., fluidized bed combustion (FBC)), and desulfurization after combustion (e.g., flue gas desulfurization (FGD)). (SEPA Science and Technology Standards Office *et al*, 1998; Wei *et al*, 1999; Wei *et al,* 1997). The following provides a brief overview of these technologies.

2.1.6.1 Raw Coal Dressing by Washing

This approach involves a certain scientific process (currently the process employed in China employs physics) to eliminate or reduce the sulfur content, ash content, or other impurities and provide coal with a composition that meets the user's requirements. Coal washing is advantageous because it saves coal, eases pressure on the coal transportation industry, and protects the atmosphere.

2.1.6.2 Fluidized Bed Combustion (FBC)

This approach involves taking coal and an absorptive agent (limestone) and placing them onto a bed in a boiler. Air is then pushed up from the bottom of the boiler, which suspends the coal bed. From here, the fluidized combustion and the turbulent conditions that follow improve the efficiency of the combustion process and reduce sulfur concentrations. If combustion temperatures are kept low, the process can also lower nitrogen oxide concentrations. The technology is currently being used in Xuzhou Jiawang Power Plant, but most of China's FBC boilers do not add desulfurizing agents when operated (SEPA *et al*, 1998).

2.1.6.3 Flue Gas Desulfurization (FGD)

Globally, this is the only large-scale commercially applied approach to desulfurization. Within FGD there are numerous variations. One such variation is FGD with lime and/or limestone, which uses lime and/or limestone as an absorbent that forces oxidized humidity to achieve desulfurization. A related method, simplified FGD with lime and/ or limestone, is similar to the former in that it uses lime and/ or limestone. However, by integrating pre-selection equipment, absorbing equipment and oxidizing equipment, this process simplifies the flue gas heat exchange and improves upon the flue gas bypass. The process uses a mid-range desulfurization rate between 78 and 80 percent that increases effectiveness and reduces initial investments in equipment. Seawater desulfurization uses soluble salt (primarily sodium sulfide and sulfate) to absorb SO_2. FGD, through an ammonium phosphate process (PAFP), uses natural phosphorous ores and ammonium as inputs. In the desulfurization process, ammonium phosphate fertilizer is produced as an output. This four-stage process consists of two levels of desulfurization: (1) the first level

of desulfurization uses active carbons and renders diluted sulfuric acid as a byproduct; (2) the diluted sulfuric acid extracts phosphorous ores forming diluted phosphorous acid solution as a byproduct; (3) the second level of desulfurization occurs via a mixed solution of phosphoric acid and ammonium ($(NH_4)_2HPO_4$); and (4) the residual slurry from the above steps is then concentrated together, dried and used to produce fertilizer.

Another variant of FGD is accomplished through spray drying. This method employs half-drying desulfurization equipment and uses lime slurry as an absorbent. The process involves spraying lime slurry into a reactor. Once in the reactor, the slurry reacts with the SO_2. As the reactive compound dries, it settles on the reactor's output portal;, and after the water evaporates, a dry particulate mixture is formed. The absorbent spray process of FGD is achieved through a drying process that, depending on the absorbent, can be either calcium or sodium-based.

There are also options in terms of the absorbent and where it is distributed. The absorbent can be dry or wet, in the form of slurry or spray, and can be sprayed into a chamber or a flue. The final FGD variant discussed here—FGD by Electron Beam Irradiation—uses high-energy electron beams to irradiate flue gas and in turn induce a radioactive reaction between N_2, O_2, and steam. The reaction produces a large number of ions, free radicals, atoms, electrons, and a variety of other active substances such as active atoms and active molecules. As a result of this process, the SO_2 and NO_X compounds that were in the flue previously are oxidized and become SO_3 and NO_2. The process concludes when these high-valence sulfur oxides and nitrogen oxides react with steam and form a sulfuric acid and nitric acid mist. Installations that use desulfurization in China are described in greater detail in Box 2-1.

Box 2-1 The Development of Desulfurization in China

China began to install desulfurization equipment in 1991. By the end of 1998, China had invested in 1.68 GW of desulfurization technology. Currently, approximately 5.00 GW of desulfurization equipment is under construction or being planned in China. Targets for commercial production of the FGD variation of this equipment were set so that the close of 2001 marked the first time thermal power plants are expected to include this technology in their construction plans. The intended purpose of this deadline was to expand the scope of domestic production of humidifying FGD projects and simultaneously help craft a plan for the implementation of their domestic production. By the year 2003, with preparatory efforts on individual humidifying FGD projects plans completed, work should be initiated that meets China's desulfurization requirements. By the year 2005, it is hoped that greater than 95 percent of humidifying FGD will be manufactured domestically. By the year 2010, the desired figure for domestic manufacturing is 100 percent. Also, by 2010, it is hoped that greater than 95 percent of other kinds of desulfurization equipment will be manufactured domestically.

Chongqing municipality's Luohuan Power Plant imported two sets of lime and/or limestone desulfurization equipment. These pieces of equipment were then matched with two 360 KW steam turbine condensing generators. The plant's generator number 1 began production in November of 1992 and generator number 2 began production six months later in May of 1993. Both systems treat 100 percent of flue gas. The desulfurization system has an effectiveness rate of over 95 percent and

produces 40,000 tons of gypsum.

Taiyuan Power Plant has imported simplified lime and/or limestone desulfurization equipment. After installation of limestone as an absorbent, the system was able to treat two-thirds of flue gas from a 300 MW generator with an efficiency rate of 80 to 90 percent.

Shenzhen West Power Company Limited's number 2 generator (300 MW) uses seawater desulfurization. In the design stages, the system had an efficiency rate of over 90 percent, but the rate fell to 70 percent after adjustments were made to the system. The pH value of discharged seawater at the aeration tank has been greater than 6.5 and the flue gas humidity at the outlet 70 degrees.

During the "Seventh Five-Year Plan," China completed a pilot experiment using FGD on the Sichuan Douba Power plant. The pilot used a 5,000 Nm^3 per hour ammonium phosphate process (PAFP). Results from the pilot revealed that the experiment's absorptive column was able to maintain a desulfurization efficiency rate between 70 and 80 percent, while the overall system's efficiency rate was greater than 95 percent. The results also showed ammonium phosphate, the byproduct of the desulfurization process, had water content less than 4 percent and ($N+P_2O_5$) content greater than 35 percent.

Another project launched during the "Seventh Five-Year Plan" involved the installation of a 70,000 Nm^3 per hour LSD high sulfur dry spray FGD device on Sichuan's Baima Power Plant (anthracite coal from Furong, Sichuan can have a sulfur content as high as 3.5 percent). When the amount of calcium is 1.4 times the amount of coal, the equipment has the potential to operate at an efficiency level of greater than 80 percent. A similar FGD project at Shandong's Huangdao Power Plant consisted of importing a FGD rotary spray-drying device from Japan. The system was first tested outside the plant in 1995, then was moved to the plant and installed on its number 4 generator in April of 1998. When operating the device, the desulfurization efficiency rate was greater than 70 percent, the rate of flue gas treatment was 300,000 cubic meters per hour, and the annual sulfur reduction was higher than 4,500 tons.

To use the FGD absorbent spray process, Fushun Power Plant imported part of a LIFAC boiler that sprays calcium to desulfurize. This part was matched with a set of 120 MW generators (the sulfur content of coal burned was .54 percent) and was designed to operate at an efficiency rate of 40 percent. Nanjing's Xiaguan Power Plant also imported LIFAC technology and matched it with a set of 125 MW generators (the sulfur content of the coal burned was 0.92 percent). The designed efficiency rate on this project was 75 percent.

Chengdu Thermal Power Plant imported FGD electron beam irradiation devices and experimented with the technology on a 100 MW demonstration project.

2.1.6.4 Sulfur Dioxide Control Costs

Washing Raw Coal

Washing raw coal has many benefits, including the income it generates for the coal washing facility, the coal saved by the end-user, the reduction in levies on the pollution sources, and the relaxation of pressure on the coal transportation industry. Of course, the biggest influences are those on the atmosphere. In 1998, SEPA's Science and Technology Standards Office conducted an economic analysis of coal washing on transported coal. Table 2-3 displays the figures in the analysis. Using a ton as a unit of measurement to calculate costs, the study determined that the damage costs from raw coal were 15 yuan, the processing costs of raw coal were 5 yuan, and the profits were 15 yuan, totaling 35 yuan. On the revenue side of the ledger, users who burned washed coal efficiently could profit 39.58 yuan. Therefore, the benefits of using washed coal according to the study were 4.58 yuan per ton (a benefit of about $0.55 ton).

Though important, the study suffered a few methodological flaws. First, it failed to

consider the investment costs required for building coal-washing facilities in its cost-effectiveness analysis. Second, the study did not consider the inflationary effects such as present and future value calculations. Third, the study neglected to directly include the non-monetary environmental benefits or costs of washing coal (for instance the water pollution problems that arise from washing coal).

Table 2-3 China's Coal Washing Cost/ Benefit Analysis Figures

Project	Element	Cost
Investment	Investment Costs of Coal Washing (yuan/ton)	45
	Cost of Raw Coal (yuan/ton)	150
	Cost of Damage from Raw Coal (yuan/ton)	15
	Cost of the Coal Washing Process (yuan/ton)	5
	Coal Washing Profit Costs (yuan/ton)	15
Economic Benefits	Benefits of Coal Saved (yuan/ton)	22.5
	Savings in Equipment Repair (yuan/ton)	3
	Reduction in Pollution Levies (yuan/ton)	10.2
	Reduction in Soot and Dust Control Costs (yuan/ton)	0.2
	Subtotal	35.9
Social Benefits	Savings in Coal Transport Levies (yuan/ton)	1.6
	Savings in Refuse Transport Levies (yuan/ton)	2.08
	Subtotal (yuan/ton)	3.68
Environmental Benefits	Reduction in Soot and Dust Discharges (kg/ton)	2.08
	Reduction in Sulfur Dioxide Emissions (kg/ton)	10.2

Source: Based on SEPA *et al*, 1998.

Flue Gas Desulfurization (FGD) Economic Benefits Analysis

Currently in China only 1,500 MW generators have been equipped with FGD systems and the vast majority of these systems are imported. Because the systems are from different countries it has been difficult to establish a uniform baseline that would be necessary to compare their relative costs and benefits (SEPA. Science and Technology Standards Office, 1998). Despite these limitations, a preliminary economic analysis on the different kinds of technologies was conducted based on available cost materials, a standardized evaluation methodology, and an indicator system,. The results from this analysis are displayed in Table 2-4.

Table 2-4 China's Desulfurization Cost Analysis Study (1995 Constant Prices)

Desulfurization Process	FGD with Lime and/ or Limestone	PAFP	LSD	Calcium Spray and Humidifying Process	Simple Humidifying Process
Generator Capacity (MW)	2x360	100	200	100	200
Flue Gas Volume (1,000 Nm^3/hr)	2x108	45	82	45	82
Sulfur Dioxide Concentration	3500	3000	3000	3000	3000

(ppm)					
Total Investment (10,000 yuan)	48174	7581	9520	2122	10006
Unit Investment (yuan/KW)	669	758	476	212	500
Annualized Invetsment (10,000 yuan)	5978.4	940.8	1181.4	311.5	1241.8
Transportation Costs	5794.3	2635.5	1700.3	920.2	1351.5
Yearly Desulfurization Costs					
Annualized Desulfurization Costs yuan/ton of Sulfur Dioxide Eliminated	856.8	1501.5	770.2	701.8	810.9
Fen /kWh	2.52	5.50	2.22	1.89	1.99

Note: PAFP stands for Ammonium Phosphate Process. LSD stands for Lime Spray Drying.

Source: Source SEPA *et al,* 1998

On Table 2-4, the category "annualized investment costs of humidifying lime and/or limestone" comprises 16 percent of the total costs associated with the FGD with lime and/or limestone alternative. This is the highest itemized to total costs ratio among all cost categories. In contrast, the "calcium spray and humidifying process at the tail pipe" category is only five percent of total costs and is the lowest percentage ratio among all the itemized cost to total cost ratios.

The cost study also reveals that the average operating expense associated with removing a ton of sulfur is 1,100 yuan. In particular, the drying process and half-drying process run approximately 800 yuan per ton and the PAFP process runs about 1,500 yuan per ton. Using desulfurization processes will unquestionably cause energy production costs to rise. Production costs for generators that have humidifying FGDs installed are expected to climb 0.02-0.03 yuan per kWh. And, increases triggered by dry FGDs are supposed to be 0.01 to 0.02 yuan per kWh.

Marginal Control Costs

In China, a concept of relative reduction cost is used to compare the provincial or industrial variation of reduction cost. Sizable gaps exist between the different kinds of SO_2 reduction methods and reduction costs. Marginal control cost are determined by many factors such as the SO_2 reduction rate, the scale of the industry, the ownership type, the provincial location, and other factors related to the industry. First and foremost among these factors are the substantial interregional and interindustrial variations. Table 2-5 uses reduction cost in Jiangxi province as a baseline to compare control costs across provinces. Assuming that all other factors are held constant, Table 2-5 displays relative reduction costs in each province.

For all sources, the variations between industries in SO_2 reduction costs are also significant. Using the power industry as baseline, Table 2-6 reflects changes in SO_2 reduction costs across different industries in the nine provinces listed in Table 2-5.

Table 2-5 Relative Reduction Cost of Sulfur Dioxide Between Provinces

Province	Relative Reduction Costs
Shanxi	1.0
Ningxia	0.7
Heilongjiang	0.8
Heibei	0.9
Guangxi	1.0
Shandong	1.1
Jiangsu	1.2
Hunan	1.3
Fuzhou	1.5

Table 2-6 Relative Reduction Cost of Sulfur Dioxide Between Industries

Industry Type	Relative Reduction Costs
Electric Power Industry	1.0
Chemical Industry	1.7
Steel Industry	1.5
Smelting Industry	0.5
Mineral Industry	0.3

A variety of SO_2 reduction methods and appreciable cost differences occur between these options. Based on research from the Chinese Research Academy of Environmental Science, the cost differences between the different kinds of FGD technologies used on power station boilers can be greater than 50 percent. This phenomenon is not unique to the power industry alone. The cost differences in desulfurization techniques employed on industrial boilers can be above 60 percent. Effectively implementing market-based environmental instruments narrows the gap between the reduction costs of SO_2 and the marginal reduction costs of SO_2. An Asian Development Bank project analyzed the cost savings from China's industries adopting market-based policies and command control policies. The study's findings are summarized in Table 2-7.

Table 2-7 Comparing Market Based and Command Control Abatement Costs

Reduction Rate (%)	Total Costs (Only Sulfur Dioxide)		Based on Market Driven Policies Compliance Cost Savings (%)
	Command Control (1 million yuan)	Market Based (1 million yuan)	
19.6	3.1	1.3	58.1
34.8	7.2	4.2	41.7
49.0	11.8	7.9	33.1
63.5	19.3	13.6	29.5
72.3	25.9	18.6	28.2
83.4	38.7	29.2	24.5
90.8	53.5	41.8	21.9

2.2 The Scope of Sulfur Dioxide Permit Trading

2.2.1 Preliminary Considerations for the Sulfur Dioxide Trading Program

Because SO_2 emission sources are scattered over an expansive region, and small polluters make up a good percentage of total polluters, management and abatement is quite difficult. Pollution sources can be classified in several ways, including industrial sources and societal sources. The sources can also be divided into high-stack sources, low-stack sources, and surface-level sources. High-stack sources primarily refer to power plants. The emissions from these sources are relatively concentrated and comparatively easy to manage. Low-stack sources primarily refer to boilers and furnaces. The location of these sources is typically decentralized, making them comparatively more challenging to manage. Surface-level sources primarily refer to residential cooking ranges and stoves. These sources are the most diffuse. Sources can also be partitioned by macro-regions. For instance, some sources lie in the acid rain control zone, some lie in the SO_2 control zone, and some lie in neither of the two special zones or what is termed the average zone. Given the above mentioned variations, when selecting a tradable permit region and scope, it is necessary to take stock of the current SO_2 management situation and take advantage of current managerial strengths.

2.2.2 The Proposed Process of Piloting Sulfur Dioxide Tradable Permits

Based upon the experience of the United States, the implementation of a tradable permit system should be divided into several stages, with the emphasis placed on initially controlling the biggest pollution sources. In light of China's current management situation and the different kinds of limitations it faces (i.e., the progress on the total emissions control program, the concrete effects of emissions permits, the level of pollution control management, data support capacity, and a host of other factors), designing China's tradable emission program should consist of four stages with time framework not yet decided and subject to the government's determination.

Stage 1: In the initial pilot, the scope for trades should be confined to large power plants in the two control zones (plants with annual SO_2 emissions over 5,000 tons).

Stage 2: Using the pilot project as a foundation, the scope should gradually be expanded to include all power plants within the two control zones.

Stage 3: The next phase should broaden the scope further, encompassing power plants throughout the whole of China.

Stage 4: The final stage should include all high-stack sources[18].

Implementing a SO_2 trading program requires legal guarantees, as well as a compatible managerial base and enough capacity to support that base. There are several policy programs that are directly related to trading, including the SO_2 total emissions control program, the emissions permit system, and emissions monitoring capabilities. Table 2-8 illustrates China's current situation with regard to these necessary policy elements.

Table 2-8 The Current Policy and Managerial Foundation for a Sulfur Dioxide Trading Program

	Legal Basis	Implementing Explanation	Implementing Barriers
Total Emissions Control Policies	*The Air Pollution Prevention and Control Law* prescribes that 'the State Council and each Provincial, Municipal and Special Autonomous Region's Peoples Congresses can designate areas that have failed to comply with emissions standards or areas in the two special control zones and mandate that they use total emissions controls to regulate the area's chief pollutant."	According to the legal regulations currently in effect, the scope of total emissions control is confined to the following areas: • The two control zones • Areas that are not compliance with the emissions standards	• China has already formulated the "Tenth Five-Year Plan" total emission control standards; • China has formulated the two control zone's "Tenth Five-Year Plan" total emission control targets; • Plans identify each city's chief pollutants
Permit System	The Air Pollution Prevention and Control Law prescribes that "people's governments within total emissions control regions, according to State Council regulatory conditions and procedures and based on the principle of disclosure, equity and fairness, can check an enterprises or social units' primary pollutant's total emission and issue a permit on the emission of that pollutant."	In 1991, the first pilot of the permit system was conducted. Currently the permit program has not been fully implemented nationally.	
Accurate Emission	The Air Pollution Prevention and Control Law prescribesthat	The program is presently being	• Data authentification

[18] The potential inclusion of all sources in emissions trading is depended on several factors such as political acceptance and monitoring technologies.

Calculations and Monitoring	"units that emit pollutants, according to the State Council's environmental protection administrative management department's regulations and regional environmental protection administrative management department's approved pollutant installations and management installations, must provide information concerning emissions type, quantity and concentration, as well as technology related to pollution prevention under normal operating conditions. At such a time when the aforementioned unit has a large change in type, quantity, or concentration of emitted pollutants, it must report this change promptly."	implemented, though the program lacks a legally based uniform calculating method. Due to expenses, data verification and auditing is insufficient, rendering low quality data. The data coverage is also insufficient; it does not include small pollution sources or livelihood sources.	problems; • emission supervision problems; • automated continual emission monitoring problems.

2.2.3 The Suggested Sulfur Dioxide Trading Program Pilot Region

Based on the regional nature of the SO_2 problem and China's management strengths, the scope of the tradable permit program should be confined to the two control zones with the first stage of the project focusing on large-scale power plants in the zones. Since the scope will initially contain a subset of power plants, a monitoring plan will be developed to ensure that power production does not shift from sources within the trading program to sources not included in the trading program. The issue of emissions transport is raised in Section 2.1.1.2, particularly in the direction from outside of the two control zones to the inner zone. Some discussion of those sources and when they would be included in the program would be helpful.

Assessing the Situation in the "Two Control Zones"

China's SO_2 and acid rain problems are most serious in the two control zones, and these zones are also the regions where air pollution regulations call for total emissions control. As such, they are the most suitable regions for launching the tradable permit program.

The "two control zones" include 175 cities and areas and collectively span 1.05 million square kilometers or 11 percent of China's total landmass. In 1995, pollution sources within the zones emitted 14 million tons of SO_2, which then was 60 percent of total emissions. The "acid rain control zone" is 8 million square kilometers and makes up 8.4 percent of China's landmass. The "sulfur dioxide control zone" is approximately 29 million

square kilometers and occupies three percent of the total landmass. (See Table 2-9)

Table 2-9 “The Two Control Zones”Background Data

Item	Two Control Zones	Broken Down by Zone	
		The Acid Rain Control Zone	The Sulfur Dioxide Control Zone
Number of Cities and/ or Areas	175	112	63
Area (km^2)	105	78	27
1995 Population (Millions)	491	374	117
1995 GNP(Billions of yuan)	363.639	257.6157	106.0233
1995 Total Sulfur Dioxide Emissions (10,000 Tons)	1395	793.4	601.6
2000 Total Sulfur Dioxide Emissions (10,000 Tons)	1179	719	460

2.2.4 Sulfur Dioxide Control Targets in the “Two Control Zones”

The national target for 2005 SO_2 emissions in the two control zones is 9.4 million tons. Province by province targets are displayed in Table 2-10.

Establishing Targets for Power Plants Participating in the First Phase of the Sulfur Dioxide Reduction Trading Program

There are 103 power plants having annual emissions over 5,000 tons in the two control zones. The acid rain zone has 57 plants with emissions totaling approximately 1.8 million tons and the SO_2 zone has 46 plants with emissions totaling approximately 1.57 million tons. The 2005 total emissions target for plants in both zones is approximately 2.7 million tons. Details relevant to the two zones and each zone are provided in Table 2-11; figures specific to each power plant can be found in the appendix.

Table 2-10 Province by Province Distribution of Sulfur Dioxide 2005 Emission Targets (10,000 tons/year)

Province	2000 Emissions Total	2005 Emissions Target	Province	2000 Emissions Total	2005 Emissions Target
Shanghai	42	34	Beijing	19	15
Jiangsu	94	74	Tianjin	20	16
Zhejiang	55	44	Hebei	68	54
Anwei	15	12	Shanxi	29	23
Fujian	17	14	Inner Mongolia	33	27
Jiangxi	17	14	Liaoning	47	39
Hubei	38	31	Jilin	8	7
Hunan	61	49	Shandong	129	101
Guangdong	68	53	Henan	28	23
Guangxi	70	56	Shaanxi	26	21

Chongqing	104	81	Gansu	8	7
Sichuan	117	92	Ningxia	11	9
Guizhou	20	16	Xinjiang	33	27
Yunnan	1	1	Total	1,179	940

Table 2-11 Targets for Power Plants Participating in the Sulfur Dioxide Reduction Trading Program's First Phase

Item	Two Control Zones	Break Down By Zone	
		Acid Rain Control Zone	Sulfur Dioxide Control Zone
Number of Participating Power Plants	103	57	46
Total Generating Capacity (kW)			
1999 Electricity Generated (MW)	2966.56	1590.43	1376.13
1999 Coal Consumption (MW)	13534.29	7288.51	6245.78
1999 Sulfur Dioxide Emissions (million tons)	3.3726	1.8008	1.5718
2005 Sulfur Dioxide Reduction Targets (million tons)	2.6981	1.4406	1.2574
Sulfur Dioxide Reduction Rate	20%	20%	20%

2.2.5 Issues Needing Solutions Before Emissions Trading Policies Can be Extended to the Power Sector

After check with the current policies on SO_2 control, we find the following issues needed to solved prior to the introduction of SO_2 emissions trading.

Though currently undergoing reform, the Chinese power industry is primarily a state-owned industry. The degree of progress in industry reforms will have a direct bearing on the implementation of sulfur emissions trading policies.

The electricity price question is essential. Electricity prices are extremely sensitive, which acts as a limitation on the power industry's sulfur reduction activity. If electricity pricing policies are not adjusted, then the electricity industry will lack revenue channels or funding mechanisms, thus making it difficult to adopt effective measures. Presently China is conducting research on electricity pricing reforms.

From the perspective of the power industry, establishing a national market for permit trading is feasible because it should help level disparities between different thermal power plants in pollution abatement costs.

Another big issue is how to determine the cap for power industry and how to break down to individual generators. This includes two levels of allocation. First, what is the cap for power industry under national cap for SO_2 emission control? Second, how to allocate the cap for power industry to individual power plants or generators.

Calculating emissions is another area in need of examination. The vast majority of

enterprises in the power sector have not installed automated monitoring devices. The only exception to this rule are ten newly constructed power plants with automated monitoring capabilities, but even here the monitors do not operate very well. If the desired goal of building a tradable emissions program is to be realized, consistent norms for monitoring equipment are essential.

Problems with resource consumption and desulfurization also need to be addressed. The primary reason that market-driven policies are adopted is to encourage reductions in total SO_2 emissions. The tradable emissions program uses the market to achieve this end. However, at present, the remnants of the previous planned economy are still quite visible in China. As soon as a tradable permit program is brought on line, whether enterprises decide to use alternative resources for energy or adopt desulfurization processes should be based on the enterprise's economic interests. Under these circumstances, it is possible that the resource market might not adjust to market forces quickly, and in the short term that might potentially lead to unemployment problems. Consequently, as the power sector implements the tradable emissions program, it will be necessary to conduct broad-based income level research to avoid such problems from coming to fruition.

A related issue concerns the expansion of the program. When the tradable emissions programs are extended to other sectors and regions, corresponding emission standards and institutions will need to be adjusted.

After automated emissions monitoring equipment is installed, an emission tracking system will need to be set up. A tracking system will improve the ability to supervise emissions that are estimated for sources unable to install CEMs initially.

2.2.6 New Sulfur Dioxide Emission Sources

China is currently in a high-speed development period. New SO_2 emitting sources may emerge in the future, especially if the power industry is part of the high growth trend. Therefore, when determining allowance distribution and formulating trading rules, there should be serious attention devoted to new sources.

There are two options to treat new sources. One is that new sources should purchase allowances every year from market to cover their emissions. It provides incentive for the new sources to adopt clean energy processes. The other option is for the new sources to purchase their allowance in the first year and be treated as existing sources in the years following, receiving their allowances based on their emission performance.

Mechanisms or incentives to encourage new sources to be cleaner should be considered. These include policies to promote the use of natural gas, renewable energy, and cleaner production.

2.3 Regulatory Basis of Sulfur Dioxide Emission Trade

This section discusses the legal and regulatory infrastructure needed to establish a SO_2 emissions trading program. China lacks concrete regulations governing the implementation of SO_2 emissions trading, and the limited regulations that do exist are comparatively weak. The reason for the absence of such regulations is somewhat circular. China's lawmakers have given little attention to the formulation of such measures, and the lack of attention, in turn, stems from the fact that there has been little experimentation with emissions trading. The argument advanced herein is that to facilitate experimentation Chinese law makers first need to create detailed and specific regulations regarding the implementation of SO_2 emissions trading.

There are two essential components of emissions trading: total amount control (TAC) and trading. Currently in Chinese law there are provisions for a TAC, an emissions permit system and other economic instruments that could be deemed as the regulatory basis for implementing SO_2 emissions trading. Though these measures are important, more concrete emission trade regulations needed to be established. The purpose of this chapter is to shed some light on what measures need to be added and what can be done in the meantime to facilitate the implementation of trading.

2.3.1 Regulatory Basis established by TAC

The TAC policy has been carried out in China since 1996 (as mentioned in the previous chapter) when it was included in the "national TAC plan for major pollutants during the 'Ninth five-year plan'". Over the course of this period, the TAC has had a noticeably positive impact on the environment, but the TAC for atmospheric pollutants still lacks regulatory support. The "Air Pollutants Prevention Law" that was amended in 2000 established a regulatory basis for the TAC of air pollutants.

The law prescribes that: The central government must take measures to control and cut down the emission amounts of air pollutants; the State Council and local government may designate regions that have not reached the atmospheric environmental quality criteria and regions in the acid rain and SO_2 control zones (otherwise known as the two control zones that were approved by State Council in 1998) as areas that can use total amount controls. One can see from the law that the TAC policy is still not very specific. Nonetheless it has been carried out in the absence of strong regulations with the hope of generating more specific regulations in the future. Following similar reasoning one could conclude that China should begin implementing emissions trading in the absence of strong regulations. The hope in the future would be to use the experiences gained in pilot projects to generate firmer regulatory guidelines.

Similarities and differences exist between the total emissions amounts needed for trading and China's current TAC policy. China's current TAC program does not guarantee that emission caps will be reached. The reason for this discrepancy is there is no consensus over how to allocate emission levels to industries participating in a given trading area. One possible approach is allocating quotas to each pollution source, and then summing the quotas of the industries in the trade area to find the TAC of that area. There are of course many other possible methods that suggest themselves. Yet as of now there are no regulations advising which approach should be employed. Such regulations need to be devised to support the SO_2 TAC in the trade area.

A concept closely related to TAC is a reduction target. Before a TAC program can begin, a regulator has to have a clear picture of the desired level of pollution reduction, a reduction target. These reduction targets need to be stated clearly in relevant regulations. Another concept pertinent to the TAC is trading scope. The trading scope includes a spatial dimension, temporal dimension, and industrial dimension. In terms of the spatial dimension, the key question is whether emissions trading should be carried out across the whole nation or in a specific area such as the acid rain control zone. In terms of the temporal dimension, the key question is whether the program should be carried out in stages. In terms of the industrial dimension, the key question is which enterprises should participate in the program and should the program be focused purely on the electric power industry. All these questions need to be answered with regulations, and as of now, none exists.

2.3.2 Regulatory Basis of Quota Allocation

There is general agreement that an emission permit system is central to quota allocations. In China there have been pilot permit programs since the beginning of 1990s on selecting pollutants, and in 1997 the discharge permit system was broadened to include several pollutants. As for air pollutants, the new revised "Air Pollution Prevention and Control Law" (APCL) is the most recent regulation to make reference to permits. The law states: local governments in TAC area should investigate and certify total emission air pollutants discharges from enterprises according to the principles of publicity, impartiality and justness following the procedure and condition prescribed by State Council, and distribute air pollutant discharge permits based on the result of their investigation and certification. It furthermore requires that enterprises discharge pollutants according to the total emissions levels of air pollutants and other conditions on the license. These articles constitute the guiding principles of allocating air pollutants permits. As such, they should help realize SO_2 emission reduction targets.

While these articles are useful in that they establish general principles for allocating permits, they should not be confused with regulations necessary to govern the trade of

SO_2 allowances. Trading regulations and laws need to address the following questions: How should the allocation unit for emission quotas be determined? What method should be used to allocate allowances? Is there any need for the environmental protection department to reserve a certain amount of the total quota in case adjustments are necessary at a later point?

2.3.3 Regulatory Basis of Emissions Trade

Emissions trading is considered an economic regulatory instrument. The revised APCL mentions controlling air pollution with economic policy. The law stipulates that: "central government should adopt air pollution prevention methods or some other methods concerning economic or technology measures." In so doing, the law encourages experimental implementation of SO_2 emissions trading. Although the revised APCL indirectly supports SO_2 emissions trading, there is no direct support for or specific wording that references "emissions trading." To strengthen the basis for emissions trading, there needs to be direct mention of emissions trading in future laws and regulations.

2.3.4 Regulatory Basis of Measurement

Measurement is another essential component of any emissions trading program because it ensures impartiality. Monitoring requirements have been established in emission declarations, registration regulations, and power monitoring regulations. For instance, the "air pollutant emission criterion on thermal power plants" (which has been implemented since January 1, 1997) requires that all newly built, enlarged, or reconstructed thermal power plants should install dust continuous monitoring equipment. The regulations go on to stipulate that thermal power plants in the acid rain control zone or SO_2 control zone and the thermal power plants that have flue gas desulfurization (FGD) equipment should install SO_2 continuous monitoring equipment.

At present the application of continuous emissions monitoring (CEM) in thermal power plants in China can be described in the following manner. CEMs have been installed on a portion of thermal power plants, primarily in new power plants that have been built with foreign capital investment, joint ventures, and individual proprietorships. After 1995, especially after SEPA issued a levy on SO_2 emissions, thermal power plants with CEMs increased, and some flue gas continuous monitoring instruments has been produced in China domestically.

Yet, as with other areas, the installation of CEM systems lacks specific guidelines. Among the obstacles facing China are the complexity that comes from the varieties and specification of the CEM systems used in thermal power plant. The CEM systems lack uniform standards, a certification system for imported equipment, technical installation

standards, special requirement for operation management, and investigation and certification regulations for equipment installation. To solve some of these problems, it is important to establish CEM standards with uniform criteria for measurement, equipment, and management.

2.3.5 Brief Summary

From the above discussion, it is clear that emissions trading and the necessary tools to support trading should be codified in law. An appropriate title might be “Regulations on SO_2 Emissions Trading in China.” The law should include general rules, confirmation of total amount, confirmation of trade scope, quota allocation, trade management, tracking management on discharge, legal responsibility, and an appendix. Without such a law it will be difficult to smoothly implement the trading program.

2.4 Emission Measurement

Implementing SO_2 trading policies requires an accurate method to determine each source’s mass emission and an effective way to monitor these emissions. Meeting these programmatic needs is essential to China’s trading pilot.

Looking at the program’s design and the associated implementation process, four subsets of data are necessary: (1) data to determine the cap; (2) data to allocate allowances (at a minimum historical emissions data and heat input (utilization) data, and perhaps also output data depending on allocation method); (3) data to track compliance; and (4) data required to test and verify the result of the program.

To strengthen pollution management, China has invested considerable time and effort on information management, including implementing a reporting system, carrying out site inspections, and constructing an information management system compatible with emission sources.

2.4.1 Emissions Reporting

China uses a reporting system to help manage pollution source emissions. This system is based on regulations that state, “units that emit pollutants must fill out a *Pollution Emissions Registration Report* for time periods stipulated by the local environmental protection bureau and provide necessary information as required.” The reporting system is fundamental to the environmental protection department’s ability to manage pollution sources. The currently used reporting system makes it possible to implement total load control policy, planning for the two control zones, the pilot of emission permit system, and the emissions trading under study.

2.4.2 Regulations Concerning Emissions Reporting

China's *Environmental Protection Law* provides that enterprises or other units that emit pollutants must register according to the State Council's environmental protection administration's regulations. The *Air Pollution Prevention and Control Law* specifies further that units that emit pollutants into the atmosphere must, according to the State Council's environmental protection administration's regulations, report to the local environmental protection administrative department its emissions facilities, its pollution management facilities and the type, quantity, and concentration of emissions under normal operating conditions and provide technical information concerning pollution prevention facilities. The unit also should promptly report any large changes in emission's type, quantity, or concentrations.

In August 1992, SEPA promulgated *The Pollution Emission Source Reporting and Registration Regulations* as well as the corollary *Emission Source Registration Form*, providing the rules necessary to make this system feasible. The rules required that reporting and registration be instituted nationally.

In January of 1997, SEPA released *A Circular Concerning the Extension of the Reporting and Registration System*, which offered further regulations on the scope and requirements of the reporting system. The circular prescribed that full extension of the reporting implied that the scope of the system include all enterprises that directly or indirectly polluted the environment (enterprises at or above the county level, township village enterprises, and the enterprises with foreign direct investment, joint venture, and share holding fall within the definition) as well as work units and individual entrepreneurs. The circular also noted that there should be uniform reporting and uniform reporting software (in this case *the National Pollution Emissions Reporting and Registration Information Management Database Software*).

2.4.3 Enterprise Sulfur Dioxide Emission Reporting

The chief content of the report should consist of the following: basic information concerning the enterprise or the work unit, including the enterprise or work unit's detailed name, the enterprise or work unit's legal representative, the main product manufactured, the raw materials needed to manufacture that product and a flow diagram of production processes; basic information on wastes that are emitted or discharged during production, including the name of the waste gas emission facility and the amount of the chief pollutant emitted; basic information on mass emissions from fuel combustion, including the boilers, furnaces, stoves, or ranges that emit SO_2 and the location of their functional area; basic information on the primary pollution abatement facilities and a floor diagram showing their location.

Work units that emit pollutants must file a report within the time period mandated by the environmental protection department. The reports should be filled out annually, with information on the previous year's production and the actual amount of emissions. New, renovated, or expanded enterprises or units that have undergone changes in manufacturing must report to the environmental protection department three months prior to beginning trial production. Enterprises or work units should file a report 15 days in advance of dismantling or leaving unused abatement facilities or altering the way pollutants are emitted when such changes have a relatively large impact on emissions. If during the course of these alterations it becomes apparent that there will be an extremely large impact, then the enterprise must file a report within three days after the change is completed.

Generally speaking, there are two ways to assess the amount of SO_2 emitted. The first involves using emissions monitoring equipment to calculate SO_2 quantities, including entrusting the enterprise to conduct its own monitoring or having the environmental protection department handle the task. The second involves deriving calculations from the production materials or using emission coefficients, which is called mass balance method. In this case, one might take the production value or quantity produced to figure out SO_2 emissions. At present the SO_2 pollution levy system relies primarily on the amount of coal combusted, its sulfur content, the type of the coal combustion facility, and the efficiency rate of desulfurization equipment to generate figures on SO_2 emission quantities. Since the efficiency rate of typical desulfurization equipment can vary depending on unit operation and since the costs to operate the equipment increase with the removal rate, self-reporting by facilities on the efficiency rate of such equipment is not likely to be an accurate and consistent measure of true emissions. Where desulfurization equipment is employed, continuous stack measurements of emissions (SO_2 concentration and volumetric flow) are highly recommended and should be prioritized for CEMS installation.

Currently the vast majority of total emissions data that pollution sources report is based on sulfur content of the coal that is burnt. Although there are a few enterprises with monitoring equipment installed, it is usually single emission, non-continuous monitoring equipment. Without continuous monitoring installed, employing methods that calculate emissions based on production materials is also a kind of non-continuous monitoring. When the raw materials and the production processes are relatively stable, using this method is relatively accurate. But if this method is still applied after the installation of desulfurization equipment, it will not meet environmental quality management needs. The measurement methods should include the type of data that must be collected and with what frequency. The quantification method dictates what data elements are needed to estimate emissions. This data should be recorded on-site and submitted periodically to the appropriate agency. If a large quantity of data is needed, it is advisable to have sources submit this data more frequently so that quality checks can be conducted on smaller

amounts of data. Again, depending on the measurement method, electronic reporting might be necessity for some sources—not an option.

2.4.4 Verifying Reported Data

An important if not critical stage of the management process is conducting an audit to verify that reported emission's data falls in line with data from previously acquired materials and actual emissions monitoring. The primary content of such an investigation is based on fairly verifying the accuracy, science, and logic of the enterprise's reported data.

There are numerous auditing methods. They include but are not limited to verifying the logic of the report, using experience to check the veracity of data, using related department's information for verification, monitoring to double-check data, and conducting on-site investigations.

The auditing process also involves several procedural steps. Pollution sources submit a report within a defined period. After the report goes through the relevant department, it arrives at the environmental protection department. At the environmental protection department, appropriate personnel, based on information and data they have acquired, carry out a thorough investigation. The reports that pass the investigation are then registered in a ledger. Those that do not are returned to the unit, whence the pollution source is given a limited time to correct the report and file it again.

2.4.5 Emissions Reporting Data Management

Emissions reports are an important data source for the national and local environmental protection departments. After these data are aggregated regionally, they are gradually transferred to the national level. Currently both national and local environmental protection bureaus have an information management system in place, helping to carry out uniform data management. These data act as the basis for environmental protection management and policy decisions.

From the previous background information it is evident that a series of problems exist in the reporting system. First, the data calculation method does not have a strong legal basis. Second, for cost reasons, data monitoring and auditing is insufficient, making the quality of data unsatisfactory. Third, the data coverage is too restricted, lacking the inclusion of small pollution sources and livelihood sources.

2.4.6 Sulfur Dioxide Monitoring

Conventional Monitoring of Sulfur Dioxide Emissions

Emissions monitoring and the emissions reporting systems are closely related. According to relevant regulations, pollution sources must carry out self-monitoring. Similar regulations require that pollution sources report their emission totals. The environmental monitoring department is responsible for inspecting monitoring equipment. The lack of long-term, concrete SO_2 control measures places a lag on monitoring and is part of the reason most enterprises do not have monitoring equipment. There are also limits on the environmental protection department's monitoring capacity, making it very difficult to develop an accurate picture of total source emissions.

Currently, China does not have national SO_2 monitoring system regulations. Based on SEPA's 1991 industrial pollution monitoring requirements, "monitoring stations at each level should annually inspect [enterprise] boiler and furnace dust and smoke removal rates." In order to better suit the needs of the total emissions control system, the reporting system, the emissions levy system, and 2000 emission compliance standards, local monitoring stations have already begun a program to test, inspect, check, and examine operational effectiveness of monitoring equipment once yearly.

Continuous Emission Monitoring

A basic condition for participating in an emissions trading program is consistent and accurate emissions measurement practices and total emissions accounting. Ideally, sources would install continuous monitoring equipment, but other methods can be used initially. From the standpoint of China's current pollution monitoring equipment, there is not enough equipment. According to China's "Thermal Power Plant Air Pollution Emissions Standards" (GB13223-1996) regulations, third-stage thermal power plants (i.e., new, expanded, or renovated plants that received approval on their environmental impact assessment after January 1, 1997) must install CEM equipment in their stacks. Second-stage thermal power plants (i.e., new, expanded or renovated plants that received approval on their environmental impact assessment between August 1, 1992 and December 31, 1996) should gradually install CEM equipment in their stacks.

The plan for the two control zones also requires that key SO_2, soot (dust), and NO_X emission sources install CEM equipment. The important issue here is the integrity of measurement—even if at first not all sources are able to install CEMs. A plan for a gradual transition from estimation methods that are accurate and consistent to CEMs would be a good addition here. Also, further discussions on CEMs might be needed. For example, are flow monitors required? If not, how will total mass emissions be measured? Measuring the concentration of SO_2 coming out of the stack will not provide enough information when assessing total emissions from sources.)

This management arrangement places the responsibility of purchasing, installing, and operating the CEM system on the enterprise. The environmental protection department is responsible for confirming the standards, examining the quality and checking the accuracy of the equipment. Assuming that there are no problems, the department is also responsible for eventually transferring the data from the equipment onto the environmental protection department's information network.

On the regulatory side, the data from continuous emissions monitoring could become the foundation of emissions reporting, the emissions levy, the emissions permit, emissions trading, and a reduction in total overall emissions. It could furthermore be entered into the environmental protection department's database and help to carry out environmental quality forecasts. On the industry side, the data could become the basis for internal management decisions, improvement in production and increases in efficiency.

In 1999, the State Power Company conducted a national survey on the operation of CEMs. The survey results showed that as of July of 1998 40 thermal power plants with 51 CEMs were already installed nationally. The study also found that 45 of the 51 CEMs were imported. The CEMs recording and reporting emissions data, however, are not connected to SEPA.

Other data, such as output and the sulfur content of the coal, and raw material should be periodically monitored to verify emissions data. The current practice is to calculate SO_2 emission this way.

Existing Problems

China has encountered some major problems using CEMs. These problems include but are not limited to the following: the purchase of the equipment is sight unseen; the location where the device is installed returns biased readings; the quality of the equipment is not examined; the equipment is not accurate; personnel lack the knowledge to use the equipment; the operation of the equipment is not ideal; and the monitoring data is not reliable. Applying CEMs in China is problematic due to the absence of environmental protection policies and related standards. The fact that there are still not regulatory standards for the application of CEMs is at the root of all these problems.

There are several explanations why plants that already have CEMs installed are not operating the monitors. Some of the plants that have purchased imported systems have found the systems do not comply with national regulations. Others have found that the equipment often requires changing of replacement parts and the plant's service becomes worse after the parts are purchased. Yet other plants have found that after the monitors are installed, management becomes stricter.

Establishing a data network is equally problematic. Because of the limited number of plants using CEMs, these systems still have not been linked together in a network and data has not been applied as usefully as might be hoped. As China strengthens its SO_2

management capabilities and begins to implement the tradable permit program, CEMs will help strengthen data linkages.

The primary obstacle stalling the extended use of CEM systems is their prohibitively expensive price tag. It takes a sizable investment to purchase automated monitoring equipment. For example, if a 3,000 MW power plant were to install CEM equipment, it would have to invest 584,800 yuan in one-time sunk costs, while additional levies would run 189,600 yuan, totaling 774,400 yuan. Currently China's domestic market is reliant mostly on foreign imports. Comparable domestic products are in the research and development or piloting stages. Although recent experiments with domestically manufactured equipment have been mostly satisfactory and have fulfilled the basic SO_2 monitoring needs, progress in improving the equipment's stability and dependability needs to be made.

Monitoring Capacity

Based on the "National Environmental Monitoring Ninth Five-Year Development Plan and 2010 Long Range Objectives," the goal is to form a monitoring network that takes account of China's special characteristics and is up to international standards. The overall goal is to form a system that agrees with China's sustainable development strategy and create monitoring stations that are on par with other countries internationally. The intended outcome is to strengthen source monitoring and supervision and thereby bring the pollution problem under control. Several steps must be taken to realize these goals and outcomes, such as: formulating monitoring methods to creating an urban monitoring network; making the enterprises own monitoring stations track total emissions; making the environmental protection agency accountable for conducting monitoring audits; and promptly, accurately, and systematically ensuring that pollution sources are in compliance with emission concentration and total emission standards providing a scientific basis for the total emissions control measures. If SEPA crafted a *National Environmental Monitoring Network*, it would also be beneficial to help reach the aforementioned goals.

Expanding the Use of CEM

Although there are relatively few CEM systems in China, several installations and experiments are underway that will help accumulate technical experience. CEM systems installed on thermal power plants that emit SO_2 will be especially valuable in this regard. At the same time, as the SO_2 levy and other environmental protection policies emerge, the speed at which enterprises install CEM will likely increase.

Taiyuan, Shanxi Province has been installing CEM SO_2 equipment since 1997. Presently, the systems are installed on ten facilities, with plans to have them installed on all boilers of 10 tons or greater. In Taiyuan there should be a total of 100 boilers with the equipment by 2001, 200 by 2002 and eventually all of the city's approximately 300 boilers will have operable CEMs. Beijing is another city where the use of CEMs is growing. Unlike

Shanxi, Beijing is using this technology primarily on furnaces. In Beijing there are already a number of furnaces linked to a CEM network called the “electronic eye” and plans call for this network to be extended to 70 units this year. Other key cities and provinces have similar programs on tap. Using CEM to calculate emissions quantities is a growing trend at the regional level.

Aside from the regional examples above, at the national level SEPA formally entrusted the State Power Management Department to put together *Technology Standards for CEM of Thermal Power Plant Emissions* in 1997. The standards are still in the drafting process. One might anticipate in the near future considerable growth in China’s application of CEM technologies. Thus, when implementing the tradable permit program, if trades are confined to a defined industry, then one of the requirements could be the installation of CEM equipment to carry out emissions calculations.

2.5 Distributing Allowances

2.5.1 Defining An Allowance

In a tradable permit program, an allowance is the participating work unit’s right to emit a given quantity of pollutant. It is the essence of carrying out emissions trades in which allowances are exchanged between units. Based on the U.S.’s experience, allowances should have the characteristics listed below:

- The environmental management department must create allowances in a legally binding manner.
- The allowances that are allocated to units are relatively firm. Though this does not imply that there will never be changes in the allowance allocation, it does mean for an extended period initial allocations will not be easy to change.
- It must be possible to measure emissions and track allowances. No matter if it is the environmental management department allocating allowances or units trading allowances, tracking allowances is essential to ensure at the end of the year that no source emits SO_2 emissions in excess of the allowances they hold.

The emissions cap in the cap and trade program determines the number of permissible allowances. The cap level determines the amount of emissions reductions needed and guarantees the environmental protection. It is possible to lower the cap level over time to increase environmental protection.

An allowance can be used for compliance beginning the year it is issued and might be used for compliance in the future, depending on the banking policy. Allowance distribution and allowance reductions must be guaranteed over a specified period of time. Especially important is continuous or perpetual reductions in the quantity of tradable allowances,

namely allowance continuity. Allowance continuity also refers to allowances that can still be used past the end of a time cycle.

Considering U.S. understanding of allowances and integrating this understanding with China's permit and other relevant systems, one could define allowances for China in the following manner: rights that SO_2 emission units obtain, that the environmental protection bureau approves, that reflect an emissions target for sources, that have a measurable quantity for a certain period of time, and can be understood to stand for the SO_2 that the unit emits into the air in the region. In actual practice, an allowance is equivalent to one ton of SO_2 emissions.

The Principle of Allowance Allocation

Because allowance allocations are a distribution of a valuable commodity, it is a very sensitive matter. It must factor in technical, social, political, and economic considerations. In sum, distribution decisions must take into account the principles of equity, science, feasibility and economic efficiency.

The Equity Principle of Allowance Allocations

The equity principle is the most fundamental of all the principles associated with allowance allocations. Simultaneously, it is closely related to the methodological basis for allowance distribution. Regardless of what kind of distribution formula is adopted, absolute equity will be unattainable. Nevertheless, in the allocation plan, the idea is to make sure that the principle and basis for allocating allowances to units with the same environmental behavior is consistent. Equity is achieved through consistency.

Allowances Allocations Must Meet the Requirements of the Total Emissions Control System

In implementing the tradable permit program, the distribution of emission allowance must consider China's current management systems and be integrated with related systems. Therefore the total emissions control plan is an important element to consider when executing allocations and determining allowance quantities.

China is currently in the process of implementing a total emissions control plan. In line with this plan, the new "Tenth Five-Year Plan" includes SO_2 total emission targets down to the provincial level and provides for a 10 percent emission reduction from 2000 to 2005. *The Two Control Zones Acid Rain and Sulfur Dioxide Pollution Prevention "Tenth Five-Year Plan"* deepens the aforementioned cutbacks in two control zones from 10 percent to 20 percent and creates reduction plans for key cities with serious pollution problems. The tradable allowance program is well suited to meet the requirements of national total emissions control plan and the reduction requirements placed on key cities.

Allowance Allocations must be Integrated with the Permit System

In reality, the permit system China started to implement in 1988 already has some of

the basic features of allowance allocations. When implementing the tradable permit program it should be possible to integrate the allowance determinations and distribution with the permit system. As of 1999, there were already 291 cities using air pollution emission permits, 34,475 enterprises that had received permits, and 12,473 enterprises that had received temporary permits (*China's Environment Annual Yearbook*, 2000). The distribution of permits has a relatively stable foundation, which should pave the way for the integration of air pollution permits and allowance allocations. However permit and allowance are not virtually the same subject to understanding and the scope of the two.

Currently permits are granted for a period of three years. As far as tradable emissions are concerned, allowance allocations should not be less than three years. Additionally, in light of national and regional development objectives, determining an allowance plan for five or ten years should also be part of the program.

2.5.2 The Allowance Allocation Method

Allowances could be distributed according to several methods. For instance, a source could acquire an allowance based on historical utilization data, historical emissions data, the intensity of emissions, by auction or a combination of these methods.

The Historical Emissions Allocation Approach

Distributing allowances based on historical data is a method that is employed frequently. In the U.S. SO_2 cap and trade program, all the distribution methods boil down to this approach. In using this method it is possible to draw upon historical data from a representative year or use the average value from several years. In terms of the power plants in the two control zones, for those facilities that have not seen drastic changes in emission using the average value from several years is feasible. For units that have witnessed large fluctuations, recent emission figures are also acceptable. The historical data approach can be expressed in the below formula:

Constraints $E_f = E_c(1-p) \geq \sum_{i=1}^{n} e_i$

Allocation Formula $e_i = e_c(1-p_i) \times \varepsilon$

Notation

E_f: Sulfur Dioxide Emissions Target for the Year *f*

E_c: Current Level of Sulfur Dioxide Emissions

P: Sulfur Dioxide Reduction Targets, the Expected Reduction by the Year *f*

e_i: Annual Allocation to Each Enterprise

e_c: Each Enterprise's Current Level of Emissions

n: Number of Enterprises Participating in the Trading Program;

p_i: The Determined Percentage of Reductions for Each Enterprises Based on Total Reduction Percentages (According to the needs the environmental protection bureau, individual enterprise percentage reductions may differ from total percentage reductions)

Adjustment Factor, Based on the Needs of the Environmental Protection Department

When allocating allowances, it is necessary to fully consider an enterprise's production technology and pollution abatement equipment to build in an adjustment variable.

The key to the historical allocation approach is determining current emissions levels and setting reduction goals off those levels. Equally important is to ensure that the sum of allowances does not exceed the total emissions target. The excess overhang between the emissions target and the sum of individual allowances can be used for two purposes. It can be given to new pollution sources and it offers the environmental protection department some flexibility to make uniform adjustments when necessary. This flexibility could compensate for the variation between enterprises in terms of technological or abatement capacity. It needs to be noted that the U.S. program uses historical fuel use data, not historical emission data to allocate allowances. The U.S. SO_2 cap and trade approach did not use historical emissions data for allocations, rather historical fuel use data multiplied by an emissions performance standard of 1.2 pounds SO_2 per mmBtu. The effect of this formula was about a 40 percent reduction in emissions from power plants.

Emissions Intensity Allocation Approach

The most common allocation approach based on emissions intensity is a method used chiefly with thermal power plants known as general performance standards (GPS). GPS are determined by the amount of SO_2 that is emitted for every unit of power that is produced. Within this approach, there are two control objectives. The first is the total emissions control objective, and the second is the environmental performance control objective, namely the GPS objective. The calculation below demonstrates how GPS allocations could be determined.

Constraints: $E_f = S_f \times G_c \geq \sum_{i=1}^{n} e_i$

$$S_f < S_c = \frac{E_c = \sum_{i=1}^{n} e_{ci}}{G_c = \sum_{i=1}^{n} g_{ci}}$$

Allocation Formula: $e_i = S_f \times g_c \times \varepsilon$

Notation

S_f: The GPS Year End Control Target

G_c: The Current Quantity of Electricity Produced by Thermal Power Plants in the Trading Program

S_c: The Current GPS

g_c: The Amount of Electricity Currently Produced by the Pollution Source Plant;

All other variables are the same as above.

In applying the GPS method to determine allocations, the first step is to determine average GPS of participant power plants. (Another project by CRAES discusses this in detail.) Then, determine GPS value for the target year based on the amount of SO_2 reduction and other factors. This determination should take full account of developmental levels, the power plant's current technology, and improvements in the resource structure. The final step is to distribute allowances to sources according to the GPS system and the amount of power generated.

The GPS approach pays attention to both the enterprise's production and abatement situation, making it relatively equitable. The approach also encourages industries with poor environmental protection records to make improvements. It carries the added benefits of inducing progress in power plant technology and, when integrated with a related set of policies, could help adjust the structure of the natural resource sector. Output based, or GPS allocations do reward energy efficient behavior when they are updated frequently (annually). However, updating allocations can be time consuming and expensive. When using GPS (output based) allocations, power producers have no incentive to produce less energy.

The Auction Method

Another method used for allocation involves auctioning allowances. This method requires a corresponding set of policies and institutions. Under this approach, the government's environmental protection department sets a low bid entry price for allowances and relies on the power of the market to determine allocations. To a certain extent, this approach has the advantage of circumventing the disparities between different kinds of industries. It is possible that the method is more favorable to large pollution sources. However, there is still an economic incentive to reduce emissions, thereby eliminating the need to purchase allowances.

The auction method is very flexible. The environmental protection department can adjust the auction time and the amount of allowances up for bid or it can confine the auction participants to only new pollution sources.

2.5.3 Determining Pollution Control Targets

In designing the trading program, the chief object of concern has been power plants in the two control zones with capacity cut off of greater than 5,000 tons annually if other

large sources other than power plants are included in the program. If a consistent capacity level is associated with the emission level of 5,000 tons annually, it would be useful to use a capacity cutoff as well as an emissions limit. The reason for this is administrative—some sources might emit slightly below 5,000 tons one year but slightly above in another year. In this example, the source could argue that it should not be included in the program during certain years. It will be easier to administer this program if the delineation is clear.) According to the two control zones, SO_2 prevention plan, the amount of total emissions in these two regions should be reduced by 20 percent from the 1999 baseline. The focal point of this cut back will be the power plants in the zones and the proportion of the cut back they will bear.

To leave open a space for new power plants to develop, every year five percent of the total emissions allocation will be reserved to auction to new sources. New sources that have needs exceeding the five percent quota can purchase allowances from old sources. If the five percent cannot be fully auctioned off, new sources still maintain the option of purchasing from old sources. Based on the yearly reduction schedule, it is possible to calculate emission control targets for key power plants in the two control zones. Table 2-12 provides hypothetical control targets under the historical allocation method.

Table 2-12 Using Historical Emissions to Determine Reduction Targets

	2000	2001	2002	2003	2004	2005
Emissions targets (1 million tons) (In 1999, 3.3726 million tons of SO_2 was emitted)	3.2602	3.1478	3.0354	2.923	2.8106	2.6981
Amount reserved to be auctioned to new sources (1 million tons according to a 5% withholding)	0.163	0.1574	0.1518	0.1462	0.1405	0.1349
Amount of SO_2 that can be allocated during any given year (1 million tons)	3.0972	2.9904	2.8836	2.7768	2.6701	2.5632
Amount of cumulative SO_2 reduction (1 million tons) (The reduction is deducted from the 1999 baseline)	0.2754	0.3822	0.489	0.5958	0.7025	0.8094
Cumulative proportion of sulfur dioxide reduction (%)	8.17%	11.33 %	14.50 %	17.67 %	20.83 %	24%

One can see that due to the entry of new pollution sources, old sources will have to bring down their emissions 24 percent to arrive at the stated goal of a 20 percent reduction.

In the above plan, the proportional reductions for current sources are average values. These percentage reductions could also be the basis for distributing allowances. That is, the environmental protection bureau could give allowances that have uniform proportional reductions to each enterprise or the department could adjust the allocation formula so it is

compatible with desulfurization plans. From the industry standpoint, the proportional reductions are a very clear bar. The enterprise can consider its own circumstances and arrange a long-term abatement strategy that meets future reductions. The above diagram also provides other information regarding the 5 percent withholding that is important for new enterprises. According to this reserve and the status of other enterprises, new industries can decide the timing and how much they will need to expend to purchase allowances.

When putting the GPS allocation method into effect, the first step is using current sulfur emissions figures and each plant's energy production figures to calculate GPS emission standards. As with the historical data method, to allow room for new sources to develop, 5 percent of the total quota should be held for auctioning. Using the old source emission and power generation quantities, GPS emission standards can be drawn up for every year out to 2005. New sources will be expected to comply with these standards as well. Table 2-13 provides an overview of how the GPS method could be employed to determine yearly emission control targets and GPS targets.

Table 2-13 Using the GPS Method to Determine Emission Control Targets

	2000	2001	2002	2003	2004	2005
Emission control targets (million tons) (the 1999 figure was 3.372 million tons)	3.2602	3.1478	3.0354	2.923	2.8106	2.6981
Quantity of emissions new sources can purchase at the auction (million tons, figures are 5 percent of the control targets)	0.163	0.1574	0.1518	0.1462	0.1405	0.1349
Quantity of emissions that can be allocated that year (million tons)	3.0972	2.9904	2.8836	2.7768	2.6701	2.5632
GPS target (kg/10,000 kWh) (the 1999 figure was 113.68kg/10,000 kWh)	104.4	100.8	97.2	93.6	90.0	86.40

The above table outlines the chief GPS control targets. When allocating to pollution sources, the amount of power generated by each source can be converted into GPS to arrive at concrete allowances. The information provided in the diagram focuses on the level of emission intensity per unit of power generated. Based on the targets, each enterprise could formulate concrete control programs and plans, fulfilling the environmental management department's requirements.

2.5.4 Allocating Allowances

Plenty of experience can be drawn from the U.S. SO_2 cap and trade program (a program that used historical heat input data and an emissions performance standard), the

Massachusetts NO_X program (a regional program in the northeastern U.S. that is implementing GPS to control NO_X), or the hypothetical figures in Table 2-12 and 2-13 when selecting an allocation method.

In the historical data method, each source's allowance is based on using 1999 total emissions as a baseline and then applying the reduction formula over 4.3 periods with the uniform percentage reductions displayed in Table 2-12 and an adjustment factor set at one. In the GPS method, each source's allowance is based on using yearly GPS targets and the amount of power currently generated with an adjustment factor set at one.

It is necessary to point out that regardless of the method employed, each enterprise's allowance is still determined by the two control zones targets. It is also important to highlight in the two control zones, the overall total emissions control objectives for the zones, and city or region-specific total emissions objectives. In the process of implementing the total emissions controls, each city or region will allocate a SO_2 emission quantity in the form of a permit to its enterprises. Hence, there must be agreement between the distribution schemes described above and the local level distribution scheme. Because the national SO_2 regulations in the two control zones are exceptionally strict, and if the regional allocation standards are more lenient than the targets generated from either the historical or GPS method, then the historical or GPS method should become the standard. If the regional standards are firmer than the above allocation schemes, then they should become the employed standard.

The figures in Table 2-12 and 2-13 show that there is an appreciable difference in allowance allocations between the historical data and the GPS method. Under the GPS method, a few enterprises receive an added bonus in allowances that they can sell or trade if they do not need to make reductions. The explanation for this excess is that the enterprise's environmental performance is greater than the current average. The frequency of updating GPS allocation and the baseline data are determined by the overall national SO_2 control plan.

2.5.5 Managing Allowances

The management of allowances is a basic guarantee that trading can be carried out smoothly. This type of management includes re-allocations, allowance purchases and sales, allowance banking, as well as fines and bonuses.

Cap Redefining and Redistribution of Allowances

The duration of the cap and allowances is very important for the successful implementation of a trading program. The schedule of reduction goal and allowances for participating utilities should be informed in advance so that they have time to adjust

themselves and determine strategy. The duration that allocations are effective should not be too short. Rather, the enterprises should have sufficient time to clean up or purchase excess allowances on the market.

The cap and allowances might need to be changed after being implemented for a certain duration to meet more stringent environmental goals for air pollution control. This allows environmental protection authorities to review the effectiveness of such a program to achieve national or regional reduction goals. The timing for program assessment and the national environmental protection plan that lays the foundation for the program goal should be parallel.

If a new cap is defined, redistribution or adjustment of allowances for the participating utilities will be followed. This might modify allowances that have been issued to them. However the modification would not be so substantial as to diminish the confidence of the affected market participants.

Allowance Trading

After the allowance distribution is complete, every unit that has an allowance theoretically can begin purchases or sales according to market force. Ultimately, all transfers should be voluntary with less administrative interference. Yet, in the early stages of implementation, the exchange of allowances should be carried out under the supervision of the environmental protection management department officials. Trading must be registered and recorded by the environmental regulatory authority.

To reduce operation costs, the buying, selling, and trading period for allowances should be one year. At the close of every year, the environmental protection department needs to inspect whether the enterprise's emissions data and the acquired allowances are equivalent and meet departmental regulations. Based on the results of this inspection, the department can adopt measures to guarantee that management targets are reached. Sanctions such as fines will be followed if there is any violation.

In the early stages of implementing the trading program, the environmental protection department should limit or even forbid groups or individuals from purchasing allowances to ensure more emission sources have economic development opportunities. After a certain developmental period is over, both organizations and individuals should be allowed to purchase allowances on the market or at auction. Moreover, as the market matures, the environmental regulatory agency can begin to relax some of its controls and devote more energy to measuring and trading emissions as well as renewing allocations and formulating relevant policies and laws.

Besides buying and selling allowances on the open market, concrete regulations should be in place for the five percent of allowances withheld. According to the auction guidelines, new, renovated, or expanding sources should be given first priority in bidding on this reserve. If the five percent excess is not enough for the new, renovated, or

expanding sources, they can purchase allowances from current emission sources. The funds that are collected from the auction can be used to develop SO_2 emissions control technology. They can also be devoted to power plants that have to shut down or slow power production due to the influence of emissions allowance system or as a subsidy for plants that use renewable or reusable resources.

Allowance Bonuses and Fines

Closely related to allowance allocations and trading are bonuses and fines. When crafting the implementing rules for the program, concrete and clear regulations need to be developed concerning the conditions, assessment, and amounts of bonuses and fines. Pollution sources that need to make large reductions in their SO_2 emissions (or agree to install advanced pollution control equipment) can be given a bonus. The bonus can come in the form of increased allowances or an appropriate amount of funding. Bonuses can also be given to sources that demonstrate improvements in energy efficiency, using renewable energy, or installing other desired technologies (like scrubbers).

Enterprises that fail to comply with their allocated allowances can incur a fine. The level of the fine can be up to two to five times the price of an allowance on the market.

Banking Allowances

The remaining allowances can be banked. These allowances have either been allocated or purchased from other sources; however, they cannot be used before they are validated. Some sources will over control and be able to sell allowances and some sources will under control and need to purchase allowances. The goal of the program is to achieve the reductions on the aggregate level among all participating sources. The ability to bank provides additional economic incentives to control emissions earlier; thus, environmental benefits begin sooner. Any restriction on banking should be simple and easily implemented and justified by environmental concerns.

Mechanisms for Pollution Sources to Participate Voluntarily

Another issue in allocation management is the design of mechanisms allowing pollution sources (either power plants or other ones) to participate voluntarily in the trading program. Operating a favorable trading program is not only achieved by registering cost savings for society, but also helping enterprises to register cost savings as well. Whether the enterprise purchases additional allowances or reduces emissions, it should be able to reap gains from the program. These gains ought to be attractive to those industries not participating in the program. Based upon the experience of the U.S., the cost savings that comes from participating in a trading program is at least double that of other management programs. An expert from Harvard University's International Development Graduate School estimated that if a trading program was implemented in Shaanxi province there would be a 20 percent savings over any other program where every source was in

compliance.

It is evident that the trading program should encourage voluntary participation. Voluntary participation has two benefits: (1) it is linked to successfully implementing the program; and (2) it requires that the program have in place rules and allowance management techniques to establish a definite set of regulations concerning the conditions, timing, and approach to new source participation. After the trading program is in place in China, efforts encouraging new source participation and crafting policies that seek to reach this end should be made. The environmental protection management department is critical to this effort, as its role is to formulate clear plans and strategies to expand the scope of SO_2 trading and deepen the influence of the program.

To encourage new source participation it might be a good idea to structure the program so new sources are not expected to make reductions until their second year of participation. To illustrate, a source that emitted 10,000 tons in 1999 would be expected to reduce emissions by 8.17 percent or to 9,183 tons according to the original requirements in Table 2-13. This would mean that the source would not be required to adjust its emission levels from 1999 to 2000. In both years it could emit 10,000 tons. But, as of 2001, it would be expected to reduce its emissions by 11.3 percent below 2000 emissions. This would be the same result as in the first year. Sources opting in should meet the same emissions measurement, reporting, and verification requirements as participating sources. For the first phase of the program, it might be worth delaying voluntary participation, because this can create a significant amount of administrative work, without an additional significant reduction in emissions.

2.6 Information Management in the Sulfur Dioxide Emissions Trading Program

The information management system in the trading program is essentially a system that tracks the participating enterprises' emissions data and the flow of allowances. The objective behind having such a system is to provide a quick and safe way to monitor transactions and verify emissions levels and allowance holdings for compliance purposes. The system can be broken into two interrelated components. One side of the system tracks emission quantities, while the other tracks allowance totals. This section of the report will examine the trading program information management system, analyzing the state of the current environmental management information, and raising suggestions pertaining to information management in a trading program.

2.6.1 Allowance Tracking System

Performing functions similar to a bank, the allowance tracking system records allowances enterprises have obtained, bought, sold, or exchanged. It is illustrated in

Diagram 2-1. The system uses this information to reconcile whether enterprises are in compliance. Automating the system protects each participant's SO_2 allowances, including those that have been allocated, purchased at auction, traded on the market, or banked. The principle reason for using the system is it acts as an automated monitor. All participating sources have the opportunity to use the computer to register allowance quantities, update quantities, and conduct trades. The system also allows the environmental protection department to ascertain and take remedial policy or legal actions when there are sudden changes in the allowance market. The system typically posts the following information: the overall number of allowances granted, the number of allowances in each account, the number of allowances banked, the number of allowances traded, the number of allowances transferred between accounts, and allowance deductions for compliance.

Allocating Allowances

After the environmental protection department determines the upper limit on total emissions, the allowances are allocated to participating sources based on each enterprise's historic information. Enterprises are required to submit an application form, which requires information such as furnace model types, overall production levels, fuel use figures, electricity generated, heat input, and historic emissions data. At the same time, new enterprises can place competitive bids on the auctioned allowances that have been set aside.

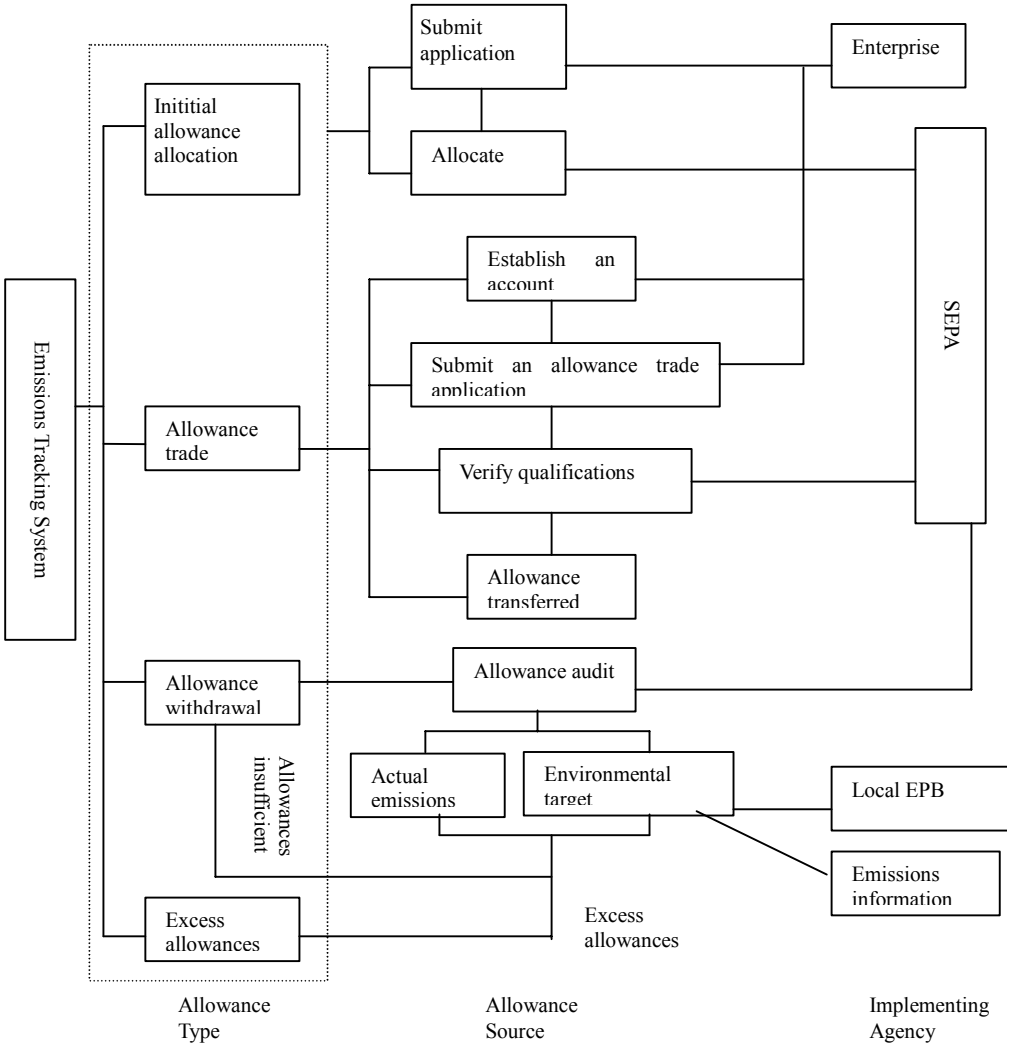

Diagram 2-1 The structure of the allowance tracking system

Allowance Trading

When accounts are opened on the allowance tracking system, the first step is to select trading representatives. The main participants in the trading market can range from enterprises, to organizations, to individuals. Currently, China has chosen to temporarily confine trading to power plants in the two control zones. Power plants at any time can sell, purchase, or exchange allowances. When a trade is made, representatives from both sides need to submit an allowance trading form to the environmental protection department so that the department can confirm the trading qualifications of both parties and register the transfer. After this process is complete, the allowances can be transferred from one account to the other and the updated account information can be handed over to the parties involved in the trade. Assuming that neither party disputes the transaction, the trade is complete. The information tracking system records the allowance adjustments in

both accounts.

Compliance Verification

At the end of each compliance period, the compliance auditing system inspects whether each participant's account has enough allowances to cover total SO_2 emissions for the period in question. If the allowances are insufficient, then a penalty is assessed. If the amount of allowances is in excess of actual emissions, the above emission allowances can be transferred over to the following year's account or sold.

The audits are based on the emissions tracking system and year-end adjustment to the system. The audits are also conducted according to regulations and documents relevant to trading, such as the principles of allowance allocation, trading rules, and fines imposed for breaking regulations. Yearly system adjustments are eventually undertaken by deducting allowances from each account. Yearly accounts in the tracking system might not be necessary. Having a compliance account for each source that would be used for checking compliance holdings each year might be sufficient. Each year's allowances could be distinguished by a different "vintage" year. At the end of the compliance period, the allowances in the account would be subtracted and the account could be used for the next compliance period. An example is shown in Part 1.

2.6.2 Emissions Tracking System

The emissions tracking system functions as a database for SO_2 emission data. The environmental protection department is able to use to the system to ascertain the state of enterprise emissions, to inspect actual emissions, and to ensure enterprises are staying within the regulatory parameters of the program. The system is illustrated in Diagram 2-2.

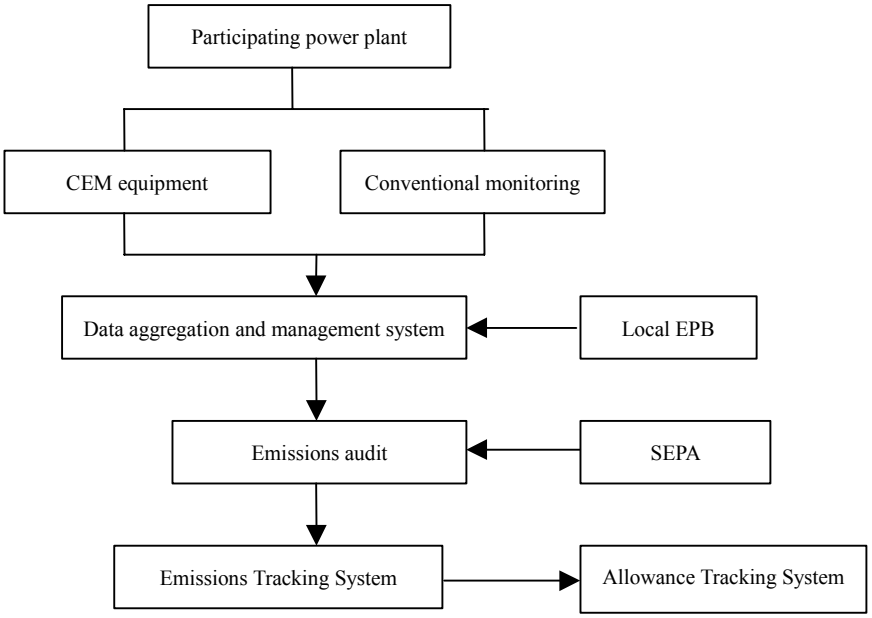

Diagram 2-2 Sulfur dioxide emissions tracking system

Emissions Monitoring

The monitoring of SO_2 emissions from sources is the sole responsibility of sources. They can either monitor emissions by themselves or entrust the environmental monitoring institutions to do it. It is strongly suggested that participating sources install CEMs. Regulations on CEMs should be drafted in order to ensure uniform operation of CEMs. Sources without CEMs can use more conventional monitoring methods. Data from conventional monitoring methods should be adjusted by an accuracy factor in order to adjust for uncertainty and provide incentives for installing CEMs. This should be one of the responsibilities of environmental protection departments. In addition to this, the departments are also in charge of checking data quality, ensuring the completeness and continuity of data, and having standard forms for electronic reporting, data verification, and data auditing.

Emissions Data Transmission

Data acquired through CEMs are transmitted to a computer station located within sources, processed, and sent to computers located in the environmental protection department that regulates the source. This system for data collection and processing is called plant data acquisition and handling system (DAHS). Through the system, data is collected, recorded, and processed and electronic information, in the form of seasonal or monthly reports, is produced. This information is transmitted through lower level government departments to higher level departments.

SEPA provides sources with the uniformed data collection and process software for

them to prepare and submit reports to environmental protection agencies. The software will allow sources to check the report format and completeness before submission. Sources can submit electronic version of reports to SEPA. The hardcopy of reports are signed by sources and delivered to SEPA for archive. Data in the reports are input into ETS and compared to other data to ensure they are consistent. If not consistent, discussion between environmental departments and sources will be held in order to solve the issue, and a fine may be imposed.

Emissions Data Audits

As for the data that is reported from CEM systems, the primary area in need of inspection is the CEM operational performance. This includes the CEM system's application for quality assessment, authenticity certificate, and results from the inspection of the equipment. The equipment's performance should be analyzed against the reported emissions data. Audits for enterprises without CEM equipment are conducted according to hands-on inspections and calculations using the type and amount of resources consumed.

2.6.3 Technology and Equipment Requirements

Building a Network

An important variable influencing the costs associated with a trading program is information. Developments in the information technology sector have been extremely important in this regard. Information networks can facilitate the information gathering process before trades, can simplify trading itself, and can enliven the market for trades. Hence China should quickly build an environmental management information network. In constructing this network, aside from meeting current needs, future networking speed and capacity requirements should be considered. Design standardization, level of advancement, level of maturity, and degree of safety should also be considered. The complete system should have breakdown safeguards, guaranteeing that the continuity of the tracking system and safety of the database are protected. Within a certain period, the technology and equipment should be updated so the life of the system is prolonged.

Hardware Needs

The equipment that is selected will influence the dependability, safety, and stability of the information management system. Where the equipment is purchased is also critical. This computer retail outlet's speed and receptivity are just two criteria that should be factored into the purchasing decision. The information management system consists of the microcomputer working station, the servicer, and the networking product. Each level of the environmental management department and all participants should be equipped with a micro-computer.

Monitoring Equipment

The SO_2 trading program is premised on using market-driven policies to lower the costs of reducing emissions. In this program, an allowance is a right to emit one ton of SO_2 in a year. During the course of the year, the allowance can be sold, purchased, or banked for use in another year. Having complete and accurate information is essential to ensuring that this market functions well. CEM equipment helps to generate this accurate data. Enterprises should therefore be provided with CEM equipment, including SO_2 concentration monitors, a flow meter, an opacity monitor, and a desktop-based data gathering and management system.

2.6.4 The Foundation of Environmental Information Management

The more than ten years of research on the development of China's environmental information management system has yielded several positive results. These include the development of environmental statistics, emissions reporting, environmental supervision, and environmental monitoring software. A national and provincial information support network and a city level information network (still under construction) has been developed. Despite these clear signs of progress, a few areas still need improvement. Information management application software lacks uniform management and technical standards, while the quality of the environmental information that is gathered and the sophistication of the technology used to manage it are unsatisfactory. Though a considerable quantity of data has been accumulated in different databases, the application of this data is rather diffuse and information does not flow freely. In the end, it is difficult to enjoy the overall benefits that might otherwise be appreciated from these informational resources.

Permit Management

Nationally, China still does not have an emissions permit system, but since initiating air pollution permit pilot projects in 1991, some areas have developed their own software to manage permitting. These systems vary by region. After the implementation of the tradable permit system, uniform software will be adopted.

There are several ways of verifying total emissions amounts. One way is carrying out an audit of the polluting unit according to management rights prescribed in the *Pollution Emissions Report and Registration Form* and the *Modified Report and Registration Form*. Another is using the amount listed on a permit and comparing it to actual emissions. A third approach involves using the approved *Environmental Impact Assessment Report (Form)* to check total emissions limits for newly constructed projects. The last method consists of checking emissions totals against data in monitoring reports.

Emissions Reporting

China has been implementing an emission reporting system for nearly twenty years.

Over these two decades, China has developed standardized reporting forms and software. The content of the reports is generally in line with the data required for the trading program. Yet, because the program began many years ago and because of rapid changes in the computer industry, linking this system with the tradable permit system might present problems. The emissions reporting and registration system at the county level and above uses essentially the same kind of inspection management. The chief management department in the industrial sector to which the enterprise belongs is responsible for checking and verifying that the data and format of the report conforms to SEPA's standards. When comparing to past years, increasing or decreasing trends in the data is evident, and determining whether these trends are reasonable is based on the logical accuracy of a technical explanation in the *National Emissions Reporting Modification and Annual Audit Form*.

The reporting goal is to have every enterprise file one report annually. The content of the report includes background information on the enterprise, the enterprise's consumption of resources, emissions concentrations, total amounts, and release directions.

In 1996, SEPA released a document titled *Environmental Monitoring Reporting System (trial)* that required every regional monitoring station to be responsible for performing audits certifying reports from emissions sources. The data from the completed audit was then to be sent to SEPA. The city monitoring stations are also charged with taking annual and seasonal pollution reports and transferring the reports to the city's environmental regulatory agency and to the superior provincial, autonomous region or municipal monitoring stations. Monitoring station reports are also supposed to be sent to SEPA.

Environmental Statistics

Environmental statistics are calculated and tabulated once a year. Pollution sources in each city and county are required to fill out an emissions statistics form and send the form to the regional environmental protection bureau. After the figures are aggregated and processed, they are reported up the chain of command to the immediately superior environmental protection bureau. The process culminates when the provincial emission figures arrive at SEPA. At the national level, the figures are aggregated again and disclosed to the public. China would not have a full picture of the pollution situation if it only required key sources to report data. To make the statistical work a little smoother uniform statistical software has been introduced.

Environmental Supervision and Management

Currently there is one organizational branch of the environmental protection regulatory structure that is responsible for conducting investigations. In particular, this team examines pollution levies, pollution source emissions, and the operation of

management equipment. To have an effective management system, SEPA developed a *National Environmental Inspection Information System*. The system works through the city's communication networks and monitoring equipment installed in the pollution source. The purpose is the inspection group can gather and transfer accurate inspection data from afar, analyzing the current pollution situation with a desktop-based software system. The software system has been developed for industrial wastewater discharges and is currently being piloted in this area.

2.6.5 The Equipment and Hardware Used to Build a Network

During the "Ninth Five-Year Plan," provinces, cities, and counties pooled investment funds to form a national environmental information management system. The system has helped to achieve the computerization and modernization of the collection, management, processing, and transfer of statistical and monitoring data. In addition to this national network, using funds from World Bank and Japanese government loans, 27 provinces and 39 cities have established environmental information centers. Another 100 city-level information centers are currently under construction. The informational web that has developed offers SEPA regional information outposts from which it can announce policy decisions, upcoming activities, scientific and technical advances, monitoring information, and relevant news. The environmental information network is already expanded outward to a considerable extent, but some agencies or bureaus are still not connected. This is especially true at the county level in the poorer parts of the country where equipment is less advanced.

Monitoring Equipment

<u>Conventional Monitoring</u>

Currently the majority of equipment in monitoring stations is relatively outdated, making it impossible to form a complete environmental information network.

<u>Continuous Emissions Monitoring</u>

At present 15 percent of power plants with an electricity generating capacity at or above 50 MW have installed CEM systems on their stacks. Although the plan for the two control zones requires that key pollution sources install CEM equipment, the plan's objectives have been difficult to realize. Domestic research and development on CEM technology has been unable to reach expectations. Internationally imported monitors carry a hefty price tag and are not clearly in compliance with national standards. The domestic market problems and the lack of clear rules on imports have impeded the prompt arrival of accurate emissions information that CEMs would provide.

Technical and Training Support

Some technical and training support for CEMs are helpful to the staff that operate

these facilities. Experience has shown that just installing the equipment is not enough; it is necessary to provide assistance operating the equipment at first and assistance if the equipment is not functioning well.

2.6.6 Evaluating the Supporting Circumstances

The aforementioned sections elaborated upon the importance of each system's distinct use as they related to environmental management in China broadly. There was no direct mention of how the differences in the management system's objectives, scopes, and approaches might fit with the needs of a tradable permit program. There was also little concrete analysis of how compatible the data and software used by or produced from these systems might be with a trading program. This is the purpose of the upcoming section.

Generally speaking, the data supplied via the reporting system is commensurate with the requirements for the tradable permit program with certain improvement. The only issue is that the current once a year reporting standards need to be adjusted so that reporting is carried out more frequently. Efforts also need to be devoted to strengthening audits of reported data and improving monitoring equipment. The pollution levy system is chiefly a supervisory management system. The data coming from the levy system is often below standards and would not be that useful for the trading program. Environmental statistics on the number of industrial enterprises in the reporting and levy system for the time period December 1999 to November 2000 are displayed in Table 2-14.

Table 2-14 1999 Number of Industries Covered by Different Management Systems

Number of units paying a pollution levy	Number of enterprises that have alreadyfiled an emissions report	Number of enterprises that have already been granted an emissions permit	Number of total permits distributed (Note: It is feasible that a single industry has more than one permit for multiple pollution sources.)	Number of industrial enterprises according to environmental statistics

Software use also involves overlap and divergence. The type of software used for emissions reporting and environmental statistics is uniform throughout China, but the pollution levy and permitting software varies regionally. The design of the software used for emissions reporting is reasonable for auditing functions. But because the data in this system is managed manually, a sizable gap exists between its operation and the operation of an emissions tracking system—the system that would be used in a trading program. Meanwhile, the software used to gather environmental statistics is even further out of line with the functional requirements of the tracking system.

2.7 Implementing a Tradable Permit Program

2.7.1 The Role of the Government

The primary role of government in a market economy is to serve as rule makers to formulate standard regulations and systems, to regulate economic activities, and serve as regulators to supervise micro-economic behaviors and make sure the market rules are respected. SO_2 trading policies are based on the principles of environmental economics that support the use of the market. To fully develop the market's potential, the government should work hard to create a competitive environment and reduce the influence of other administrative and command control policies that might run counter to a trading program. Main responsibilities of the government for the trading program include determining which sources are required to participate in the program and assessing program compliance for each source. The chief departments involved in the SO_2 trading program are SEPA, local environmental protection bureaus, and each level of the power company.

In the trading program itself, the government agency's chief responsibilities are allocating allowances, recording allowance transactions, auditing enterprise allowances, and inspecting and supervising CEM systems. As it stands now, there is no single department that possesses enough capacity to manage a SO_2 trading program. Government agencies face definite human resource and funding limits.

To carry out flexible, equitable, and procedurally balanced trading, the formation of a specialized management body temporarily titled the "Sulfur Dioxide Trading Program Management Center" is recommended. The body will be entrusted by SEPA to manage the SO_2 trading program and be responsible for tracking and compliance verification. SEPA's duties will focus on the formulation of the programmatic rules and management regulations of the program. SEPA's inspection team will perform management inspections, assist with trades, verify the quality of CEM systems, and enforce laws when enterprises exceed their permitted emission quota. The local environmental protection bureaus will assist the newly established trading program management center and provide support for emissions and allowance tracking data.

2.7.2 Auditing Emissions Quantities and Allowances

There are two ways to audit total emissions. The first is having the enterprise install CEM equipment and periodically checking the equipment's operation. If the equipment is inoperable or if it frequently malfunctions, then appropriate management measures should be adopted. The second approach for industries without CEM equipment depends on the

current reporting system. A conservative missing data procedure should be developed to ensure that missing data from all sources are treated in the same fashion. Such a missing data procedure should produce an estimate of emissions that reflects the uncertainty associated with equipment failure, and provides an incentive for sources to maintain their equipment and avoid equipment failure.

The primary approach for auditing allowances is examining whether the number of allowances tallies with the actual quantity of emissions. Based on the trades registered in the tracking system, a yearly reconciliation can be undertaken.

2.7.3 When and How to Trade

Both purchaser and seller are free to submit a transfer application form at any time. SEPA then has to register the transfer within a stipulated time period, and approve and record the exchange. At the inception of the program, the trading system will need time for piloting and adjustments. This is in part due to the fact that the informational network has not been completed. In the initial stages, trades will have to be done on forms or transferred from disks. On the network there will be allowance holdings and intended exchanges. Eventually, after an informational network is fully in place, trades will be conducted instantaneously on this Web.

2.7.4 Developing Allowance Tracking Software

SEPA will develop an allowance tracking system to keep tabs on the allowance holdings of all participating sources. China's environmental information categories are currently subdivided at the national, provincial, city and county, or district level. The informational objectives and scope for the trading program will require broader categories. Therefore, the information system developed for the trading program should have built in room for expansion, creating a network of information that can freely cross cut regional and industrial boundaries.

2.7.5 Developing Emissions Tracking Software

The approach to emissions tracking currently in use relies on reporting from industries and inspections from SEPA and its subordinate agencies. The trading program will require that participating units be provided with CEM systems. Regulations concerning the two control zones also stipulate: key pollution sources in the zones are required to install CEM equipment as well as engage in long term monitoring. The next emissions tracking system will rely on the operation of the monitoring system and emissions data, including monitoring emissions data management and CEM technology trials. For the time being,

however, it is not possible to ensure that every participating unit installs CEM systems. There will still be a proportion of the industries that employ traditional monitoring methods.

Another related issue is that sometimes the monitoring systems will not be able to record and provide information or the systems may be inoperable. A missing data routine could be used to apply default emissions estimates when systems are down. Such a default should be conservative enough to provide an incentive for sources to keep their monitoring systems running as often as possible.

The emissions reporting software in use was developed for the traditional monitoring method whereby data is managed manually. The development of the tracking system will prioritize CEM data and consider how to apply the current reporting method when CEM equipment cannot be used. In addition, linking together the emissions tracking system and the allowance tracking system needs to be considered.

2.7.6 Adjusting the Current Emissions Reporting System and the Air Pollution Permit System

At present the historical emissions data and environmental goals determine total emission standards on permits. Though the permit system has not been implemented nationally, regional pilot programs have already been an important stage in the development of environmental management. In the event that total emissions standards and allowances are not consistent, then this will likely cause some difficulties for the environment. Therefore, the allocation of tradable allowance should agree with the current permit system, creating uniform standards and certification. The air pollution permits need to have appropriate adjustments made to ensure this compatibility.

The enterprise reporting and registration system, accompanying software, and reporting regulations have already been implemented nationally. Therefore, when setting up the emissions tracking system, it seems reasonable to adjust content in the current reporting system and software, excerpting what might be useful for the trading program and then linking the system to the allowance tracking system.

2.8 The Sulfur Dioxide Trading Program and the Pollution Levy System

The implementation of the SO_2 trading program must be coordinated with other policies and regulations that are already in force, such as the pollution levy system. The pollution levy system has many years of institutional history, and during this time, it has produced favorable results. In recent years, the levy system has been altered. On April 29, 2000, the Standing Committee of the Ninth National People's Congress clearly required in the *People's Republic of China Air Pollution Prevention and Control Law* that emission levies be based on total emissions as opposed to emissions concentrations. Against this

backdrop, the question emerges as to whether the levy contradicts the tradable permit program or whether they will be able to coexist. A related inquiry worthy of discussion is if they do coexist, how should they be coordinated so as to keep the overall social costs of running two programs within reason.

2.8.1 A Comparative Analysis of the Trading Program and the Levy System

Similar to the levy system, the trading program is a management tool that is based on reasoning in environmental economics. The aim of both the trading program and the levy system is to achieve total emissions control targets at a relatively low cost to society. Comparing the two systems to simple management methods (refers to command and control measures), both the trading program and the levy are more flexible. The flexibility stems from the fact that they provide the polluter with more decision-making autonomy, under the precondition that total emissions control targets are protected. If this precondition holds, then the levy system or the trading program can minimize social costs. Yet from a broader perspective, the levy system and the trading program are two distinct environmental economic regulatory mechanisms with unique characteristics that make them more appropriate in certain situations. To get a better appreciation for the differences, we will analyze these two approaches from a micro-economic perspective. Diagram 2-3 illustrates a rise in emissions demand, showing what happens with an increase from D to D'.

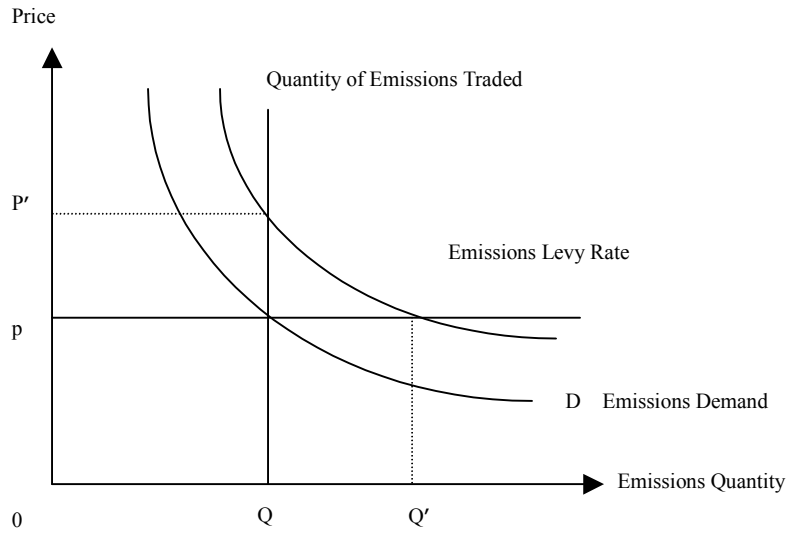

Diagram 2-3 Comparing the Emissions Trading Program and the Emissions Levy System

In implementing the emissions levy system, the emissions demand curve shown in Diagram 2-3 shifts right relative to the emissions levy rate. The levy price *P* does not change and the increase in emissions does not reach *Q*'. In implementing the tradable permit program, the emissions demand curve shifts up relative to the fixed emissions amount, causing the price of tradable allowances to increase from *P* to *P*'. The emissions quantity does not change. It is apparent from comparing these two systems that only the trading program can guarantee that total emissions do not change.

Table 2-15 Comparing a Emissions Levy System and Tradable Permit Program

	Emissions Levy	Tradable Emissions
Theoretical Basis	Using policies that impose relatively low social costs to meet environmental protection regulatory objectives (total emissions control targets).	
Purpose	Cause the marginal abatement costs of different pollution sources to converge to society's average marginal abatement cost, thereby minimizing pollution reduction costs.	
Applicable Scope	All sulfur dioxide emission sources. Among them the program will probably be more effective on small-scale sources such as low stack or surface-level sources.	Suitable for high stack sources with management standards. High-stack sources and low-stack sources should not be allowed to trade with each other.
Use	When marginal abatement costs fall below the levy standard or the allowance price, then the source carries out pollution abatement. Conversely, when marginal abatement are greater than the levy standard or the allowance price, then the source opts to pay the levy or purchase the pollution right; Promote the use of clean energy resources and adjustments in the resource sector	
	Create a revenue source for pollution control to initiate sulfur dioxide abatement projects	Generally does not have a revenue generating function; funds can be raised from auctions. Can raise the effectiveness of distributing abatement fees, lowering management costs. Can create incentives for enterprises to continue improving their emission reduction capabilities even after they are in compliance with standards.
Management Costs	The government is obliged to collect fees, which requires a significant investment of human resources. Requires accurate and consistent emissions measurement and reporting.	Management costs are relatively low. The government formulates related regulations and implementing standards, carries out mandatory inspections, and, once the trading program is complete, relies on the market to handle transactions. Requires accurate and consistent emissions measurement and reporting.

Determining Standards	The government determines levy rates based on the marginal abatement costs of pollution and environmental protection objectives. The level is not easily located since it is based on many factors.	The government determines the total emissions control target and the initial allocation of allowances. The market decides prices.
Implementing Conditions	Pollution source emissions monitoring; Formulation of levy rates.	Total emissions control standards and pollution source permits; Pollution source emissions monitoring; Compliance determination to ensure that each source has an allowance for each ton of pollution emitted.
Implementing Foundation	Each level of the environmental protection bureaucracy helps to build a comprehensive environmental management structure.	
	Already formed a complete set of laws and regulations; Already accumulated a considerable amount of experience, initially forming a set levy system and investment management structure.	Still dealing with the construction of a legal base and necessary regulations; Having a few difficulties in this regard; The total emissions control system and permit system are still incomplete. Having difficulties with inspections and supervision. The current market is still imperfect.

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The conditions under which the levy system is implemented are such that the government is responsible for determining the levy rate. In contrast, the trading program requires that the government stipulate a pollution emissions amount and related rules. The actual activity is trading between pollution sources and the market sets the allowance price.

Beyond this theoretical discussion, we can further integrate the current SO_2 control strategies, control policies, management methods, and management levels with China's conditions and motives for implementing the levy system and the trading program to make a more concrete comparison. The results of the comparison can be found in Table 2-15.

In comparing the two, the levy system, besides its definite use as a stimulus, can also raise comprehensive funds for prevention and abatement pollution investment, adjust the structure of the resource sector, and indirectly reduce SO_2 emissions.

Assuming that total emissions controls are in place, the tradable permit program possesses the greatest degree of flexibility, as exchanges of allowances are used to adjust costs. For example, it is not possible that all enterprises will have sufficient funds and technology to simultaneously improve their management facilities. If only a portion of the industries engage in pollution abatement projects, they can take part of their allowances and put them on the market. Other enterprises can purchase these allowances. The end result of this mutually beneficial exchange is total costs of pollution reduction fall.

The two mechanisms also differ with regard to their effectiveness on various pollution sources. For small-scale polluters, such as low stack and surface-area sources, adopting

a levy to gather funds for pollution prevention is more effective. High stack sources with large pollution loads usually have mature abatement technology that makes it easier to change management processes. Adopting a trading program would likely be more efficient for these sources.

From this comparison, we should note that implementing emissions trading requires that a series of necessary conditions be met. In particular, the program rests on the degree of market development, the level of environmental awareness among the enterprises, and the capacity of the government regulator to supervise and manage.

2.8.2 Can the Levy System and the Trading Program Coexist?

It is evident from the comparison above that the levy system and trading program are two different mechanisms with uniquely distinct features. The comparison also gives rise to two pivotal questions: when implementing a SO_2 trading program, is a levy system needed? Should current pollution sources be granted tradable allowances without providing compensation (new sources are another consideration)? We propose three scenarios that will allow us to explore these matters in greater detail. The first scenario is that while implementing the trading program, a levy system cannot be implemented and pollution sources must pay a fee for their allowances (note that this scenario runs contrary to legal reality. China's laws require the imposition of a pollution levy so this proposal is only a hypothetical). The second scenario is that while implementing the trading program, a levy system cannot be implemented and pollution sources are granted free allowances. The third scenario is that both the trading program and the levy system are implemented simultaneously.

We offer Jia, Yi and Bing, three pollution sources of similar types and magnitudes. Based on the previous analysis, the average abatement cost to society of each ton of SO_2 is 1,000 yuan. Jia, Yi and Bing's situations are illustrated in the table below.

Table 2-16 Hypothetical Cases

	Jia	Yi	Bing	Total (rows 1 and 3) Average (row 2)
Amount of SO_2 emitted per source	100	60	40	200
Reduction cost for each ton of SO_2 (yuan)	1200	1000	800	1000
Quantity on allowance	60	60	60	180

The Table shows that Jia's number of allowances falls below his actual emissions, Yi's number of allowances is equal to her actual emissions, and Bing's number of allowances is greater than her actual emissions. At this time, Jia has four options: he can reduce production, change fuel types, purchase and install abatement equipment, or purchase

allowances from Bing. The goal of industry is to maximize profits, so we assume that more often than not Jia would select the most economical choice.

The first scenario: The two programs are not implemented simultaneously and sources are required to pay a fee for allowances.

To set the costs of each allowance take (a)—the low-end limit that Bing would be willing to sell an allowance—and 1,200—the high-end limit that Jia would be willing to buy an allowance—and add (b)—the transaction cost. Every unit exchanged between Jia and Bing will fall in the range [a+b; 1,200-b]. In the event that Jia thinks the allowance price is too high, he can choose to install abatement equipment or reduce production.

Assume that Bing has no buyers for her surplus allowances. If Bing emits 40 units of pollution, then the cost of each unit of pollution is 1.5(a). If Bing emits 60 units of pollution, then the cost of each unit of pollution is 1(a) and the cost of each ton of pollution emitted decreases.

The influence on Yi is minimal.

Strengths

The allowance granting agency acquires a x 80 in funding that can be used toward pollution management and abatement.

Motivates pollution sources with low abatement levels to reduce their pollution.

Weaknesses

The low-level limit at (a) with the added transaction cost (b) shrinks the range within which allowance transactions might occur.

For sources that have abatement costs equal to the average abatement costs of society there is no incentive to reduce pollution.

The second scenario: The two programs are not implemented simultaneously and sources are granted allowances for free. Because allowances are allocated freely, the transaction range for every unit of pollution is quite large [b; 1,200-b].

Strengths

The range of possible exchange prices is quite large, allowing the parties to the transaction to realize the full benefits of the transaction.

Weaknesses

In situations when pollution abatement funds are scarce, there is no way to collect the needed funds for environmental protection purpose in a country where the budget is very limited.

If allowances are granted for free and there is no levy system, enterprises can devise ways to contest allocation decisions, causing the costs of allocation to increase.

The third scenario: The trading program and the levy system are implemented simultaneously. Allowances are granted for free, but levies are assessed on actual emissions. Because the allowances are allocated free, the range in which transactions between Jia and Bing occurs is sizable [b; 1,200-b]. Meanwhile, a reasonably set

emissions fee encourages sources to upgrade their pollution abatement technology. The greater the potential reduction from this technology, the greater the savings to the pollution source. This is the commonly cited rule that levies can build incentives for technological innovation.

Besides these advantages, the levy system has the added benefit of improving the economic efficiency of the pollution source. On the one hand, the pollution source has the incentive to increase its management efficiency with technological improvements because these upgrades cause production costs to drop and increase marginal net benefits. On the other hand, the more efficient use of natural resources means that pollutants generated during production and emissions begin to decline. The end result is the efficiency gains realized in the early phases of production affects the pollution reduction burden in the later phases, causing the marginal costs of pollution abatement to fall.

The integration of a trading program and a levy system will help gather needed revenue, compensate for environmental degradation, collect abatement funds for pollution sources, and realize total emission control targets. At the same time, exchanges between different pollution sources will allow the system to adjust itself as necessary, lending it an even greater degree of flexibility. To show how the two systems might work together, suppose in a given year Yi has acquired funds to build abatement facilities (the funds come from the levy system). The facilities reduce 50 percent of Yi's total emissions. Yi can sell the 30 units of allowances that she has acquired due to the 50 percent emissions reduction and Jia can purchase Yi's allowance because they are cheaper than what it would cost him to reduce his own emissions. Through these transactions, both Jia and Yi are made better off and the total costs to society of emissions reduction is lower.

Furthermore, because the trading program increases flexibility and reduces abatement costs, it is likely to be attractive to those sources that have not entered the program and can create an incentive for them to participate.

Strengths

The range on possible exchange prices is quite large.

If the levy rate is set reasonably, then it can encourage sources to reduce pollution. (In this scenario the levy should be set relatively low so as not to compete with the economic incentive signal from the emissions trading program (See Ellerman paper).

Pollution sources can raise their level of economic efficiency.

The revenue collected from the levy system can be used for pollution abatement and the construction of cleanup facilities.

The costs of pollution reduction to society decreases.

There are incentives for sources to enter the trading program voluntarily.

Weaknesses

The levy system causes management costs to rise.

From the above comparison, it is evident that the trading program is not capable of

replacing all of the function of the levy system. Having the two in place simultaneously offers the greatest benefits. This view is elaborated in Part 4.

Is There a Conflict Between the Rules for the Current Levy System and the Trading Program

China has already implemented the levy system for emissions that exceed standards, developed a levy for SO_2 emissions in the two control zones and gradually begun the transition to levies imposed on total emissions. China has also piloted trading programs in a few key cities. The implementation of either trading or levies involves several conditions and a strong management base. Because China is still in the process of economic reform, its market is imperfect, the pressure on the environment is growing, and interregional variations in implementing conditions are considerable. At the same time, China has many interwoven policies, laws, and regulations. Given these various forces, it is difficult to determine whether levies or trading better suits China. Using both simultaneously provides the best hope that each system's strong points will compensate for the other's respective weak ones.

2.8 Other Problems

Putting a trading program in place gives rise to other previously unmentioned issues such as market construction and market development strategy as well as publicizing and educating others about the trading. This section will carefully explore these issues.

2.8.1 Market Construction

The key actors in a market are buyers, sellers, and an intermediary that brings them together. In the SO_2 emissions market, the buyers are those that have a demand for a SO_2 allowance and the sellers are those that have an allowance to sell. At the outset, the environmental management department can play the intermediary role. As the program matures, it is possible to establish a specialized market for SO_2 emissions trading, which, similar to today's stock exchanges, would operate free of intermediaries.

Market Development Strategy

The difference between a SO_2 emissions market and markets for other products is that the emissions market is government-made. Hence, in the process of cultivating the market, it is necessary to formulate market development strategies and methods that lead to correct market construction. To create this institution quickly and accurately and to ensure that trading program is implemented smoothly, adopting a step-by-step strategy is advisable.

In the initial stages of building the tradable market, the market participants lack a

sufficient understanding of market functions and prices. At this point, confusion and disputes can easily create problems. Consequently, in the early stages, trades should be carried out under the leadership and supervision of the environmental management department. The emissions market is in reality kept under the watchful eye of the government. This is beneficial for setting up the market and beneficial for adopting remedial measures promptly to correct any problems that might surface as the market is established.

To illustrate how the market may work in the early period, take two pollution sources that have completed negotiations on a transaction. These sources must report the quantity, timing and price of the transaction to the trading management department. The trading management department then requests that the two parties prepare relevant documents and forms. After the department investigates and verifies the trade, the transaction can go forward. During this period the management department is playing the role of a market administrator, being deeply involved in the activity, and the market is incomplete.

While the presence of the environmental management agency restricts the market, it is also an important step for establishing a free-market base. Within a certain period of time after the market has received this management support, pollution sources should have a firmer a grasp of the trading process, rules, and prices. It is at this juncture that the government can gradually ease its way out the direct management role and play a more indirect role. Participants can begin to freely engage in trades, and the market itself can begin to evolve into a more complete institution.

Market Management

Managing the emissions market is still the responsibility of the management department. In fact, a management group that specialized in SO_2 emissions trading could be designated to handle management of the market. This group would be a branch of the environmental protection department. The group\up would initially act as the primary location where purchases and sales of allowances were performed, post continuous information on the allowances bought and sold, and verify the status of parties involved in the transaction.

After the market developed to a certain extent, the environmental management department could then allow intermediaries to enter into the process. For a commission, the intermediaries could provide specialized allowance transaction services, help sources hoping to trade allowances locate a compatible purchasing partner, and assist with other trading formalities. Once the market had developed, the intermediaries could directly participate in the buying and selling of allowances, becoming a fully independent, profit-making entity.

To strengthen management, all intermediaries must register with the environmental management department. The extent of the intermediary's involvement hinges on the

simplicity of market procedures, how much time and money they can save participants, and the overall cost reductions from trading. Regardless of whether they play a big or small role, intermediaries must carry out activities under the unified management of the environmental management department. The environmental management department should clearly spell out their scope, put in place concrete regulations and establish comprehensible business norms.

2.8.2 Public Outreaching and Training

SO_2 emissions trading represents a new stage in pollution prevention, involving numerous aspects of environmental management. The notion of emissions trading has a deeply established theoretical basis and has several powerful technical elements. In China, although a few places have experimented with trading, the extension and the implementation of the program has been difficult. Therefore, in the early implementing stages, there needs to be efforts to increase the public as well as relevant personnel's awareness of the program.

Publicity

The purpose of publicizing the tradable permit program is to get the public and social groups acquainted with the program, helping them to understand the program's basic principles and motivations, as well as getting them to grasp the procedures, methods and rules associated with trading. The broader the support from the public and other groups, the more involved the public will become in supervising trades and exchanges.

As for generating popular understanding, relying on the television, radio and the newspaper news media is arguably the most effective method. Special programs could be made and articles could be written to discuss issues pertaining to emissions trading. Another important venue for creating publicity is the Internet. A Web page, aside from introducing general background information, should be developed with specialized properties, so that when the trading program is actually being implemented all relevant information could be posted there.

Publicizing the program is not just important for the general citizenry, it is also important because information needs to reach polluting enterprises and different levels of the bureaucracy. These units and departments are direct participants in the program, and they must have a very clear understanding of the program. Their appreciation of the technical and theoretical details of the program must be deeper than the general public's if the program is going to be able to expand its range of influence.

In light of these varying publicity needs, different forms of information could be disseminated. SEPA could author a book on trading that would be distributed to enterprises and government agencies. Other informational materials could have content

with fewer specifics for the average reader. This material should include an introduction to the basics of the program, an explanation of the program's basic rules and technical methods, and the foundation that is being laid for future implementation plans.

Training

Compared to publicity, educational efforts are even more specific in their intended audience. The chief targets of these efforts are the enterprises participating in the program and government agencies that are directly responsible for the program. Because the regulators and regulated are different, two distinct educational programs should be designed. The first should be focused on government personnel. The second should concentrate on participating enterprises.

As for training of environmental management personnel, content should consist of the basic theory behind emissions trading, trading procedures and trading management techniques. National environmental protection personnel that are involved in the trading program, provincial personnel that are involved in the program, and relevant personnel from the power sector should receive this training. The training should be organized into concentrated classes where environmental experts from the U.S. and China discuss pertinent subject matter. The lectures should specifically include exercises with management software and allow the trainees to engage in automated sample trading scenarios.

As for the training of enterprise officials, initial efforts should be concentrated on power plants in the two control zones. One or two representative(s) from the plants should attend two sessions. The content of these sessions should focus on the actual implementation process, trading rules, and trading technology. While experts from the U.S. should conduct a small portion of the instruction, the majority of instruction should come from Chinese experts. The Chinese experts should design implementing details that are specific to the two control zones and allow the trainees to engage in automated trading scenarios.

Through publicity and training, the hope is to build the kind of strong social foundation and accompanying reserve of technical understanding that will facilitate the implementation of SO_2 emissions trading in China. This local knowledge will be crucial as China prepares for emissions trading in the two control zones and beyond. As the program is implemented, new problems may arise calling for new policy solutions. It is also feasible that there might be changes in industry personnel. Thus, training should be carried out intermittently so that the program continues to evolve with China.

3. Conclusions

The Chinese Government currently faces a sizable challenge in the effort to reduce

total emissions of SO_2, mitigate the harm caused by acid rain, and improve air quality. Introducing an SO_2 emissions trading program has been the central issue in this paper because it promises to help China realize these goals. The analysis above reaches the following conclusions concerning the feasibility of implementing SO_2 emissions trading in China.

3.1 The Threat from Sulfur Dioxide Pollution and Acid Rain

In 2000, the total emissions amount of SO_2 nationwide reached 19.95 million tons. Acid rain has grown from a largely regional problem centered in Southwest China during the 1980s to an interregional problem that now spans south of the Yangtze River and east of the Qinghai-Tibet Plateau. Approximately 70 percent of the southern cities receive some form of acid rain, while the area with an annual average pH value lower than 5.6—the threshold for acid precipitation—accounts for approximately 30 percent of China's total landmass. Combined these figures mean that China has become one of the three largest acid rain regions in the world.

Acid rain and the emissions that cause acid rain can impose serious harm on human health and visibility as well as the ecosystem and physical infrastructure. According to experts' estimates, the total economic loss stemming from SO_2 pollution and acid rain totaled 110 billion yuan (approximately $13.3 billion) in 1995, close to 2 percent of China's GNP that year.

3.2 A Series of Measures Taken for the Control of Sulfur Dioxide Pollution

The Chinese government at the central and local level has attached great importance to the control of SO_2, and has adopted a series of measures to arrest the problem. These measure include, but are not limited to, the designation of "two control zones" (for acid rain and SO_2), implementation of "one control and two compliance" action, and collection of a pollution levy fee on SO_2 emissions. In addition to these macro-measures, some regulations in China have also advanced specific requirements on the control of SO_2 emissions and pollution. For instance, the "Air Pollution Prevention and Control Law" stipulates that those newly-built or expanded thermal power plants and other large- and medium-sized enterprises that emit SO_2 have to be equipped with corresponding desulfurization and dust reduction facilities or take other measures to control the SO_2 emissions and dust when the pollutants they emit exceed the stated emissions standard or the total emissions control target. Within the "two control zones," the enterprises have to treat the air pollution they produce within a deadline according to the requirements laid out by the State Council if the air pollution emitted from these enterprises exceeds the required emissions standards or the total emissions control target. China has also

formulated a set of technology policies related to SO_2 emissions, such as restricting the exploitation and use of high sulfur-content coal, coal washing and dressing, and desulfurization.

3.3 Economic Instruments Encouraged for Controlling Sulfur Dioxide Emissions

Effectively controlling SO_2 emissions requires comprehensive and coordinated policies, especially policies that use economic incentives. China has already begun to employ these incentive-based policies in many areas. For instance, China collects a pollution levy fee on SO_2 emissions within the “two control zones” at a rate of 0.2 yuan per kg. Although the charge is rather low and this frustrates its ability to encourage polluters to reduce SO_2 emissions, the pollution levy policy still is important in that it signifies China has considered using economic instruments to cut down SO_2 emissions. Another economically driven policy is the preferential treatment China gives to investments in energy saving and SO_2 control.

3.4 Total Emissions Control of Sulfur Dioxide Emissions Provide a Basis for Sulfur Dioxide Emissions Trading

China’s “Tenth Five-year Environmental Protection Plan” clearly establishes a total emissions control target for SO_2 during the tenth five-year period. The plan calls for a 10 percent reduction in total load of SO_2 emissions at the national level in areas outside the “two control zones” and a 20 percent reduction in the “two control zones.” Both cutbacks use the year 2000 total emissions level as a baseline. To realize these reductions, SO_2 total emissions control targets have been allocated down to provinces and cities. But realizing these regional targets with minimum social cost poses some as of yet unresolved issues. The primary sticking point is how to allocate the total load down to individual pollution sources and how to finalize the effective reduction in SO_2 emissions and supervision. The implementation of a SO_2 emissions trading program will hopefully clear up some of these issues.

3.5 Awareness on SO_2 emissions trading program

In addition to the strides made in environmental management and the steps made to improve market conditions in China, awareness of emissions trading is growing. Early in 1994, China’s then National Environmental Protection Agency (NEPA) selected six cities to pilot air pollution emissions trading, piggybacking the project on a 16 city trial implementation of air pollution emissions permits. The trading pilot helped to explore both the conceptual issues relevant to trading and the operational methods needed for trading.

However, due to the lack of a firm managerial base and the absence of supporting policies, it was difficult to spread the experiences gained in the pilot cities to other cities. But now the situation has changed markedly. Total emissions control, improved management capacity, a maturing market and requirements on environmental quality all seem to suggest China should formally embrace emissions trading.

3.6 U.S. Experiences with Sulfur Dioxide Emissions Trading

The U.S. has implemented SO_2 emissions trading and reaped significant gains from the program in terms of both cost savings and pollution abatement. China might have something to learn from the United States. Perhaps the most valuable lessons are the following: (1) the cap is an effective tool to achieve significant levels of emission reductions; (2) trading is an economically efficient policy to reduce SO_2 emissions at lower costs; (3) SO_2 cap and trade programs are most affordable to large scale emissions sources with a wide range of marginal control costs and large sources tend to be easier to monitor accurately and consistently; and (4) sufficient supervision and management instruments like emissions and allowance tracking systems as well as compliance and enforcement programs need to be in place. There are, of course, some noteworthy differences between China and the U.S. China's economic and policymaking systems are unlike those in the U.S. China is several steps behind the U.S. in pollution control technologies, environmental management, and market development. Thus, these differences must be taken into consideration when introducing SO_2 emissions trading in China.

3.7 Lacking the Support of Powerful Laws and Regulations

The basis of emissions trading is the right to emit. Only when the right to emit has been unambiguously defined is it possible to implement emissions trading. In 2000, China revised its air pollution prevention and control law, clearly defining the total emissions control policy for air pollution. The law also requires that local governments within the total emissions control zones for air pollution, in compliance with the conditions and procedures stipulated by the State Council, inspect and verify the total load of major air emissions from enterprises and institutions, and grant a permit for the major air emissions to these enterprises and institutions, based on the principles of openness, fairness, and equity. Provisions in related laws go further in establishing this right via the creation of pollution permits. The acquisition of an emissions permit gives the enterprise the *de facto* right to emit pollutants and forms the foundation of emissions trading.

Emissions trading relies on market mechanisms to choose optimal pollution treatment methods, thereby ensuring the realization of environmental protection targets at the lowest

social cost. China's current air pollution prevention and control law does not directly prescribe the application of emissions trading, but it indirectly suggests using economic and technical measures to control air pollution. The indirect mention of economic measures implies that it is possible to employ emissions right trading. However, there is a lack of explicit legal provisions regarding emissions trading in the new law. Emissions trading is both an economic measure used to realize the total emissions control policy as well as an economic activity itself. Its success is contingent on many factors, such as the identification of total emissions control targets, allocation of total emissions control targets, establishment of a market, creation of trading rules, supervision and management, and punishment for infractions. Without explicit legal and regulatory provisions covering these areas, emissions trading is extremely difficult to apply.

3.8 Supervision and Management

An SO_2 emissions trading program requires the accurate measurement of emissions and tracing of the emissions process. At present, China has in place an emissions declaration and registration system and conducts supervision-based monitoring. But, if China wants to satisfy all the requirements in the management of SO_2 emissions trading, a significant gap still exists between theory and practice. The U.S. experiences suggest that pollution sources participating in trading program be outfitted with automated SO_2 emissions monitoring equipment. Due to the large number of SO_2 emissions sources in China, it is difficult to imagine China installing this type of equipment over a wide area in the near future. China needs to continue contemplating what might be the best way to supervise emissions sources in light of these obstacles. The most important aspect of emissions measurement is that the method is as accurate and consistent as possible. There will likely be a transition phase with emissions measurement that includes some sources using existing mass balance estimation methods and sources that are able will use CEMs. Careful attention will be paid while we work through these important program details.

3.9 Pilot and Implementation

As of now, China has some of the necessary elements for trading in place, but the dispersion, variety, and multitude of small pollution sources make it nearly impossible to envision creating a comprehensive program spanning all sources in the short term. Therefore, the focus of SO_2 emissions trading should be placed on large emissions sources in major pollution areas. The report recommends that the development of emissions trading program be divided into four stages: (1) during the introductory pilot stage the scope of emissions trading should be limited to large scale power plants (annual

SO_2 emissions exceeding 5000 tons and/or 600 MW) in the “two control zones”; (2) on the basis of the pilot results, the trading program should be extended to all the power plants in the “two control zones”; (3) the trading then can be extended to all the power plants in China; and (4) finally trading can cover all other types of elevated sources.

3.10 Coordination of various policies

Developing an SO_2 emissions trading program is a systematic process involving a complex array of issues. One of the issues is to blend the program with existent command and control instruments, economic instruments, and related management regulations. If China is to create a truly comprehensive system to reduce SO_2 emissions, another area in need of redress is how to integrate the trading program with other systems, such as the pollution permit system, pollution levy system and emissions standards.

In summary, China currently possesses the necessary conditions for application of SO_2 emissions trading, but a considerable amount of work still needs to be done. When China adopts a trading program, it should be focused initially on major pollution sources, phased in gradually, and aimed at combating acid rain in the regions that the problem is most serious.

Following are the summary of the Results from the Feasibility Study for SO_2 Emissions Trading in China:

Table 2-17 Feasibility Analysis for SO_2 Total Emissions Control Target

Factor for Consideration	Current Status	Legal or Regulatory Basis	Existing Problems
1. SO_2 Total Emissions Control target	During the “Ninth Five-year Plan” period, China implemented the total emissions control policy for SO_2 emissions; The total emissions control target for SO_2 emissions in the “Tenth Five-year Plan” has been established. Using the year 2000 as a baseline, the total emissions control of SO_2 emissions at national level will be reduced by 10 percent and by 20 percent within the “two control zones.”	“Air Pollution Prevention and Control Law” stipulates: the total emissions control should be implemented in the “two control zones” and the regions where the environmental quality has not reached standards. There is a clear legislative requirement supporting the implementation of the total emissions control of SO_2	

		emissions.	
2. Allocation of SO_2 Total Emissions Control target	The total emissions control target for SO_2 emissions has been allocated down to each province and most cities; Some cities have allocated the total emissions control target down to individual pollution sources.	The legal basis for total emissions control is the same as above; Provisions are in place concerning the allocation of total emissions control target down to individual pollution sources, and the emissions permit in "air pollution prevention and control law."	How to link the national total emissions control target with the local targets; Allocation of total emissions control target down to the total emissions controlled regions and uncontrolled regions; The total emissions control target has not been integrated with regional environmental quality.
3. Distribution of Total Emissions Control quota to each pollution source	Some of the pollution sources have been allocated a total emissions control quota of emissions and granted emissions permits; A large majority of total emissions control target has not been allocated and distributed to individual pollution sources.	Clear regulatory requirements are in place.	Lack of unified, scientific and reasonable allocation method; The primary techniques used to create total emissions control quotas are based on the concentration emissions standards. Lack of authority over the allocation of quotas; Lack of effective supervision.
4. Foundations for SO_2 emissions trading program	Emissions trading program was piloted in 6 cities in 1994, and the concept of emissions trading has been tested; At present, some cities are trying to implement SO_2 emissions trading.	There is a lack of a firm legal basis at the national level; In some cities, there is already legislation for total emissions control and emissions trading.	Need specific legislative basis for the program; The decision makers should have a clear understanding of their roles in emissions trading.
5. Scope of SO_2 emissions trading program	China is preparing an SO_2 emissions control program in the "two control zones"; SEPA is cooperating with the State General Power Corporation in formulating a plan for SO_2 emissions reductions in the power		How to select the regions for emissions trading; Coordination between the national-level target and the regional-level

	sector.		target; Coordination between the emissions reduction in a certain sector and the total emissions control in the region where the sector is located.
6. Measurement and supervision of SO_2 emissions	The emissions declaration and registration system have been established; A statistical database tracking pollutants has been established; Supervision-based monitoring mechanisms have been created.	There are clear legal requirements on the emissions declaration and registration system; There are strict monitoring criteria.	Lack of legal data calculation methods for monitoring; Poor quality of the data; Limited coverage of the data (there is virtually no data for smaller pollution sources and domestic area sources).
7. Automated monitoring system for SO_2 emissions	Only a few power plants in the power sector have installed CEMS; The monitoring criteria for the power sector stipulates that newly-built power plants be equipped with CEMS; SEPA and local EPBs are strengthening the monitoring on emissions from pollution sources, and encouraging the installation of CEMS in larger areas.		Technological standards are not unified; Input is great; The existing automatic monitoring data has not been effectively used, which limits the development of CEMS.
8. Tracking system for Total Emissions Control quota	The management system for pollution sources has been established at the local level; Database for emissions declaration and registration system has been put in place at national and local level. Some cities are planning to establish tracing system for emissions; Periodic monitoring and supervision on pollution sources has become a regular activity.		Real-time supervision of actual emissions from pollution sources cannot be carried out yet; Most data is obtained based on mass balance techniques.
9. Creating a market for emissions	Some cities have experiences in the paid transfers of emissions permits; Chinese enterprises are familiar	There is no related legislation at the national level; In the local	Lack of detailed operational rules; Need to formulate management

trading	with markets.	regulations of some cities, there is a provision for implementing paid transfers of emissions permits.	methods for the emissions trading system.
10. Coordination with other policies	Similar economic instruments, such as the pollution levy system for SO_2 emissions; Coordination between the national-level total emissions control and local environmental quality; Coordination between the management of the involved and noninvolved pollution sources in the trading program	The pollution levy system has been codified in existing laws and regulations.	The relationship between pollution levy system and emissions trading program should be clarified. The reforms in pollution levy system and establishment of emissions trading program should be coordinated fully.

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PART THREE:

CASE STUDY ONGOING SO_2 EMISSION TRADE IN TAIYUAN CITY

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1. Background

In 2000, the SO_2 emissions in Taiyuan City were 250,000 tons. Annual daily-averaged SO_2 concentrations were 0.2mg per meter^3, far higher than the Class II national ambient standard of 0.06 mg per meter^3. The city is thus one of the most polluted cities in China and even in the world. To improve the urban air quality, the *Outline of Economy and Social Development Plan of Taiyuan City in the Tenth Five-Year Plan Period* points out that by 2005 the use of high-quality, low-sulfur coal should reach 9 million tons and SO_2 emission be controlled within 125,000 tons. By the end of the "Tenth Five-Year Plan" period the annual daily-averaged TSP, SO_2 and NO_2 concentrations in the city should all meet Class II ambient air quality standards, and the number of days with air quality being the same or better than Class II should be more than 70.9 percent. This is not only a commitment of the city Government to the people, but also a demand of socioeconomic development as well as a guarantee of people's healthy life in the city.

This means that in the five years from 2000 to 2005, SO_2 emission in Taiyuan City will be reduced by at least 50 percent, or 125,000 tons. If calculated at a cost of 1,500 yuan per ton of SO_2 reduced, the total cost will be around 190 million yuan. This cost is undoubtedly a heavy burden for Taiyuan City. It is also a huge environmental challenge for the City.

Under the technical assistance of Asian Development Bank and with technical support from U.S.-based Resources for the Future (RFF) and the Chinese Academy for Environmental Planning (CAEP), Taiyuan City started and established an SO_2 emissions trading program in an effort to realize SO_2 emission reduction targets with least costs. According to the U.S.'s successful experience of implementing SO_2 emissions trading,

emissions trading has the potential to reduce total SO_2 reduction costs by over 30 percent. Therefore, the implementation of SO_2 emissions trading can help realize the total SO_2 emissions control target of Taiyuan City for the "Tenth Five-Year Plan" period with the least cost, so as to reduce health effects and realize integrated development of the economy and the environment.

2. Design of Emissions Trading Framework

Considering the features and requirements of the city, the SO_2 emissions trading in Taiyuan City adopts the "Cap and Trading Model," (i.e. SO_2 allowance trading under total emission control.) The design of an emissions trading framework mainly includes two issues: strategic elements and management elements.

Strategic elements mainly consider the expected environmental objective, the applicable scopes of emissions trading, and the allocation methods of allowances. The objective of implementing SO_2 emissions trading in Taiyuan City is to reduce the SO_2 emission of the city by 50 percent. The government has identified 26 enterprises to participate in SO_2 emissions trading program. These enterprises' SO_2 emissions accounted for over 50 percent of the whole city's SO_2 emissions in 2000. These enterprises are thus key control sources of SO_2 emission. At the same time, they have sound basis of environmental management, facilitating implementation of a trading program. Considering the actual situation in Taiyuan City, the allowances are allocated among the first batch of enterprises at no charge. But new sources in the "Tenth Five-Year Plan" period must purchase allowances from the market. Only after the emission allowances are re-allocated, can these enterprises obtain the allowances through the market.

The management of emissions trading mainly includes monitoring of enterprises' SO_2 emission, checking reports, allocating allowances, and managing trading. The management elements are the core design of the emissions trading program. The management elements of SO_2 emissions trading in Taiyuan City are described in detail below.

3. Allocation of Allowances

The allocation of SO_2 emission allowances in Taiyuan City uses historic data. The allocation of SO_2 emission allowances for the next five years is based on historic emission of the individual enterprises. It involves three aspects: identification of emission targets, base year emissions, and annual abatement schemes.

The identification of emission targets of various sources should abide by the following principles:

- The necessary abatement by 2005 is not less than 50 percent of that in 2000.
- For key SO_2 treatment enterprises identified by Taiyuan City environmental protection plan in the "Tenth Five-Year Plan" period, if the planned values of emissions limit are lower than 50 percent of that in 2000, the planned values are used.
- If the emissions stipulated by objective responsibility statements of environmental protection in 2001 are less than 50 percent of those in 2000, the control targets in 2005 should be 20 percent lower than those in the 2001 objective responsibility statements.

Identification of base year of emission:

- For enterprises having been listed for environmental protection objective responsibility examination in 2001, the values in 2001 objective responsibility statements are used.
- For enterprises not listed for environmental protection objective responsibility examination, the emission values in 2000 reporting are used.
- For enterprises with 2001 objective responsibility statements already less than 50 percent of 2000 values, the permitted emissions in 2001 objective responsibility statements should be abated by 5 percent year by year from 2001.

Identification of yearly abatement schemes:

- From base year to target year, the equivalent abatement is pursued among years.

The SO_2 emission allowances of individual sources from 2002 to 2005 will be issued to the sources with specific forms. Once the allowances are issued, the sources must strictly abide by them. If some SO_2 sources are substituted due to reasons such as central heating, the city environmental protection bureau (EPB) will re-examine their emissions and re-issue the allowances for the next years.

4. Monitoring and Checking of Emissions

Accurate measurement of SO_2 emission is one important component for successful implementation of an emissions trading system. There are currently about 15–50 sets of CEMs for SO_2 monitoring in Taiyuan City. In addition, it was planned that the number of CEMs would increase to 100 by the end of 2001, and to 200 by the end of 2002. All these CEMs are to be connected to the central monitoring station. Taiyuan City EPB is establishing a central database of CEM data that can be put into use in the fall of 2002. In spite of this, due to differences among enterprises and other limitations, the installation of CEM equipment may still not meet the requirements for implementing emissions trading. Therefore, some other auxiliary methods to estimate SO_2 emission, such as material

balance, can be adopted during implementation of trading.

For the enterprises with CEMs installed, checking emissions mainly consists of calibrating monitors and verifying measurement. This should be conducted by the environmental protection department and the technical supervision department in accordance with national requirements. For checking emissions using the material balance method, there are several options: (1) the Taiyuan City air quality monitoring system can provide data for verifying emissions (the Taiyuan City Environmental Monitoring Center currently performs monitoring for key sources once a quarter); (2) the self-measurement data in qualified enterprises should also be regarded as basis for emission checking.

In order for the enterprises to better report the emissions and for the administration to verify them, RFF and U.S. EPA have developed a computerized emissions tracking system for Taiyuan City to facilitate the enterprises' reporting of emissions and the environmental management department's data management.

5. Management of Trading

The management of SO_2 emissions trading in Taiyuan City is mainly realized through an "*Emission Tracking System*" (ETS) and "*Allowance Tracking System*"(ATS), both of which are based on Microsoft Access and developed by U.S. EPA. ETS is mainly used for enterprises' reporting emission data and the EPB's checking of reported data. ATS is mainly used for the EPB to supervise and manage allowance trading.

The data required by ETS for enterprise emissions comes from three sources: material balance, self-monitoring, and EPB monitoring. The enterprises mainly fill in data forms of material balance, including production situations, coal use, change of coal stock, sulfur content of coal, and other data with a close relationship to SO_2 emissions. The enterprises report the data to the EPB every month and the EPB checks the data to guarantee accuracy.

The management of trading is mainly tracking on allowances. In ATS, the EPB sets up emissions accounts for each participating enterprise to track changes in their number of allowances . The trading is voluntary but all transfers must be recorded by the EPB. The EPB publicizes the trades of allowance transactions, compares the allowances with the allocated values, and punishes those enterprises whose emissions exceed the allocated values.

6. Administrative Regulation

The guarantee by a regulation is the basis of implementing SO_2 emissions trading. In the design of SO_2 emissions trading mechanism in Taiyuan City, experts from RFF and

CAEP assisted the EPB in drafting the *Administrative Regulation for SO_2 Emissions Trading in Taiyuan City*, which should be the basis for SO_2 emissions trading in Taiyuan City. From December 2001 to January 2002, the Project Expert Group discussed the draft version of the regulation with the Taiyuan City EPB and Bureau of Legislative Affairs. Several revisions were made for comment by provincial and city governmental leaders and related departments in mid 2002.

The *Administrative Regulation* consists of seven sections:

(1) Identifying Taiyuan City EPB as the supervising institution for SO_2 emissions trading and stipulating that the participating enterprises are not exempt from other environmental protection responsibilities.

(2) Stating the allocation methods of allowances for each enterprise in each year during the "Tenth Five-Year Plan" period. New sources must obtain the allowances through purchases.

(3) Obviously stipulating the trading and deposit of allowances. At the end of each year, any emission allowances held by the source in excess of its actual emission can be banked for future use or sold to other sources. The trading prices are based on bilateral negotiations according to market situations.

(4) Stipulating an auction of allowances by Taiyuan City EPB. The auctioned incomes are to be used for improvement of environmental quality in Taiyuan City.

(5) Supervision and management of emissions trading. The data on SO_2 emission and trading will be managed by the newly developed ETS and ATS. In order to encourage compliance with standards, the punishment on emissions in excess of allowances must be higher than the cost to treat SO_2.

(6) Legal liabilities, which stipulates the punishment rate for emission of one ton SO_2 in excess of the allowances and the legal liabilities of enterprises.

(7) Stipulating the implementation period and the method to formulate implementation rules of the *Administration Regulation*.

The *Administrative Regulation* is China's first local legal document on emissions trading. It has opened a new page in for implementing emissions trading in China.

7. Implementing Plan

The formal approval of the *Administrative Regulation* by the city Government should play a determinative role in implementation of SO_2 emissions trading in Taiyuan City. After the formal approval, the emissions trading can be initiated throughout Taiyuan City.

According to the project implementation plan, from September to December 2002 after the formal approval of the *Administrative Regulation*, Taiyuan City will organize 16 enterprises to perform a series of demonstration trades in accordance with the

Administrative Regulation. A series of trainings for participating enterprises and environmental management departments will also be held. These efforts will strengthen the enterprises' understanding of emissions trading and the capacity building of environmental management departments.

As designed by the trading program, the formal implementation of the *Administrative Regulation* will begin on January 1, 2003. By then, all the preparations for SO_2 emissions trading will have been accomplished and the emissions trading will go into the essential implementation phase. After some period of implementation, experts will evaluate the program and propose suggestions for further improvement. Currently, Shanxi Province has been identified as a pilot province for implementing SO_2 emissions trading in China. The pilot work in Taiyuan City on SO_2 emissions trading will provide very good ideas for the whole province to borrow from. It can also provide precious experience for other provinces and cities in conducting SO_2 emissions trading.

PART FOUR: TECHNICAL ANALYSES

DESIGNING A TRADABLE PERMIT SYSTEM FOR THE CONTROL OF SO_2 EMISSIONS IN CHINA

A. Denny Ellerman (Massachusetts Institute of Technology)[24]

1 Introduction

As China's economy has grown, atmospheric pollution has become a greater problem and a matter of increasing concern to policy-makers at all levels of government. One of the principal pollutants has been SO_2, which is emitted in varying intensity when coal, China's most abundant energy resource, is burned without emission controls. Excessive SO_2 emissions can cause serious health problems, when ambient concentrations are high, and non-health related damages from acidification often at some distance from the source of emissions.

In recent years, Chinese environmental authorities have expressed interest in the use of tradable permits as an instrument for the control of SO_2 emissions. This interest arises from the greater priority placed on controlling pollutants in China, the successful use of tradable permits to reduce and limit SO_2 emissions in the United States, another large country in which coal use is significant, and the increasing attention given throughout the world to the use of market-based instruments as a means of achieving environmental objectives. Moreover, the least-cost property of market-based instruments makes them particularly appropriate in China where the competition to meet social needs is great and the available resources are few.

This paper provides a discussion of the two main issues that will have to be considered in adopting a tradable permits program for the control of SO_2 emissions in China. The starting point of the paper is the existing structure of Chinese policy for controlling SO_2 emissions, but the main focus concerns first the transition from non-tradable facility permits to tradable emission permits and secondly the integration of tradable permits with the pre-existing pollution levy system. Reference is made

occasionally to the experience with SO_2 emissions trading under the U.S. Acid Rain Program (Ellerman *et.al.*, 2000), which is the world's first large-scale application of tradable permits for controlling emissions of any kind, but the applicability of this precedent is limited, as will become increasingly evident in the following discussion.

Certain issues have had to be glossed over in writing the paper in order to keep the discussion and the length of the paper manageable. Three of these are sufficiently important that they should be signaled to the reader. First, no attempt is made to provide a comprehensive consideration of the relative merits of tradable permit systems as compared to alternative instruments for controlling pollution, such as taxes or command-and-control type regulatory instruments (technology mandates, efficiency standards, emission rate limits, etc.) Comparisons between the requirements of a tradable permits system and those of tax or more conventional regulatory systems will be unavoidable in the body of the paper, but these comparisons should not be considered as complete. Readers interested in a more general and comprehensive discussion of the relative merits of tradable permits, taxes, and command-and-control mandates are referred to virtually any standard textbook on environmental economics (for instance, Tietenberg, 1996).

Second, no attempt is made to address the full range of problems involved in creating an effective system for regulating air emissions. Rather, a greatly simplifying assumption is made: that China will be successful in controlling SO_2 emissions at an appropriate level regardless of the instrument used. This assumption allows the discussion in the paper to focus on how the requirements of a tradable permit differ without going into the full detail of the standard-setting, monitoring and enforcement capabilities that will be required for successfully controlling SO_2 emissions in China, regardless of instrument choice. A major theme throughout this paper is that, while different in some respects, the requirements for establishing an effective tradable permits system are little different from those for an equally effective tax or command-and-control regime. Although each instrument has its distinctive features, the differences are mainly ones of form. All require that the same fundamental problems be solved: How to allocate the cost burden, what specific requirements to place on polluters, and how to ensure compliance.

Third, the transitional nature of the Chinese economy is recognized but not discussed. China's transition is two fold, from a pre-industrial and socialist economy to one that is industrial and market-oriented. As suggested by the name, market-based instruments for controlling pollutants presume markets; and, where the set of laws, institutions, and practices that are associated with market economies are not fully developed, these instruments, whether they be taxes or tradable permits, are likely also to experience a transitional phase. These transitional conditions do not mean that the goal of efficient and effective environmental control be abandoned, but they do require that these reforms take into account the special conditions of these economies and they imply that progress in

implementation will be heavily conditioned by the more general economic transformation.

2 The Existing Framework for SO_2 Control in China[19]

2.1 General Context

Responsibility for the development and implementation of environmental policy in China is split between national and local levels. In general, the central government provides the policy direction and the general legal and institutional framework, while local levels of government are responsible for implementation and enforcement, often including the choice of the appropriate measures to achieve national goals. At the national level, the two principal bodies are the State Council, which provides the broad policy guidance, and SEPA, which is administrative agency charged with the development and elaboration of this policy. At the local level, the Environmental Protection Bureau (EPB) is the responsible body. This division of responsibility is similar in some ways to that in the U.S. where primary and secondary standards for criteria pollutants are established at the national level and the states are expected to come into compliance with these standards through State Implementation Plans.

Despite this similarity in structure, three salient differences should be noted for those seeking comparison with the U.S. First, the devolution of authority to the local level is even greater in China than in the U.S., at least at this stage of policy development. Second, there is more experimentation at the local level in China, typically with pilot programs, than there ever was in the U.S. Furthermore, the central authorities encourage this experimentation as a means determining effective measures, which can then be adopted and propagated on the national level. Third, the significant devolution of responsibility to the local level and the emphasis on experimentation results in a more incremental approach to policy. In the U.S., environmental policy concerning air emissions is largely a matter of elaborating the concepts and structure embodied in the 1970 CAA Amendments. In China, one would look in vain for an analogue. Instead, in a process that can be described as both pragmatic and ad hoc, policy emerges out of successive steps taking the form of guidance and the provision of progressively stronger legal basis for specific actions at the local level.

The policy framework for controlling SO_2 emissions has emerged only within the last ten years. The first general measure to address SO_2 emissions dates back to 1982 when the pollution levy, which was introduced in the late 1970s, was applied to industrial SO_2

[19] This section draws heavily from Benkovic (1999) and Luo *et.al.* (2000).

emissions.[20] Serious attention began to be given to SO_2 emissions only in 1990 with the State Council's "Suggestions on the Development of Acid Rain Control." This procedural document provided the guiding concept of Two Control Areas, designating priority areas, and it generally cleared the way for more concrete actions to be taken in the following years. In 1992, the first of what were to be a series of extensions and increases in the rate of the SO_2 pollution levy took place. The adoption of the "Ninth Five-Year Plan" in 1996 provided the occasion for introducing the concept of Total Emission Control and for linking it to the Two Control Area guidance, as well as taking a variety of more concrete measures to reduce sulfur emissions. Finally, in April 2000, the People's Congress adopted sweeping changes to the 1987 Air Pollution Prevention and Control Law (APPCL) that incorporate and provide a stronger legal basis for the implementation of the policies and measures developed during the 1990s. These changes can be summarized as focusing efforts on the most polluted areas, changing the emphasis of control from concentrations to total loadings, shifting the base of the pollution levy from excess emissions to total emissions, and establishing (non-tradable) emission permits as the vehicle by which national policy would be implemented at the local level.

This last change is an important further step in moving away from a centrally directed, project-specific approach to implementing environmental policy towards one in which national policy is translated by the local authorities into firm-specific instructions contained in a facility-specific emissions permit. Heretofore, environmental policy has been implemented through requirements imposed on new projects, National Environmental Pollution Treatment Projects, and, for a few processes, emission standards coupled with a low pollution levy for excess emissions. Unless singled out by project or process, most existing facilities were unaffected by national policy. Emission permits were tried on a pilot project basis in 16 cities starting in 1991, and the 2000 revisions of the APPCL provide the basis for generalizing their use. Although non-tradable, these permits are seen as a precondition for emissions trading and in fact some limited trading has occurred in the sixteen trial cities.

At present, SO_2 emissions control policy consists of three principal components: The Pollution Levy System (PLS), Two Control Areas (TCA), and Total Emissions Control (TEC), each of which will now be described in more detail.

2.2 The Pollution Levy System

The most long-standing component of China's regulatory structure for controlling emissions is the Pollution Levy System, which applies to air emissions and water

[20] During the 1980's, abatement efforts were centered on specific projects, known as National Environmental Pollution Treatment Projects, instead of more general policies and measures.

discharges and in most cases involves a penalty imposed on emissions *in excess* of the standard for the applicable processes. The use of the term "levy" is important in indicating that, at least legally, it is not a tax within the jurisdiction of the national tax authorities. Instead, the levy is imposed and collected at the local level and to be used both to fund the administrative expenses of the local Environmental Protection Bureau (EPB) and to provide funds for investment in abatement projects.

The PLS provides a good illustration of the relations between the national and local levels in the development and implementation of environmental policy. The basic guidance and the legal authority to impose the pollution levy derive from the national level, but assessment, collection, and distribution of funds resides at the local level. Perhaps, the most important effect of the PLS has been funding the local Environmental Protection Bureaus, of which more than 1,600 have been established throughout China, employing more than 20,000 persons to implement environmental policy along the guidelines received from national authorities. As such, the Chinese pollution levy has empowered local regulatory authorities and created a unique and considerably decentralized administrative structure that is increasingly has the capacity to implement and to enforce national policy at the local level. As noted by other authors (Wang, 2000; Wang and Wheeler, undated), this decentralization lends itself well to endogenous enforcement in which community pressures reflecting differences in economic development and environmental quality appear to explain differences in effectiveness.

The PLS was applied to SO_2 emissions starting in 1982 as a fee of 0.04 RMB per kg (≈ $4.50 per short ton at 8 RMB per US$) on excess emissions from industrial processes only (excluding electric utilities). With the increased emphasis on SO_2 emission control in the 1990s, a trial program was begun in nine cities in which the PLS rate was increased five-fold to 0.20 RMB per kg (≈ $23 per short ton) and the PLS became a tax applied to *total* SO_2 emissions (not just excess emissions) from utility as well as industrial sources. Starting in 1996, this trial program was expanded to include all jurisdictions within the Two Control Areas. Higher levy rates have been tried in two instances. New sources face a double levy rate of 0.40 RMB per kg. (Meng *et. al.*, 2000) And in 1998, a pilot program with a higher tax rate of 0.63 RMB per kg (≈ $70 per short ton) was initiated in three cities. Finally, and most significantly, the 2000 revisions to the APPCL changed the base for the pollution level from excess to total emission.

Despite its success in funding the requisite administrative structure, the PLS has a number of problems. First, it applies only to medium to large sources; with rare exception smaller enterprises, particularly town and village enterprises, are not included. Even so, collections are far below what emissions data indicate they should be.[21] Second, the levy

[21] For instance, collections from electric utility sources, which are relatively large and more easily monitored, have been estimated to be about 25% of what could be expected based on actual utility emissions (Benkovic, 1999).

is set at too low a level to be effective in encouraging significant SO_2 abatement. The frequently cited, preferred alternative 1.26 RMB per kg (≈ $140 per short ton) is roughly six times the current level in most jurisdictions. Third, the utilization of the reinvestment portion of the PLS leaves much to be desired. The target level for recycling revenues to local enterprises for abatement is 80 percent, with the remainder for EPB administration, but the actual percentage recycled is estimated at more nearly 50-60 percent. Then, the recycled portion is often given back to the firm paying the levy to defray its own abatement expenditures, and this practice has led naturally enough to firms negotiating to withhold what is to be the recycled amount. At best, this recycling of PLS revenue to firms as a proportion of their assessment does not direct the funds to where the most economically attractive abatement projects exist; and at worst, the effective pollution levy rate is reduced from an already low level. Fourth, deficiencies in emission measurement often lead to what are negotiated payments only roughly if at all related to actual emissions. Negotiated payments are an effective and perhaps initially unavoidable way to raise revenue; however, for the pollution levy to have significant effect on abatement behavior, liabilities must be closely correlated with actual emissions.

2.3 Two Control Areas (TCA)

The State Council's 1990 "Suggestions" first introduced the concept of two control areas, one for acid rain and the other for SO_2, and this concept was embedded in actual planning in the Ninth Five-year plan, adopted in 1996. The TCA component of SO_2 control policy is not an instrument for affecting abatement behavior, like the pollution levy, but a means of prioritizing SO_2 control efforts. In essence, it defines the cities and regions that will be held accountable for reducing SO_2 emissions and the amount of reduction to be achieved. In general, the SO_2 Control Zone comprises cities in North China where the ambient SO_2 concentration exceeds 60 μg per meter^3, and the Acid Rain Zone includes areas in South China where the pH value of precipitation is lower than 4.5 and where sulfur deposition exceeds the critical load. These two areas cover 11.2 percent of China's overall territory and include about 76 percent of the country's population. Within the two control areas, 47 municipalities (out of 275) are designated as "key" and they are slated to receive more aggressive emissions control targets.

As a device for prioritizing abatement effort, the TCA component of Chinese environmental policy is neutral with respect to instrument choice. It is intended to work with the pollution levy, Total Emission Control, emissions trading, and any other measure that might prove useful and effective. As can be seen with the evolution of the PLS on SO_2 emissions, changes in coverage or levy rate are tried first in key municipalities and if successful there, expanded to apply more broadly within the two control area zones, and finally extended into the non-TCA areas of China in keeping with environmental priorities

and political limitations. The April 2000 changes in the APPCL and the implementation of those changes in the Tenth Five-year Plan have maintained and intensified the focus on the Two Control Areas by setting specific targets for total SO_2 loadings and expanding the number of key cities slated for priority efforts from 47 during the Ninth Five-year Plan to 100 in the Tenth Five-year Plan.[22]

2.4 Total Emissions Control

Total Emissions Control is the newest and, since 2000, the most important element of Chinese environmental policy applying to SO_2 emissions. Specifically, it provides a ceiling on total emissions for twelve major pollutants including SO_2. The concept arose in 1996 out of a series of State Council documents and SEPA action plans and became incorporated by amendment into the "Ninth Five-Year Plan" to work in concert with the already existing Two Control Area component. The 2000 revision of the APPCL embedded TEC in the fundamental law and thereby shifted the focus from controlling concentrations to controlling total loadings. In the absence of measures to ensure against exceeding these ceilings, the TEC provides a target more than a cap, but it still provides a measure for judging the effectiveness of control measures and the 2000 amendments also strengthen enforcement powers.

The TEC limit for national SO_2 emissions in the Ninth Five-year Plan was 24.5 million metric tons, approximately the 1995 level of emissions,[23] and this national target was then allocated to the 31 regions. These targets are intended to limit emissions to the 1995 level for all areas within the TCA zones, except for a group of municipalities in Eastern China that will receive target allocations at a level 10-percent below the actual 1995 baseline because of their greater population density, higher level of economic development, and greater availability of local resources for policy implementation. The 47 key municipalities within the TCA zones were required to meet the proposed TEC targets by 2000, while other cities will have until 2010 to comply.

As of 1999, total SO_2 emissions in China were 18.6 million tons, 25 percent below the national TEC target, and all but three regions had met the regional targets in the Ninth Plan. Although local efforts to control emissions from major sources have contributed to this remarkable decline in SO_2 emissions, two other aspects of the restructuring of the Chinese economy have played a large role. First, economic changes and explicit policy have succeeded in closing down small enterprises, particularly small coal mines producing

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[22] Monitoring results in 1999 indicate that approximately one-third of 338 cites in China did not meet National Class 2 standards for normal residential areas (0.06 mg/m^3) and that 15% did not meet Class 3 standards applicable to special industrial zones (0.10 mg/m^3). SO_2 emission air density in Chinese cities has been falling slowly but steadily over the past years. (Wu, Wang, and Meng, 2000)

[23] Actual SO_2 emissions for the 1995 base year were 23.7 million tons. The 2000 target reflects additions to the base year that are said to reflect abnormally low SO_2 emissions during 1995.

relatively high sulfur coal and small, inefficient thermal electricity generating units. Second, the ongoing economic transformation in China has diminished production from large and medium-sized state operated enterprises (SOEs) whose output is typically emissions-intensive.

The Tenth Five-year Plan has set a national TEC ceiling for 2005 of 18 million tons, approximately the 2000 level, and a much tighter total of 10 million tons for the Two Control Areas. The allocation of this target to lower jurisdictions is currently taking place in conformance with the Two Control Area criteria with special focus on municipalities characterized by high existing SO_2 pollution, high SO_2 emissions, and failure to achieve prior emissions targets.

3 From Facility Permits to Allowances

The development of a tradable permit system for SO_2 emissions in China can be usefully seen as a process of moving from non-tradable facility permits to tradable emission permits, or allowances. This distinction is subtle, but it is important to understanding the likely pattern of development in China. A facility permit imposes conditions that typically limit emissions from the facility in some manner. These permits are called emission permits in China, but the permits are not tradable. Deviations in emissions from the conditions imposed in the facility permit may be traded through credit trading, but this form of trading must be distinguished from allowance trading.

Both types of permits—facility permits and allowances—are effective in reducing emissions, although one does so by imposing emission-reducing conditions on particular facilities while the other does so by requiring that all emissions from the facility be “covered” by an equal number of the limited number of allowances. Furthermore, trading of emissions can occur with both forms of permits: in the one case, as a credit granted after appropriate administrative review, while in the other the trading is a matter of right. Both create rights to emit: in one case, the right attaches to the facility meeting the specified conditions and can be traded only by leave, while in the other, the right is explicit and readily separable from any particular facility.

The process of moving from non-tradable facilities permits to tradable emissions permits will be different in China than it has been in the U.S. or other OECD countries where tradable emission permit systems have been implemented or proposed. Facility permit systems with all the associated monitoring and enforcement capabilities were already in place in these countries, and the cap and trade system was simply added on top. In contrast, there is little experience with facility permits in China and the two will be

developed more or less concurrently.[24] It is tempting to contemplate avoiding facility permits altogether and moving directly to allowances, but the practical reality is that facility permits will be indispensable in the early stages of the implementation of emission control measures, particularly in countries where the markets assumed by market-based instruments exist in rudimentary form. Moreover, where environmental goals are multiple, such as improving ambient air quality in cities and reducing acidic deposition, the existence of more than one instrument is desirable. Such is in fact the case in highly market-oriented economies such as the United States, where facility permits co-exist with tradable permits and effectively allow multiple goals to be achieved.[25]

Even so, there is an advantage in moving quickly to primary reliance on a cap and trade system and gaining that advantage requires that facility permits be designed in a way that is consistent with tradable emission permits and that will lead naturally and quickly to their use. To that end, this chapter discusses the distinctive requirements of a tradable emission permit system and how these requirements can be incorporated in the design of facility permits to encourage the development of allowance trading.

3.1 Setting the Cap

The distinguishing feature of a tradable permits system is the "cap," or the limit on the total amount of emissions. Assuming enforcement, this constraint makes emissions scarce and imparts value to allowed emissions. As discussed earlier in connection with the Total Emission Control component of Chinese environmental policy, this feature of a tradable permit system is already in place, although much remains to be done to ensure that it is effective.

Not only has a national TEC cap been decided, but that cap has been broken down and distributed to subordinate levels of government in what can be seen as regional caps, the sum of which equal the national cap. In the Ninth Five-Year Plan, the 24 million ton national cap was distributed to the 31 regions, but not further down; and, as noted earlier, nearly all of these regions met their regional caps in many cases for reasons that had more to do with the transformation of the economy than the effectiveness of the environmental control system. The process of distributing the 18 million ton cap to regions is underway currently as part of the Tenth Five-Year Plan,[26] but with the difference that the

[24] During the 1990s, China experimented with the use of facility permits in a series of pilot projects and recent legislative changes to the APPCL aim to generalize their use. The permits issued in these pilot projects are often called emission permits when translated into English, and emissions trading took place in some of the projects, generally in the form of offset credits; but they are facility permits.

[25] In the United States, ambient air quality standards are met through the use of conventional command-and-control regulation and these regulations could and in some cases do restrict the extent to which facilities can trade emissions.

[26] Wu *et.al.* (2000) provide a proposal for allocating the 18 million ton national and 10 million ton TCA targets to the 31 regions.

cap will be further broken down and distributed to even lower levels of government and ultimately to emitting facilities.

The main question remaining is how the local EPBs will translate their caps into instructions to firms that will ensure that the cap is not breached and the environmental objectives achieved. These instructions will determine how costly it will be to achieve the caps and whether a tradable permit system emerges. For the latter to develop, the cap received by the EPB must be allocated to emitting sources within its jurisdiction as tradable permits.

3.2 Allocating the Cap and Establishing Tradability

The EPBs enjoy considerable discretion in the specific requirement they impose on emitting facilities within their jurisdictions. One form the requirement might take is an instruction to pay a tax per unit of emissions that is sufficiently high to cause firms to reduce emissions sufficiently to stay below the cap. Alternatively, the source might be required to install equipment or undertake practices that will in the aggregate reduce emissions to the required levels. Finally, the facility might be told simply to make sure that emissions do not exceed some total quantity, as was done in some of the emission permit pilot projects in China during the 1990s. This last instruction is a logical extension of the process by which the national TEC cap is broken down and assigned to subordinate levels of government.

An aggregate quantity limit embedded in a facility permit is similar to the instruction to firms that characterizes a cap and trade system, but the latter would be different in two important ways. First, the quantity limit would take the form of allowances that would be issued in many small units; second, the instruction to the firm would be to give back an allowance for every ton emitted, not to keep emissions below the number of allowances issued to the firm. In the one case, the facility has a cap of say 100 tons imposed within its facility permit and is told to stay within that limit. In the other case, the facility receives 100 allowances to emit one ton and is told to return an allowance for every ton emitted. With trading, the facility might actually emit more than the number of allowances received if it can acquire allowances from other sources at less cost than to reduce emissions; but it might equally emit much less in order to sell allowances if its marginal cost of abatement is less than other facilities facing the same compliance requirement.

If there is no market for allowances, the two sets of instructions are equivalent. In the tradable permit case, the allowances issued would be returned and any not used would have no further value. But the important aspect of tradable permits is the potential value that such permits have for it is virtually certain that the distribution of the EPB cap to firms, whether in the form of an aggregate limit or of an equal number of allowances denominated in tons, will not be such as to equalize marginal costs among all emitting

units. Initially, firms may treat their allowance allocations as quantity ceilings and incur differing marginal costs of compliance; however, if the ability to sell and to buy is clearly understood to be acceptable, firms will seek out trading partners in order to reduce their costs by eliminating these differences in marginal cost. Thus, issuing the quantity restriction in a form that makes trading emission reductions at the margins practicable and easy creates the potential and provides the incentive for firms and other intermediaries to create a market in allowances with the consequent well-known gains in economic efficiency.

One of the most difficult challenges faced by the EPB in issuing allowances will be deciding how many allowances to issue to each affected source in its jurisdiction. This allocation is often seen as highly political and thankless because it is so explicit and transparent. But the fundamental task—distributing the cost burden of the required emission reduction among firms and sectors within the EPB's jurisdiction—is no different than what the EPB would face if it chose to meet the cap through the use of the more familiar command-and-control measures. Imposing a uniform emission rate limit or a technology mandate on all sources sufficient to achieve the cap may appear to provide a more objective basis for the reductions required of all firms, but the burden of the emission reduction has been distributed just the same. Moreover, since firms will have different abatement cost opportunities and control technologies are not equally applicable across firms, this distribution of the cost burden is likely to be both inequitable and inefficient. The regulator may even seek to achieve a more equitable and efficient distribution of the burden by imposing more stringent requirements on firms having lower abatement costs and less stringent requirements on those facing higher abatement costs, but such differential application of requirements assumes more knowledge of the abatement opportunities and costs facing firms than the EPB is likely to have. At the very least, identifying the firms belonging in high cost, low cost, and intermediate categories is time consuming and costly. And, in the end, the regulator is adjusting the burden just as would be done, more explicitly, by assigning specific limits or caps to each source. It is precisely problems like these that a tradable permit system can help solve. Although the EPB may never know which firms face higher and lower abatement costs, trading allows these firms to find each other, and by trading permits, to reduce the disparities in burden sharing that will be inevitable in any effective emission control system.

The allocation of permits to emitting sources will be easier if some basic principle is applied, and that principle can be the standard that might have been applied in the absence of a tradable permit system. This was the case in the U.S. Acid Rain Program. An emission rate of 1.2 pounds of SO_2 per million Btu had become embedded in the air emission regulatory structure in the United States as an appropriately stringent level of restriction based on estimates of the emission rate that could be attained by best available control technology in the early 1970s. Accordingly, the initial principle for allocating

allowances to firms was this emission rate multiplied by average annual fuel use during a three-year, historic baseline (1985-87).[27] The aggregate amount of emissions allowed by this standard was approximately nine million short tons, or approximately half of 1980 emissions, which was a level that was deemed sufficient to meet the environmental objective of eliminating acid rain damage.

Adjustments from the basic principle can be made and they were made in the US SO_2 emissions trading program. The enabling legislation contains more than thirty deviations from the basic allocation principal whereby certain types of facilities were given more allowances than they would otherwise have received and the amount available to all others was "ratcheted down" by a small amount to preserve the cap.[28] For example, the state of Florida successfully argued that, because of its high rate of in-migration by retirees, the cap would impose higher costs upon its citizens than upon the citizens of the other states, who were the source of the in-migration. As a result, utilities in Florida were awarded more allowances than would have been received under the basic principal, at the expense of everyone else.

These adjustments in the allocation of allowances redistributed costs among facilities affected by the SO_2 cap, but the important aspect of tradable permits is that the process does not stop at this point as it would with other instruments. With tradable permits, firms are still free to buy and sell permits among themselves, and thus to reallocate the burden further among themselves when mutually advantageous. Unlike the zero-sum game that is encountered in allocating allowances from a fixed total, this market-driven reallocation of permits and of abatement effort provides opportunities for both seller and buyer to benefit, and for total societal costs to be reduced as well. One of the advantages of tradable permit allocations is that the most important equity concerns can be met through the reallocation of allowances within the fixed total without detracting from environmental effectiveness and economic efficiency. In contrast, adjusting command-and-control regulations or taxes to meet equity concerns typically involves some departure from either effectiveness or efficiency, if not both.

3.3 The Scope of Trading

Making emission permits tradable presumes that the permits can be traded over some domain in space and time. When emissions trading occurs through the creation of tradable credits for doing more than required by the facility permit, the scope of trading is decided on a case by case basis, but it is this process that imposes high transaction costs and generally leads to the poor results associated with this form of emissions trading. In

[27] Sources having an emission rate in 1985 less than 1.2 lbs SO_2/mmBtu were issued permits equal to this lower rate multiplied by baseline energy use.
[28] See chapter 3 of Ellerman *et.al.* (2000) for a discussion of these deviations.

contrast, allowance trading avoids the transaction costs and provides better results by issuing allowances from the bottom-up and making them tradable as a matter of right, but it also requires the regulatory authority to determine the scope of trading at the beginning.

3.3.1The Spatial Dimension

The geographic scope of trading can be defined as narrowly as several sources within an industrial facility or all sources within the EPB's jurisdiction, or even more broadly. The basic consideration is the environmental effect of a unit of emissions, but this effect must be interpreted realistically. Obviously, the environmental effect of emissions from several different exhaust stacks at a single facility is the same, and this logic can be easily extended to emissions from adjacent facilities. The question is how far can the trading zone be extended, since it is equally obvious that trading with a distant source having no effect on local conditions will frustrate the achievement of the environmental objective.

An EPB with several geographically distinct urban areas in its jurisdiction has several alternatives. One would be to allow trading within each urban area but not among them. Nevertheless, it will rarely be the case that emissions in each area affect only that area. Typically, some portion of the pollution in any given area originates from emissions transported by wind from other areas. An alternative that addressed this concern would provide different redemption values for permits from different sources. Thus, permits issued in area A could be deemed to cover a ton of emissions for all sources in area A, but permits issued in the adjacent area B would be deemed to be cover only half a ton if presented for compliance in area A. Given sufficient information about atmospheric transportation and transformation, schemes of differential pricing can be devised; however, such information is not always available and even when it is, the added complication may overwhelm the environmental benefit. When wind direction is variable, as it usually is, and atmospheric transformation depends upon meteorological conditions that also vary, it will often be found that different areas are polluting each other. This reciprocal nature of pollution suggests yet another alternative, which is to broaden the scope of trading to include both areas so that permits issued in areas A and B are equally valid when presented for compliance in either area. This last alternative is attractive when there is considerable uncertainty about what happens to emissions from particular sources or when the policy goal is to effect a general reduction in emissions in order to meet multiple environmental goals.

Still, even acknowledging the uncertainties and the reciprocal nature of pollution, both of which argue for geographically wide trading areas, a potential problem remains: "hot spots." This term refers to the possibility that the spatial pattern of abatement arising out of a wide and unrestricted market in allowances may lead to concentrations of emissions in certain areas, the hot spots, that will violate the local air quality goals. The solution to this

problem is not to restrict trading but to use another instrument to ensure achievement of the purely local goal.

This is the case with the U.S. Acid Rain Program, which was enacted on top of an elaborate, pre-existing command-and-control structure aimed at avoiding local, health-based effects of SO_2 emissions. This conventional regulatory structure had been in existence for over two decades when the SO_2 cap and trade program was enacted, and it remained in place to ensure that the ambient air quality standards for SO_2 were not violated. Although it is frequently stated that SO_2 emissions trading is unrestricted within the United States, this assertion is not true, strictly speaking. A more accurate statement would be that trading in SO_2 allowances is unrestricted within the limits and mandates imposed by the pre-existing regulatory structure. Since nearly all sources were in compliance with the pre-existing ambient air quality standards for SO_2 when the Acid Rain Program was enacted and that program required a further, aggregate fifty percent reduction in SO_2 emissions, most sources are effectively unrestricted in trading around the lower allowed emission level. Still, they must operate within the limits imposed by local environmental regulations. Thus, hot spots, defined as violations of local ambient air quality standards, did not appear as a result of emissions trading in the United States mostly because of the sequence in which the regulatory structure for controlling SO_2 emissions was developed.

There is no particular reason why the sequence followed in the U.S.—getting the local conditions right first, and then trading to deal with regional problems—should be observed in China. The practical reality is that, for the most part, neither local nor regional requirements are being met and that both require emissions to be reduced. The all-important imperative is to reduce emissions; where and how are secondary considerations. If allowance trading leads more surely to emission reductions, then it should be adopted because it will reduce emissions sooner. The argument is not to ignore local details, but to recognize that there is as much logic, and perhaps more, in stressing emission reduction and then tending to the local details, as there is in making sure that the details are right before engaging in emission reduction. After all, both goals require that SO_2 emissions be reduced. As noted in a recent CRAES study, Class 2 ambient air quality standards for SO_2 are not likely to be met unless total SO_2 loadings within the Two Control Areas were reduced to below 12 million metric tons. (Wu *et. al*, 2000)

This argument applies as much at the level of the EPB as it does at the national level. In practice however, the implementation of the emission reductions will occur at the local level. The argument is therefore one to risk erring on the side of defining trading areas too broadly rather than too narrowly. The pattern of emissions will be determined by the instructions the EPBs give to emitting firms and by how strictly those instructions are enforced. Those instructions will presumably take local considerations into account. The concern about hot spots arises mostly when the instructions take the form of tradable

permits. For, if the emissions causing the worst pollution are relatively costly to abate, a trading system will eventually abate these emissions less than others. Still, if allowance markets and trading are slow to develop, then these problems will become evident only over time. And if the cap has been successfully enforced and is adequate in the aggregate, then it is not possible for all or even most areas to be hot spots. Those that do appear can then be treated with supplementary instruments, either a higher pollution levy as discussed in the next section or other command-and-control restrictions that can be incorporated in a facility permit. These supplementary instruments will create differences in marginal cost of abatement but that is the logical consequence of uniform ambient air quality standards that will necessarily be more costly to attain in some areas than in others.[29]

3.3.2The Temporal Dimension

The spatial scope of trading is not the only dimension that needs to be decided. Emissions trading can also take place across periods of time, and there are many advantages to doing so. Temporal trading can occur through banking, being able to use permits issued for one period and not used during that period in a later period, and borrowing, using allowances for future periods in the current period. In most allowance-based systems, banking is allowed but borrowing is not.

Banking serves several important purposes as has been demonstrated by its use in the U.S. Acid Rain Program. The most important of these is the incentive to move emission reductions forward in time when emission reductions are being phased in over time. As an example, the phased-in structure of the U.S. Acid Rain Program resulted in approximately 11 million allowances issued for use in 1995-99 being banked for later use after 1999 when the marginal cost of abatement is expected to be higher. In effect, emissions were 11 million tons lower than allowed in the first years of the program, and they will be 11 million tons higher than the number of permits issued in the later years of the program. In China, the intent under the TEC policy is to reduce the limit progressively over time, from 24.5 million tons in 2000 to 18.2 million tons in 2005 for all of China and to 10 million tons by 2010 within the Two Control Zone area. Although the 2000 target for all of China was easily met and the 2005 target imposes a no-growth-in-emissions policy for all of China, the TCA target of 10 million tons will call for more than just offsetting emissions from new sources or what is likely to occur without any special emission

[29] Taking these supplementary measures in hot spots will also increase emissions outside of the hot spots; however, these areas have reduced more than the hot spots and are therefore more likely to have over-complied with local requirements. By the same process as before, additional actions can be taken as new hot spots appear until the desired set of environmental goals is achieved. Over time, trade between sources lying within the jurisdiction of different EPBs may become desirable until eventually a national trading system or one encompassing a large portion of the national territory exists.

reduction effort as a result of the continuing transformation of the Chinese economy. Thus, in one way or another emitting firms within the TCA area will be required to reduce emissions progressively more.

Banking provides an incentive to firms to reduce emissions more than required in the early years because the banked allowances can be used to defer the higher marginal costs associated with the more stringent later requirements. For example, imagine a firm that faces three abatement options: 1) reducing emissions by 10 percent at low cost, 2) reducing them by 25 percent at somewhat higher cost, and 3) reducing emissions by 50 percent at relatively high cost. Suppose further that the firm faces an initial requirement to reduce emissions by 10 percent and a later requirement to reduce them by 50 percent. Without banking, the firm would adopt the 10 percent reduction technology and the costly 50 percent reduction technology only when required; there would be no incentive to reduce emissions by 25 percent in the early years. With banking, an incentive is provided to adopt the 25 percent abatement technology, which will reduce emissions more in the early years at the expense of delaying the adoption of the 50 percent technology by some period of time depending on the amount of banking. Over the entire period, cumulative emissions are the same, but they are reduced more rapidly in the early years. For a country seeking to reduce highly polluted areas quickly, such an incentive is highly desirable, even if the incentive implies a few more years of moderate pollution.

This incentive is particularly important when there is some doubt about how quickly allowance markets will develop. For instance, in the preceding example and speaking strictly from the standpoint of a single firm, it might adopt the 25 percent reduction technology early on, even without banking, if it could find buyers for its unused allowances in each period. But in the absence of such a market, the only incentive would be that provided by banking, the ability to defer (not avoid) future more costly reductions. Moreover, with phased-in caps, firms as a whole will have an incentive to bank even when individually they can readily sell unused allowances to others in the current period. In effect, firms would, by their own actions, accelerate the timing of the cumulatively required emission reductions so that more would occur earlier, while the cumulative amount of emissions would be the same.

The second important purpose served by banking is avoiding undue volatility in allowance prices. Banking allows a firm to maintain an allowance inventory just as would with fuel or other requirements of the production process. Without such carry-over, prices in each period would be subject to greater fluctuation reflecting random variations in demand such as those caused by weather. Without banking, the supply of allowances for each period is fixed and any unexpected changes in demand will cause prices to be bid up very greatly or to fall precipitously as firms try to get rid of allowances not needed in the current period. With banking, an unused allowance has value in the next period and this places a floor on how low prices can fall. Similarly, inventory or banks carried over from

earlier periods will cushion the effect on price of unanticipated increases in demand through the draw down of inventory. Although not usually allowed, borrowing forward could provide a similar dampening effect.[30]

Temporal flexibility serves important purposes—providing incentives for cost-effective emission reduction and moderating otherwise volatile permit prices—in most allowance trading programs, but it is particularly important when the spatial dimension of the trading market is limited either for environmental reasons or as a result of slow market development. For an economy in transition, such as China, this latter is an especially important consideration.

3.4 Measurement, Registries, and Compliance

The instruction issued to firms in a cap and trade system imposes unique measurement and accounting requirements on the regulator. First, emissions must be measured to determine the number of allowances to withdraw from the system. In contrast, most command-and-control regulations, such as technology mandates or emission rate limits, do not require that emissions be measured. Second, the regulator must have some means of knowing whether allowances submitted for compliance are valid. This requirement is accomplished through the use of a registry or, as it is called in the U.S. Acid Rain Program, an Allowance Tracking System, that accounts for all allowances issued, transferred, and submitted for compliance.

The cost or difficulty of measuring emissions is one of the reasons for the use of command-and-control measures rather than tradable permits or taxes. Compliance with a requirement to burn low sulfur fuel or to install specified abatement equipment can be presumed to reduce emissions based on the characteristics of the fuel or equipment. All that is necessary to determine compliance is to ensure, usually by periodic inspection, that the fuel burned is of the specified quality or that the equipment is installed and operating. For the Chinese environmental control system that is just getting started using facility permits, actual measurement might seem an unnecessary refinement.

Yet, the adoption of the Total Emission Control policy, not to mention the pollution-levy system, implies some estimate of total emissions and this estimate can come very close to providing the needed measurement. For instance, a requirement to burn coal of sulfur quality below some specified level implies that some data on the sulfur quality of the coal be available. Demonstrating the use of coal of the requisite quality may suffice where the

[30] Recent experience in California with the Los Angeles NO_x allowance trading program (RECLAIM) provides an example of where borrowing would have been useful. Because the spatial dimensions of this market are relatively narrow and virtually no banking or borrowing are allowed, an unusual confluence of events increasing the demand for the generation of electricity in Los Angeles caused NO_x prices to increase about forty-fold from $2,000 a ton to $80,000 a ton.

regulatory requirement is to burn coal of only a certain quality or to emit below a certain emission rate; however, for the EPB to demonstrate that emissions are less than the cap, it will have to make some estimate of the amount of coal burned, or of the output of the facility. Similar considerations apply for abatement equipment. In practice, if the EPB cap is taken seriously, the EPB will require the information that would allow it to determine total emissions, as it would do for a tradable permit or tax system.

An increasing number of power plants will have the requisite monitoring capability as the requirement that all newly built, expanded, or transformed thermal power plants within the Two Control Areas install continuous SO_2 monitoring systems is applied; however, the monitoring required for a tradable permits system need not be real-time and continuous. Approximate methods will suffice and material balance calculations based on fuel sampling and engineering specifications can provide measurements of sufficient accuracy. In fact, such alternative methods are used in the U.S. Acid Rain Program for small sources where the installation of such equipment would be unduly expensive. The important issue is the quality and integrity of the data obtained, not the manner by which it is obtained.

The importance of measuring emissions also makes it critical for determining which sources would be included in a tradable permits system. Some sources are likely never to lend themselves to developing data of sufficient quality for use in a tradable permits system, even though the EPB will have to estimate emissions from all sources in determining compliance with its allocation of the TEC policy. Household emissions are an example, and it would likely be easier to restrict the use of coal in households, for instance, than to attempt to obtain accurate reporting of coal use and quality for home heating and cooking. Thus, some sources within the EPB's jurisdiction may not be included within the allowance trading system, and some portion of the cap received by the EPB will have to be reserved for these sources where acceptable measurement is not feasible or too costly and for which emissions can be controlled by more conventional regulatory measures.

The requirement to maintain a registry of permits arises from the nature of compliance in a tradable permits system. A source is deemed in compliance when it gives up a number of permits equal to emissions. Since the permits deducted need not be the same as those issued initially to a particular source, some means must exist to keep track of permits from the time they are issued until they are withdrawn from the system for compliance. Thus, if firms A and B are both issued permits allowing 100 tons of emissions each, and A buys 25 permits from B to cover 125 tons of emissions, the regulator would know that the permits came from B who could then emit only 75 tons (unless it had purchased permits from some other source).

Registries are bookkeeping systems that have at a minimum one account for each emitting source into which permits are initially deposited by the regulatory authority and subsequently deducted in an amount equal to emissions at the end of each compliance period. Since no actual certificates are issued to sources, the permits are bookkeeping

entries which can be readily transferred from one account to another upon appropriate instruction from account holders or sources, in the same manner as funds are transferred upon appropriate instruction among checking accounts with a bank. Typically, permits are also assigned serial numbers to facilitate tracking.

Although a registry is a unique requirement of a tradable permit system, the task of determining compliance is simplified for all. First, there is no need for a corps of inspectors, as there is with command-and-control regulation, to determine whether the required technology is installed and operating, or that the prescribed emission-reducing practices are being followed. The only on-site inspection that is required concerns the emissions monitor or alternative means of determining the quantity of emissions. Second, there is little discretion in determining whether a source has complied or not. Unlike the situation with technology mandates and best practices where equipment breaks down or the practices cannot always be followed, the only criterion is whether the source has a permit equal to the quantity of measured emissions. The requirement is identical in this sense to that with an emission tax: the only question is whether the tax corresponding to the quantity of emissions has been paid. A third simplifying feature of the registry is that the means of paying are at all times in the regulator's hands. There is never any question of collection as can be the case with taxes. It is as if polluters were required to place in escrow the estimated amounts of tax due. There is still a penalty and enforcement issue if insufficient taxes/permits are on deposit, but most of the compliance procedure will occur automatically.

4 Integration of Tradable Permits with Pollution Levy System

Tradable permits and taxes are often presented in the theoretical and applied literature as alternative instruments for achieving environmental goals. This treatment of the two as alternatives could be interpreted as implying that a tradable permits system should replace China's pollution levy on SO_2 emissions, but doing so would pose many practical problems. Not only is the PLS the most well established instrument for meeting environmental goals in China; but more importantly it is the source of funding for the EPBs, which are the critical level of government for implementing effective control of SO_2 emissions regardless of instrument choice. Fortunately, the choice is not so stark. As explained in this section, replacing the PLS on SO_2 emissions is neither necessary nor desirable in implementing a tradable permit system to control SO_2 emissions.

Nevertheless, a decision must be made concerning which is the primary instrument for controlling SO_2 emissions. Primary reliance can be placed on tradable permits, and the PLS can continue to exist as a subordinate instrument to serve other purposes. What must be avoided is confusion concerning which is the primary instrument. For instance, if

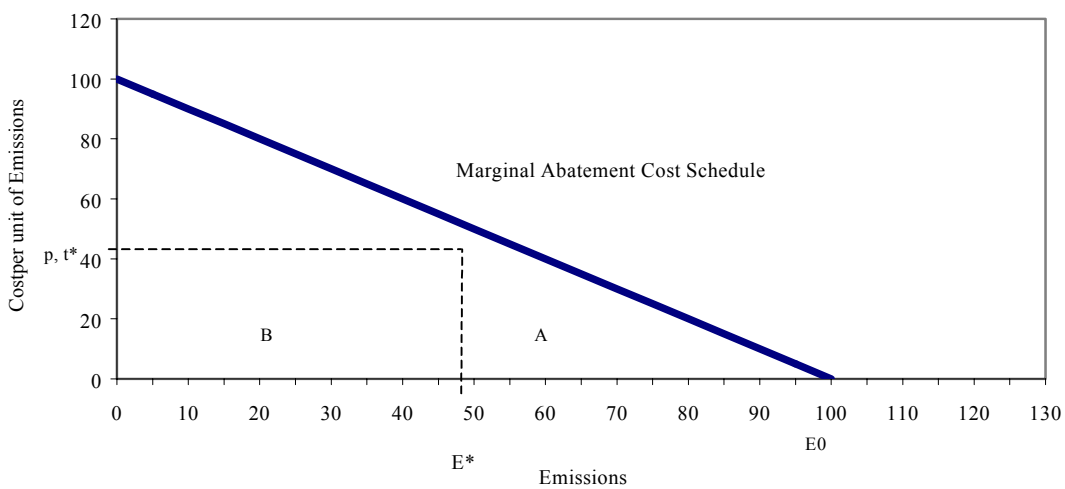
the PLS were set at a level that would achieve the quantity limitation expressed by the cap, the tradable permits would be redundant and there would no point in maintaining a registry, allocating permits, or determining trading areas. The converse is, however, not true. A tradable permit system does not make taxes redundant: a more binding cap will reduce tax revenues, but taxes would still be collected on allowed emissions.

4.1 Some Basic Aspects of Taxes and Tradable Permits

Before proceeding with an explanation of how the pollution levy and a tradable permit system could work together, some basic characteristics of the use of taxes and tradable permits in a market economy should be explained. Figure A presents the most basic representation of the relationship between emission levels and the costs of emission control.

The horizontal axis represents total emissions and the vertical axis indicates the cost per unit of emissions. The downward sloping line represents the marginal cost of reducing emissions to the corresponding level of total emissions. In Figure A, the numbers are purely illustrative, but the marginal abatement cost schedule could be that for a single firm, for all the firms within the jurisdiction of an EPB, or for China as a whole. The emission level, E_0, indicates uncontrolled emissions, for which the marginal cost of abatement is zero, by definition. Any lower level of emissions requires some cost to be incurred and the cost of the last unit of abatement is reasonably presumed to be steadily increasing as more emission reduction is undertaken, as represented by this marginal abatement cost schedule. At some relatively high marginal cost, such as that required to switch all sources to natural gas, SO_2 emissions would be zero.

Figure A



The fundamental equivalence between tax and quantity instruments (i.e., between the PLS and tradable permits) can be illustrated by Figure A. Suppose that the environmental regulatory authority wishes to limit total emissions to E^*. One way to do so would be to issue tradable permits in the amount E^* and to impose a very large penalty for emitting without a permit. With a functioning permit market, the clearing price would be p, the marginal cost of achieving the last unit of abatement required to meet the cap, E^*. The alternative would be to impose a tax, t^*, equal to p. This would cause firms to undertake abatement costing less on the margin than t^*, which is to say in the same amount as would occur with the issuance of permits equal to E*. As presented so far, there would appear to be no difference between imposing a tax in the amount t^* and distributing permits in the amount E^*. The aggregate level of emissions and the total and marginal costs incurred by firms would be the same. The differences arise in the informational and distributional aspects of the problem, and these are important.

The informational aspect concerns the regulator's knowledge of the backward-sloping line in Figure A. As presented there, the regulator is assumed to know with certainty the price and quantity relationship that define the marginal abatement cost relationship. Armed with such information, the choice between t^* and E^* makes little difference from the standpoint of emission control. However, the regulator will not have such information or at best only a vague idea of the relationship between abatement and marginal cost. As a result, the regulator faces a choice: either to fix quantity by issuing permits in the amount E^* while remaining uncertain about marginal cost, or to fix marginal cost (price) by imposing a tax of t^* on emissions and remaining uncertain whether the desired level of emissions E* will be achieved.

The distributional aspect can be described by reference to the areas A and B in Figure A. The area A is the total cost of abatement incurred by firms in reducing emissions from E_0 to E^*, that is, the integration beneath the marginal abatement cost curve. Firms incur this cost regardless of whether the tax t^* is imposed or tradable permits are issued in the amount E^*. The area B represents the scarcity rent that is associated with constraining total emissions to E^*, and the distribution of this rent constitutes one of the distinguishing differences between tax and permit systems.

When a tax t^* is imposed, the area B is the amount of tax revenue paid to the government for the right of emitting E*, and the emitting firm will naturally avoid all emissions for which the marginal cost of abatement is less than t^* thereby incurring abatement costs equal to the area A. In effect, the government receives the scarcity rent by charging an appropriate amount for the use of these limited rights.

When a tradable permit system is used, the distributional consequences for the SO_2-emitting firm depend on the allocation of the permits. For instance, if the government were to auction the permits, as is often recommended, the consequences to the firm would be largely the same as with a tax, incurring a cost equal to A + B. The more

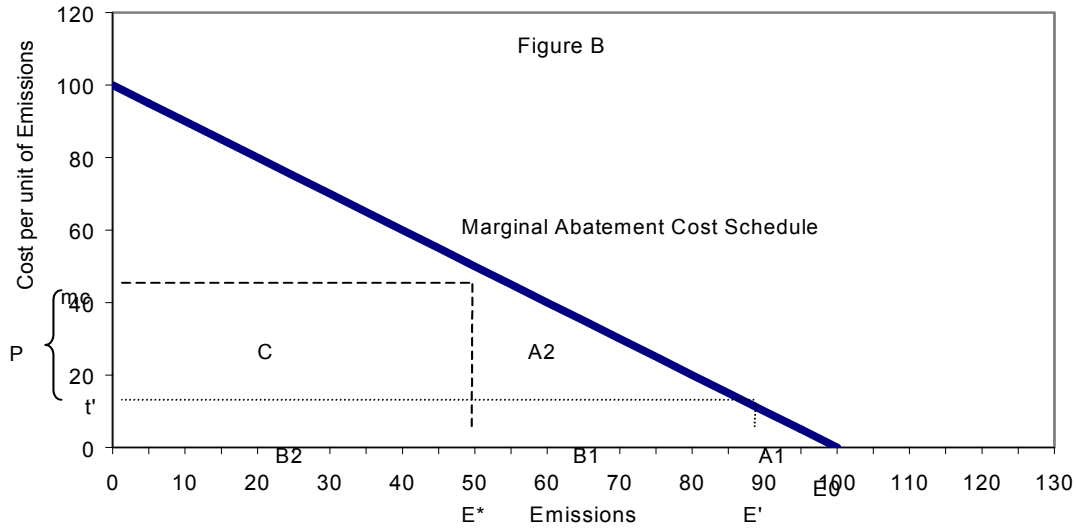
common case is that the permits are allocated to the SO_2-emitting firms, and these firms then arrange payments among themselves to the extent that a more efficient reallocation of these rights to emit is desirable. A firm having reduced emissions to the level of permits it received would pay itself and its net cost of abatement would be the area A less the area B. Firms facing relatively low marginal costs of abatement would reduce emissions even more in order to sell allowances and recoup some of the abatement cost. Depending on the shape of the marginal abatement cost curve, this net amount could be positive (A > B), or even negative (A < B), but in all cases the firm is better off than it would be with a tax or with auctioned permits.[31]

The ultimate distributional consequences of these alternatives depend on how firms or governments further recycle these proceeds. A large literature exists on the possibilities of the government beneficially recycling the revenues from environmental taxes and permit auctions to obtain a "double dividend," but the more immediate and practical problem for the environmental regulator is likely to be the firm's very different attitudes toward the use of these alternatives for controlling emissions. While taxes promise only higher costs, grandfathered permits hold out the prospect of additional profit, and this prospect can operate as an incentive (or bribe) for accepting an enforceable constraint on emissions. For instance, experience in Chile has shown that grandfathered permits encourage firms to come forward with information about emissions and means of measuring them in order to obtain a share of the limited permits (Montero *et.al.*, 2000). In contrast, tax systems offer no comparable inducement to reporting emissions or accepting the emission constraint.

4.2 The Interaction between Tradable Permits and a pre-existing PLS

The preceding discussion concerning Figure A treats the price and quantity instruments in a binary fashion as if only one or the other will be chosen. Such a discussion is useful for setting the stage of how the PLS and tradable permits might work together, which is now illustrated using Figure B.

[31] This illustration of the distributional consequences assumes that the output of the firm (steel or electricity for instance) would be priced to include the marginal cost of abatement, as would be the case in a market economy.



The diagram is the same except that the PLS is represented by the relatively low tax *t'* which leads to a small amount of abatement and a level of emissions *E'* that is greater than the desired level, *E**. Assuming that the PLS is effectively collected from all sources, then the total cost of abatement is represented by the area A_1 and levies paid to the government are equal to the sum of B_1 and B_2.

The imposition of a grandfathered tradable permits system with *E** permits on top of the PLS has several consequences. The amount of abatement and the marginal cost of abatement is higher in order to reduce emissions from *E'* to *E**. PLS revenue is reduced by the amount B_1, which the firm will allocate to abatement expenditure plus an additional amount represented by A_2. The scarcity rent received by the firm is the area C, which is smaller than the amount B in Figure A by the amount of the PLS revenues B_2. In effect, the scarcity rent is shared between the firm and the government in an amount determined by the relationship between marginal cost, *mc*, and *t'*. Finally, the clearing price of permits in the market, *p*, is not *mc*, as it would be if there were no PLS, but the difference between *mc*, the level of marginal cost required to meet the constraint *E**, and *t'*, the level of the pollution levy.

One consequence of an effective tradable permit system that may concern the EPBs is the reduction of potential PLS revenues by the amount B_1. To the extent that this is a problem, several responses are possible. First, the word “potential” should be stressed. To the extent that the PLS is not collected from all sources or incompletely collected from those that do pay something, the amount B_2 may be larger than the partial amount currently collected. A second response to reduced PLS revenues could be an increase in the PLS levy rate by some amount that would replace part or all of the revenue loss B_1. Such an increase in the levy rate would change the split of the scarcity rent between the EPB and the polluting firms, but the amount of the increase in the EPB share may not

need to be large. Yet a third response would be to change the split between the EPB's administrative expenses and the amounts reinvested in abatement activities. Instead of allocating 80 percent of PLS revenue to reinvestment in abatement as before, and keeping 20 percent for EPB administrative expenses, that ratio could be altered. Using the numbers in Figure B, if 20 percent of revenues collected on 90 units of emissions is required to keep the EPB going, then 36 percent (18/50) of the revenues collected on 50 units of emissions must be retained for administration. In fact, the amount of reduced pollution levy collections, B_1, has been allocated to abatement expenditure as a result of the more stringent cap.

4.3 Using the Pollution Levy to Reinforce a Tradable Permits System

The role of the pollution levy need not be limited to that of a useful pre-existing feature of air emission regulation that can passively co-exist with a tradable permits system. In the spirit of making full use of what is already available and familiar, the pollution levy can be used to reinforce the tradable permits system to constitute an integrated package of instruments working to reduce SO_2 emissions. Two such reinforcing uses can be envisaged.

4.3.1A Second-tier Penalty Rate

Like any other regulatory system, a tradable permit system must penalize non-compliance, in this case, for uncovered emissions. The pollution levy is a natural candidate in keeping with its tradition of being a charge for emissions in excess of some standard. However, in keeping with the recent decision to extend the existing pollution levy to cover all emissions from a facility, using the pollution levy as a penalty would involve a second, higher tier for any emissions in excess of allowances held and surrendered. Under such an arrangement, an emitting firm would be required to surrender permits and to pay the low, first-tier pollution levy for all emissions and to pay the higher, penalty rate only for any emissions not covered by allowances.

The critical issue in such a system is the level of the second, penalty tier. If the penalty rate is too low, little incentive is provided to reduce emissions beyond what is justified by the existing pollution levy; and if the rate is too high, it can lead to exorbitant cost or, more likely and worse, exemption from the tradable permit system. When enforceable, high penalty rates are very effective at encouraging trading and ensuring that the cap is observed, but if the market for allowances is non-existent or slow to develop, a high penalty rate can lead to undesirable results.

Tight cap and trade systems are characterized by penalties for uncovered emissions that are many times higher than any conceivable market price. For instance, in the U.S.

Acid Rain Program, the penalty is over ten times the highest market price observed. But, this was in a program where trading is nation-wide in scope and unlimited banking is allowed. The situation facing an EPB attempting to implement measures to meet its cap will be very different. If local allowance markets are slow to develop, firms facing high abatement costs may not be able to find other firms with lower costs with whom to trade. Under these circumstances, a relatively low penalty rate—one that would preserve incentives to abate and to trade but without imposing very high costs—would be appropriate. Over time, and as allowance markets develop, the penalty rate can be raised to the level that would ensure attainment of a hard cap.

Such a transitional, two-tiered approach to controlling SO_2 emissions would seem particularly appropriate in China. The current pollution level is widely recognized as being too low to provide much incentive to reduce emissions, yet there is resistance to increasing the levy. Tradable emission permits offer a way out of this impasse, but they presume allowance markets and this could be a problem in an economy without well-developed and long-standing market institutions. A relatively low penalty rate avoids the undesirable effects of high penalties when there is no “market out” while preserving the needed incentives both to abate and to trade. Low penalty rates also recognize the likelihood that initially the EPB’s portion of the national TEC limit will be targets as much as hard caps and that the latter will be possible only as allowance markets develop. As these markets develop, the penalty rate can be raised to the point that the TEC targets have become hard caps.

4.3.2Using the first tier as a second instrument

The other reinforcing use of the pollution levy would be as a second instrument for achieving air emission goals. As explained in the section on the geographic scope of trading, a potential conflict exists between meeting local ambient air quality goals and trading emissions over broad areas. Experience with the U.S. SO_2 allowance trading program suggests that these problems may not be as severe as often feared, but they exist nevertheless and their emergence depends only on the right combination of circumstances. Where those circumstances obtain, a second instrument will be needed to ensure that the local air quality goals are met. That second instrument could be some form of command-and-control regulation operating independently of the permit trading system, but it could also be achieved by raising the level of the first tier of the pollution levy within the local area of concern to make the purchase of allowances from outside the local area less attractive.

The circumstances in which a second instrument would be called for will not general; and, on the presumption that the EPBs do not have particularly good information about relative control costs within their jurisdictions, these circumstances will not be initially

evident. When fully implemented, a tradable permit system will distribute the allowed emissions in a manner than will equalize marginal costs of abatement. It is possible that with this distribution of emissions all localities will meet local ambient air quality goals in which case there is no need for a second instrument. It is equally possible, however, that the firms facing particularly high abatement costs may be concentrated in some area, which furthermore may be especially in need of local emission reductions to meet local air quality goals. Trading will allow these firms to reduce emissions less than they would otherwise by paying others outside the area of concern to reduce more on their behalf. The other areas are made cleaner, but this does nothing for the local area of concern. In this case, the second instrument is needed.

The first tier of the pollution levy becomes a potential instrument because of its interaction with a tradable permits market. As explained earlier, in a fully developed market, the price of allowances will be equal to the marginal cost of abatement that firms will incur to meet the aggregate quantity restriction and the first tier pollution levy. Raising the levy for some firms within a trading area with an unchanged total cap will reduce their willingness to purchase permits and cause them to abate more. As a consequence, the price of permits in this market will decline somewhat causing other firms not subject to the higher first tier levy rate to abate less. In effect, the change in the first tier levy rate will redistribute the unchanged allowed total emissions within the trading area in a manner than will allow the area of concern to meet local air quality goals. Trading between the sensitive area and other areas could still occur and there will be a difference in marginal abatement costs between the two zones, but that difference will reflect the differing value placed on emission reduction in the two zones. More importantly, trading between the two zones would still be allowed so that the efficiency advantages of tradable permits could be obtained, within the limits imposed by various air quality goals. Eventually and ideally, a broad geographic market, perhaps China-wide, can be envisaged in which the allowed TEC emissions are distributed by a combination of allowance trading and local tweaking of the first tier pollution levy rate to ensure the achievement of local ambient air quality requirements.

5 Conclusion

The creation of an effective SO_2 cap and trade system in China will not be easy, but the difficulty can be easily overstated. Most of what may seem so difficult will be required anyway for any regulatory system that is effective in controlling SO_2 emissions. Tradable permit systems impose some special requirements in how the regulator goes about setting up the regulatory structure, but the differences are more in form than they are in substance. Where the alternative is a command-and-control system, as it is in China, the

gains in economic efficiency and environmental effectiveness would seem to justify the greater effort that may be required to overcome the novelty of tradable permit systems.

Even less so that elsewhere, Chinese regulatory authorities do not have the luxury of creating an tradable permit system and imposing it upon emitting firms without much regard to environmental measures already in place or to the market institutions that are presumed by market-based environmental instruments. Fortunately, the policies that have already been developed are not inconsistent with developing a tradable permit system and total emission control can be seen as creating a presumption for instruments such as tradable permits that fix quantities. The problems lie, however, at the local level where the discretion about instrument choice largely resides and where decisions are likely to be dominated by very practical considerations. Two of those considerations are particularly important: 1) how to issue facility permits that will allow and even encourage the development of a tradable permit system, and 2) how to integrate tradable permits with the venerable pollution levy system. Most of this paper is devoted to a discussion of these two topics.

Much can be learned from experience in the U.S. and elsewhere using tradable permits, but the conditions in which Chinese regulatory authorities are attempting to develop a tradable permit system for SO_2 emissions are distinctly different. China's simultaneously top-down and bottom-up structure of environmental regulation places a premium on local experimentation and incremental progress, and this resolutely pragmatic approach precludes the all-at-once, top-down implementation that characterized the U.S. Acid Rain Program. Instead, the process seems likely to be one in which Total Emission Control targets are selectively and progressively transformed into soft caps that will evolve over time into hard caps as the appropriate institutions and markets develop. The pace at which a tradable permit program can be put in place will depend then on the more general transformation of the Chinese economy. Recognizing this dependence is however no reason to delay implementation. Rather it is incumbent on environmental regulators to be a part of the more general economic process by adopting measures that will anticipate and facilitate the more important transformation.

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USING SCIENCE TO SET ENVIRONMENTAL GOALS AND UNDERSTAND ENVIRONMENTAL IMPLICATIONS IN CHINA

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Summary

Scientific investigations, which develop and use a variety of analytical tools and databases, help characterize the relationships between emission changes and impacts on the environment in the past and present. Such investigations also provide a basis for developing scenarios for emission management in the future and for illustrating how these strategies will affect human health and the environment. Most recent analyses have helped identify SO_2 emission control levels needed in different provinces to meet the national goal in China. New modeling studies are being conducted to more rigorously characterize potential impacts of emission changes now and in the future. The following efforts will enhance China's ability to develop an effective SO_2 emissions trading program: enhanced monitoring of SO_2 and acid deposition, development of more comprehensive emissions inventories, increased use of geographic information systems (GIS) mapping to illuminate spatial distributions of sources and impacts, and continued application of state-of-the-art chemical/physical models to studies of emissions and impact causal relationships.

Introduction

Energy use is increasing gradually with China's economic growth. Almost all of the commercial energy consumption is derived from fossil fuels. As a result, air pollution and acid rain, the by-products of fossil fuel combustion, have become serious environmental challenges in China.

Scientific investigations using a variety of analytical tools and databases are helping characterize the relationships between emissions and these impacts in China. Such investigations also are providing a basis for developing scenarios for emission management in the future and for illustrating how these strategies will impact human health and the environment.

SO_2 and its chemical product, sulfuric acid—the main component of acid rain, are recognized as the current major chemicals of concern. While other pollutants contribute to

the overall air pollution and acid rain problem, the sulfur chemicals are the leading contributors to air pollution and acid rain in China. Because of the immediate importance of SO_2, it is the focus of numerous regulatory control efforts and the proposed market trading program. This paper discusses how science is being used and can be used to help develop such a program. Other pollutants will also need to be considered in future assessments and emission management strategy development. The policies developed should be flexible enough to adapt to increased scientific understanding across time.

In this paper, we summarize information on the following topics:

- Areas of greatest concern based on monitoring of SO_2 and acid deposition
- Impacts to human health and the environment
- Emissions of SO_2 and other pollutants needed for analysis of source and impact relationships
- Recent modeling studies of these relationships
- Current thinking regarding the required SO_2 emission reduction levels throughout China

1. Sulfur Dioxide and Acid Deposition Monitoring

Long-term monitoring of air pollution and acid deposition has quantified the importance of sulfur in the problem. As noted in a recent study by Larssen et al, the composition of acid rain is on the average about 32 percent sulfate; 21 percent Calcium, 16 percent ammonium, 5 percent nitrate, and the remaining is made up of numerous other constituents. The high levels of basic calcium and ammonium, which neutralize the acids, are preventing the acid deposition problem from being even worse.

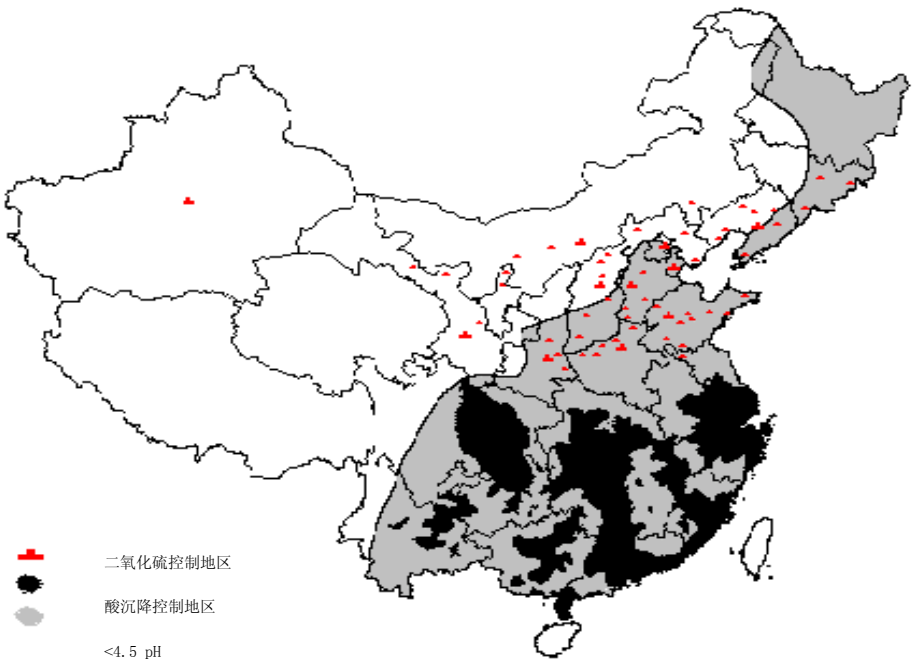


Figure 1

Monitoring also has provided an indication of areas where levels of SO_2 and acid deposition are hazardous. These areas are captured in the two-control zone policy. Cities where average ambient SO_2 concentration exceeds 60 μg/m^3 are designated as the pollution control regions for SO_2. Regions where the pH value of precipitation is lower than 4.5 and the sulfur deposition exceeds the critical load are designated as the acid rain control regions. These areas are shown below in Figure 1 as illustrated in Shah et al (2000). The red dots are the SO_2 control zones and the black areas are the acid deposition control zones. The gray areas are those where pH is less than 4.5.

It is important to have monitoring data on the key pollutants in order to continue tracking trends in chemicals that contribute to adverse health and environmental impacts. This monitoring data also is essential for estimating initial and boundary conditions for complex modeling exercises and for providing data for evaluating model performance.

A monitoring network exists in China, but most of the stations are in urban areas, making extrapolation to regional estimates more uncertain. These few precipitation monitoring stations only measure pH values. There is a need to measure gaseous concentrations of acid precursors and other pollutants in air and in cloud water in order to be able to understand more clearly the relationships between emissions and impacts.

1.1 Health and Ecological Impacts

A number of published and ongoing studies of the impacts of air pollution and acid

deposition indicate significant human health and welfare concerns related to emissions in China. Several of the key findings are noted here.

The *Clear Water Blue Skies* 1997 report by the World Bank found that:

• 178,000 premature deaths in the major cities can be related to emissions of SO_2 and particles

• 111,000 premature deaths in rural areas can be related primarily to cooking fuels

• 10 percent of the crops and forests, mainly in southern China, are damaged as a result of acid rain

• 8 percent GNP is the estimated cost due to pollution

Other air pollution health impacts estimated by the World Bank study are noted below. These are estimates of respiratory damage that could be avoided by meeting Class 2 Air Quality Standards in China.

A more recent study (Shah *et al*, 2000) puts the premature death total in major urban areas at 180,000, an increase over the 1997 report estimate. Several other reports and studies in progress that are focusing on conditions in the heavily polluted areas are confirming significant health impacts. For example, the recent study of impacts in Shanghai attributes significant health impacts to sulfur and nitrogen oxides and total suspended particulates (Chen Changhong *et al*, 2000). The potential economic value of reducing these health impacts though integrated strategies for air pollution and greenhouse gas mitigation currently is being assessed (NREL, 2000). The Guangzhou air quality action plan 2001 also outlines serious health effects related to air pollution in that region (NORAD Project, 2000).

Problem	Number of Cases Averted
Urban Air Pollution	
Premature deaths	178,000
Respiratory hospital admissions	346,000
Emergency room visits	6,779,000
Lower respiratory infections or child asthma	661,000
Asthma attacks	75,107,000
Chronic bronchitis	1,762,000
Respiratory symptoms	5,270,175,000
Restricted activity days (years)	4,537,000
Indoor Air Pollution	
Premature deaths	111,000
Respiratory hospital admissions	220,000
Emergency room visits	4,310,000
Lower respiratory infections or child asthma	420,000
Asthma attacks	47,755
Chronic bronchitis	1,121,000
Respiratory symptoms	3,322,631,000
Restricted activity days (years)	2,885,000

Source: The World Bank, *Clear Water, Blue Skies: China's Environment in the New Century*. The

World Bank, Washington, DC, 1997 (Table 2.1, p.19).

A review by Larssen *et al* (1999) cited negative effects on forests, including die back, have been reported for areas near large cities. Results from other studies (Feng Zongwei and Tao Fulu) indicate that forest volume loss rates due to acid deposition range from 7 to 20 percent in seven provinces of south China. The Zhejiang province is the most affected, while Anhui province is the least affected.

The World Bank report (1997) states that in Asia a limited amount of work has been conducted on the ecological impacts from acid rain. The work that has been completed focuses on the forest and crops impacts. Aquatic impacts have yet to be assessed. The report also points out that terrestrial impacts have been documented in the vicinity of Chongqing, Sichuan, and Guiyang, Guizhou. The results of that work include the following:

- 50 percent dieback of forests on Nanshan mountain
- more than 50 percent reduction in biomass production in commercial spruce forests experiencing acid rain with a pH of less than 4.5,
- yellowing of rice in large areas near Chongqing after rainfall with a pH of less than 4.5, and
- wheat fields that are seriously affected by rainfall with a pH of less than 3.5 during the middle and late growing periods.

Jikun and Rozelle (1995) also outline the relationships between environmental stress and grain yields in China.

A new 5-year Chinese-Norwegian research project was launched in the autumn of 1999. The study is focusing on forested areas in the Chongqing municipality and in Guizhou, Hunan, and Guangdong provinces in southern China. At one site in Guizhou and one in Chongqing, soil research has been ongoing for several years and the forest at these sites appears to show symptoms of reduced vitality (Tang et al, 2000).

The 1999 SEPA Report on the State of the Environment in China summarizes the current situation. SEPA states that the statistics and analysis of the environmental monitoring results show that the environmental situation in the whole country is still rather severe. The report notes that emissions are quite large, pollution levels are still rather high, and the environmental quality in some areas continues to be degraded. In addition, the report states that the water, air, noise and soil pollution in many cities is still rather serious and the rural environmental quality has decreased. The report concludes that ecological degradation has not yet been controlled in an effective way and the ecological destruction in some areas is becoming worse.

1.2 Emissions—Sulfur Dioxide and Nitrogen Oxides Focus

Emission inventories for SO_2 and related pollutants have resulted in estimates of

current and past levels as well as projections of the likely levels under various emission management scenarios. Here we summarize some of the main points regarding emissions and provide more detailed discussion of the most recent work on SO_2 and NO_X inventories. In general, estimates show high levels of SO_2 emissions are located in the two control zones. Unlike the U.S., where about 73 percent of the SO_2 emissions come from the utility sector, utilities account for only approximately 37 percent of SO_2 emissions in China. Industrial sources contribute about 39 percent and other various sectors contribute about 24 percent. This broader distribution of emissions through sectors makes emission control potentially more challenging than the approach taken in the U.S. that primarily focuses on the power sector.

In order to assess the relationships between the emissions and impacts in more detail, information on emissions for other key chemicals in addition to SO_2 is needed. The availability of emission data in China varies by pollutant species. The SO_2 data are available and relatively accurate, and, recently, a more thorough inventory has been developed for NO_X. The emission inventories for the other key pollutants—VOCs (volatile organic compounds), NH_3 (ammonia) and TSP (total suspended particulate)—are not as comprehensive. Some work on NH_3 emissions inventory compilation has been done at CRAES with emission factors mainly adopted from European sources. Also, there have been some measurements of biogenic emissions of VOCs in China by a group from Peking University, focusing on tree species in the Beijing area.

Anthropogenic SO_2 and NO_X emissions are mainly emitted from fossil fuel combustion, such as coal, oil, and natural gas, in various sectors. The other sources of SO_2 emissions are from the processing of sources such as metallurgy and vitriol production. The mobile source sector is another major source of NO_X emissions, besides the energy and industry sectors.

The emissions inventory reported here is taken from Meng et al. effort that was first reported in January 2001 at the third experts working group meeting on transboundary air pollution in Northeast Asia held in Seoul, Korea. Data in this study are from open statistic yearbooks of the whole nation, provinces, and concerned sectors. The emissions of SO_2 and NO_X are estimated by using the emission coefficient of each pollutant for each source category and then allocating emissions to cells with the resolution of 1 degree × 1 degree. To facilitate modeling work, emission sources with large amounts and high stacks are defined as large point sources and the other emissions as area sources.

1.3 Sulfur Dioxide Emissions Estimates

In the Meng et al. study, SO_2 emissions are estimated from fuel combustion in the energy and industry sectors, and from processing in metallurgy and vitriol production.

Sectors. SO_2 emissions are mainly from fossil fuel combustion, the major contributing

sectors include: power plants, heating, metallurgy, chemistry, iron and steel production, construction material producing, boiler emission in other industry sectors, and emissions from agriculture and domestic sources.

Sector	Emission approach
Power plant	Coal, oil, and gas burning
District heating	Coal, oil, and gas burning
Metallurgy	Copper, lead, zinc, and nickel smelting
Chemical industry	The processing of Vitriol production
Iron and steel industry	Ore agglomeration
Construction material industry	Cement and glass producing
Other industry sector	Burning of various boiler
Agriculture	Coal burning in agriculture activity
Domestic	Coal burning
Restaurant	Coal burning
Others	Fuel combustion

Sulfur Content of Coal and Oil in China. China covers a large geographic area so the sulfur content of coal varies tremendously within the country. In the Meng *et al*. study, there was an assumed constant value for sulfur content of coal and oil consumed in the same place. The sulfur content of fuel in various regions is as follows.

Total Emissions of SO_2 in China. Annual emissions from large point sources is 10 million tons, while the area sources have annual emissions of 12 million tons. The total annual emissions in China is 22 million tons. Of these countrywide totals, 5.4 million tons of the large point source emissions are in eastern China which is shown in the figure. Similarly, for this region, the area sources total 5.2 million tons. The distribution of large point source (LPS) and area sources are shown in Figures 2 and 3 respectively with a resolution of 1 degree x 1 degree. The eastern China totals for major point sources and area sources for 1998 are shown below.

Sulfur Content of Coal in Regions of China

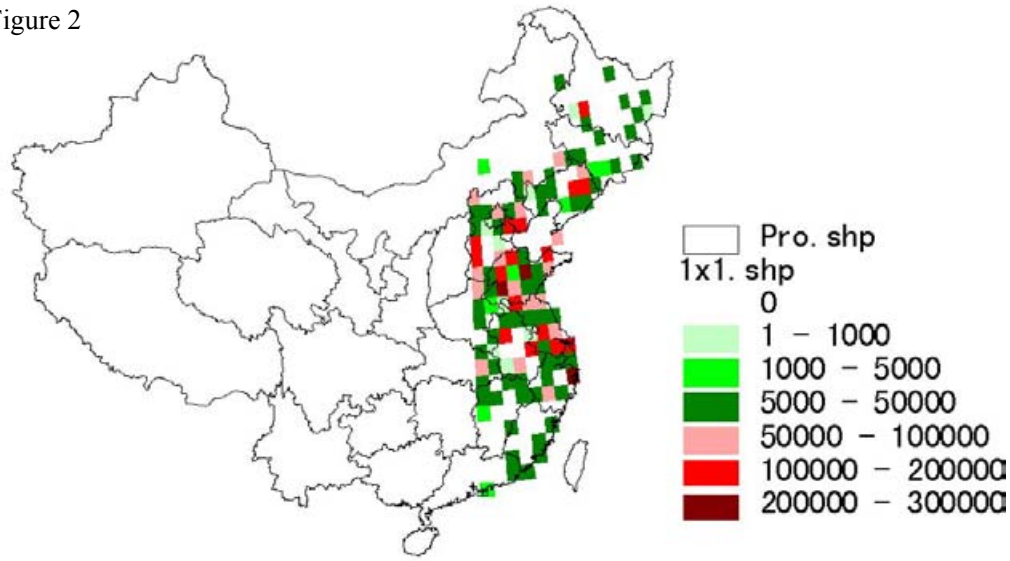
Region	Sulfur content %
Beijing	0.66
Tianjin	0.75
Hebei	0.85
Shanxi	0.87
Neimenggu	1.27
Liaoning	0.66
Jilin	0.51
Heilongjiang	0.55
Shanghai	0.91
Jiangsu	1.57
Zhejiang	0.95
Anhui	0.9
Fujian	1.1
Jiangxi	1.21

Shandong	1.72
Henan	0.94
Hubei	0.87
Hunan	0.77
Guangdong	0.95
Guangxi	1.94
Hainan	0.68
Sichuan	2.79
Guizhou	2.58
Yunnan	2.7
Shanxi	2.38
Gansu	0.86
Qinghai	0.61
Ningxia	1.7
Xinjiang Ur	0.87

Sulfur Content of Oil in China

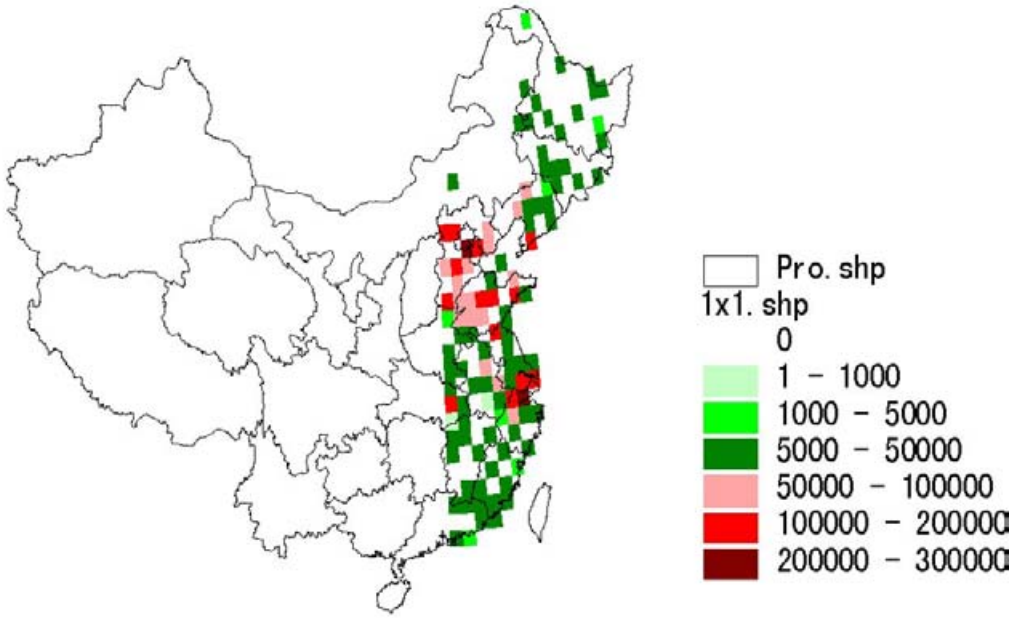
Region	Oil field	Sulfur content (%)
Tianjin	Dagang oil field	0.12
Hebei	Renqiu	0.31
Helongjiang	Daqing	0.11
Shandong	Shengli	0.8
	Gudao	1.81
Hubei	Hanjiang	1.83
Shanxi	Changqing	0.08
	Yanchang	0.09
Gansu	Yumen	0.13
Xinjiang	Ke la ma yi	0.13

Figure 2



annual LPS SO2 emission distribution ton/1X1

Figure 3



annual area sources SO2 emission ton/1X1

1.4 Nitrogen Oxide Emission Estimates

NO_X emissions are mainly from combustion processes in boilers and automobiles. The estimations are based on two primary types of sources: stationary sources and mobile sources. The breakdown in detail is shown in the following table.

Stationary source	Power plant	Coal combustion boiler Gas boiler Oil boiler	Coal consuming Gas consuming Oil consuming
	Industry	Coal combustion boiler Gas boiler Oil boiler	Coal consuming Gas consuming Oil consuming
	Other	Coal combustion boiler Gas boiler Oil boiler	Coal consuming Gas consuming Oil consuming
Mobile source	Automobile emission	Cities have done the test Others	Emission factor, mileage Fuel consuming

Stationary Sources. Stationary emission estimates have been broken down into two types: power plant and industry. The power plants include coal, gas and oil boilers. The industry sources include coal, gas and gas boilers. Under the gas category, natural gas, butane and propane are included.

Mobile Sources. In the study, only automobile emissions from urban driving have been included. Emissions from mobile sources during highway driving should be included in mobile emission estimates. However, since there is little documentation of vehicle volume on highways, the emissions from highway driving have not been included in this study.

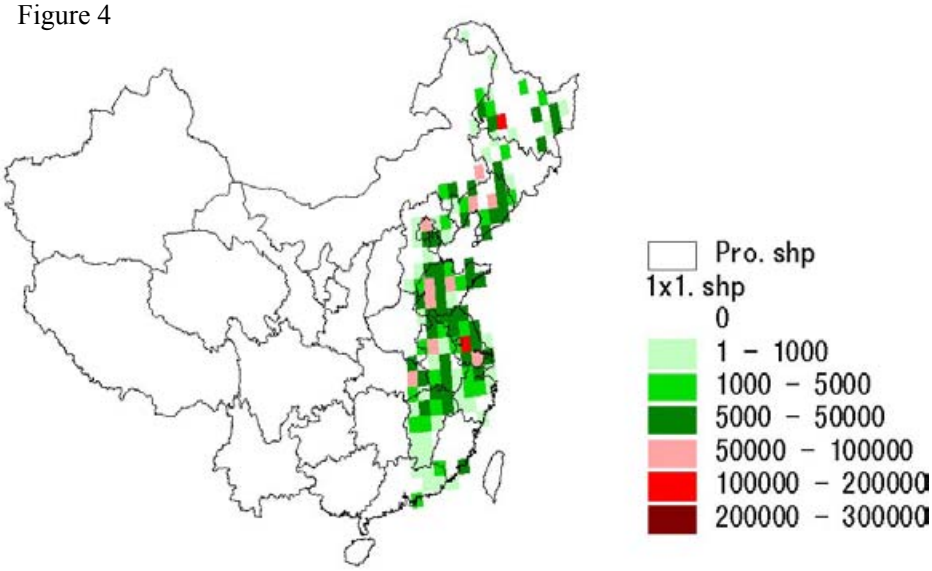
Road conditions, amount of traffic, and other factors vary remarkably between cities, thereby making it impossible to use emission coefficients interchangeably between cities. As a result we use the following guidelines to develop the mobile estimates for city driving.

- For cities (e.g., Beijing, Shanghai, and Guangzhou) that have calculated emission factors available, emissions are calculated as Emissions = emission factor x mileage
- For others, the NO_X emissions are estimated from annual gasoline and diesel usage by the automobiles.

NO_X Total Emissions. Annual emissions from large point sources is 3.5 million tons and 4.4 million tons from area sources. Emissions from automobiles in urban areas is 1.3 million tons annually. For the eastern China region, these totals for large point sources, area sources, and mobile sources are 2.3, 2.2 and 1.3 million tons, respectively. Emissions distributions for this eastern China region are shown in Figures 4, 5, and 6 with a resolution of 1° x 1°. These results for major point source, area and mobile emissions for

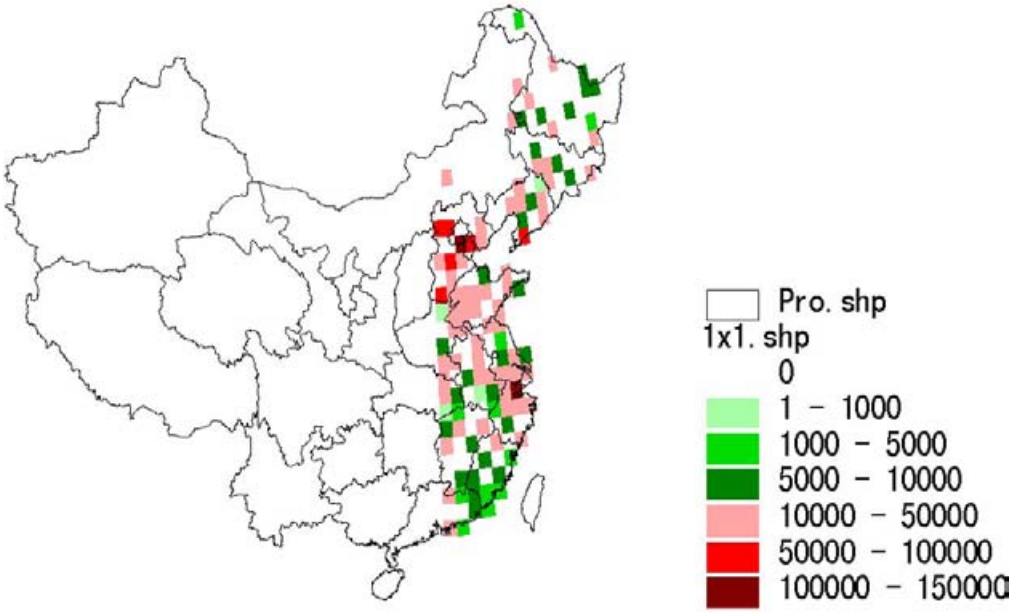
1998 annual averages are shown below.

Figure 4



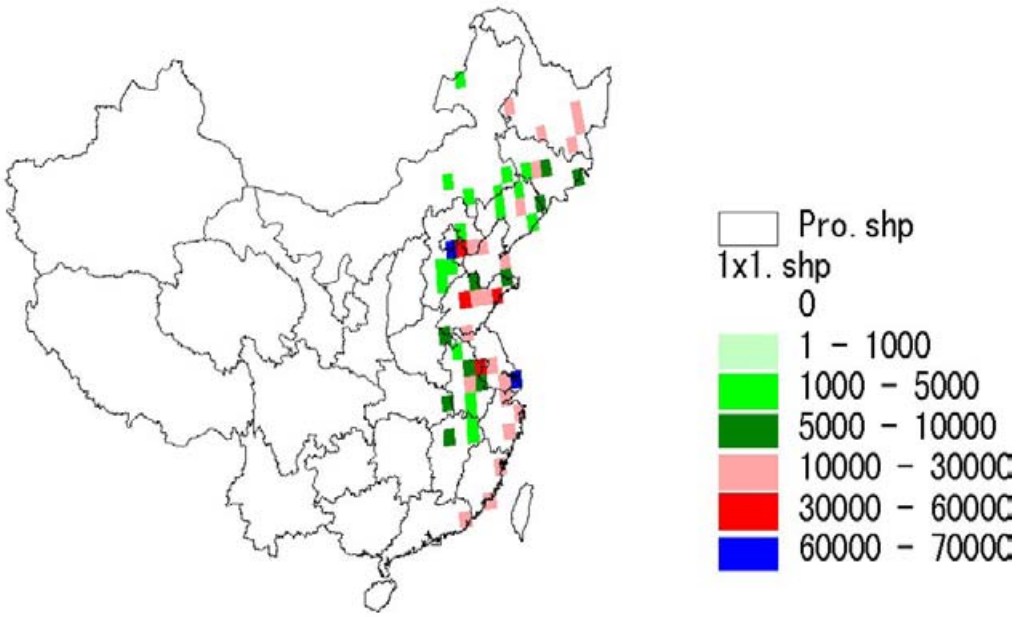
annual LPS NOx emission ton/1X1

Figure 5



annual area source NOx emission ton/1X1

Figure 6



annual nox emission from automobile ton/1X1

1.5 Modeling Source and Receptor Relationships

Modeling has been helping to characterize the relationships of emissions, air quality and acid deposition throughout the country. There have been many modeling research projects focusing on SO_2 pollution and acid deposition. In the Sixth, Seventh, and Eighth Five-Year Plans, studies of the regional transport of air pollutants and acid rain were conducted for southwestern China, southern China and eastern China, in the Minan area and in Xiameng, Quanzhou, Zhangzhou, and Qingdao. In the “Ninth Five-Year Plan,” a national project addressing the SO_2 control policy was carried out.

Powerful prediction and assessment tools have become available and applied in China since the 1980s beginning in the “Sixth Five-Year Plan.” Among these tools, the Eulerian models are preferred because they can handle complicated physical and chemical processes. Many foreign models, such as RADM and STEM II, have been adopted, and at the same time, Chinese modelers have developed models as well. At this point, many models have been adopted and applied. In this paper we highlight the Eulerian models that have been applied and developed by the Chinese modeling-subwork group of the long range pollutant transport (LPT) project.

In the “Seventh Five-Year National Research Plan,” CRAES developed a simplified

Eulerian model for southern China. The model uses the chemical bond mechanism and a one-dimensional model for cloud and precipitation. A traditional finite difference algorithm has been used for advection. In the “Eighth Five-Year National Research Plan,” this simplified model was used to study eastern China with a special focus on Southern Fujian. The model used a new Taylor-Garlerkin finite element algorithm for advection (1990) and only has a constant SO_2 to sulfate conversion rate.

In 1998, supported by a UNDP project in Guiyang, the China Air Quality Model (ChAQM), which is the RADM/SAQM model adapted for China, was used by CRAES to identify the possible long-range transport of SO_2 emissions in neighboring provinces and other areas of China. At the same time, also supported by UNDP, the CAMx model was used by the Peking University to simulate the ozone pollution in Guangzhou City caused mainly by mobile sources.

Other institutions such as Science Academy of China, Meteorological Sciences Academy of China and Nanjing University, Tongji University have also developed and employed Eulerian regional air quality and acid rain models.

1.6 Model Features

The major features of key Eulerian air quality models in China are listed in the following table. These features illustrate the range of complexity of the models. Blanks mean that the model does not include that feature. The CRAES Sulfur model is the simplest, with the ChAQM and CAMx being of similar complexity.

Name	RADM/SAQM/TAQM(ChAQM)	CAMx	CRAES Sulfur
Major Concern	SO_2 acid deposition, O_3	O_3	SO_2
Organization and contacts	CRAES, Meng Fan, Xu Jun	PKU, Hu Yongtao, Zhang Yuanhang	CRAES, Meng Fan
Domain	60×64,	27×27	24×28
Horizontal grid	60km,20km,6.7km	27km, 9km,3km	45km
Nesting	Two-way	Two-way	
Vertical grid and top	15 layers 100mb[spell out]	13 layers about 3,800 meters	9 layers 5000m
Advection algorithm	Bott(1989)	Smolarkiewicz (1983) Bott (1989)	Euler-Taylor-Galerkin definite element (Donea, 1987)
Subgrid transport and Diffusion	K-theory for non_convective boundary Pleim asymmetrical model for convective boundary	K-theory	K-theory
Gaseous Chemistry	RADM2 SAPRC97 CBMIV	CBM-IV/ SAPRC97	Constant conversion

Chemistry Solver	QSSA	ENVIRON CMC	
Cloud and precipitation model	1 dimension dynamic with microphysics	none	Diagnostic
Meteorology	MM5	MM5	MM4
Dry Deposition	Wesely	Wesely	Constant deposition velocity
Wet Deposition	Henry's Law for gases, complete scavenging	CALPUFF(EPA1995)	Constant

1.7 Model Studies

Each of these models has already been used to explore the relationships among emissions and impacts in China. Below are some highlights from these assessments. Each is summarized in terms of the study goal, episode or case examined, spatial domain and resolution (i.e., grid size) and emissions inventory year used for the analysis.

2. Sulfur Model Application by CRAES

Meng *et.al* (1996) combined use of a simplified 3-dimensional Eulerin model and a Lagrangian trajectory model to study the transport and deposition of sulfur in the Minnan area in Fujian province. They concluded that long-range transport (i.e., from sources outside of Fujina province) accounted for almost 60 percent of the total sulfur deposition.

Goal: To investigate the reason for high sulfate deposition in the Minnan area in Fujian province where SO_2 emissions are small.

Case: Southeastern China , Apr.3~9, 1990

Horizontal Grid Size: 45km

Domain: Horizontal: 1080km x 1260km; Vertical: 5000m.

Emission inventory: 1990

2.1 CAMx Application

Hu (2000) provides the detailed study of ozone done for Gangzhou City.

Goal: Simulate the Ozone pollution in Guangzhou City

Case: Guangdong Province, Oct. 16-20,1995

Horizontal Grid Size: 27km, 9km, 3km

Domain: Horizontal: 729km x 729km, Vertical: 3000m

Emission inventory: 1998

2.2 ChAQM Application

More details regarding this study can be found in Meng *et.al*. In the third working group expert meeting reports (meeting held in Seoul, Korea January 2001). A sample of results being analyzed for the ChAQM application are provided in the following section on analysis results.

Goal: Simulate the acid deposition and long range transport of SO_X, identify the impacts on Guiyang acid rain of the possible long-range transport from neighboring areas

Case: Eastern China, May 25 0:00 GMT 1998 -June 1 0:00GMT, 1998.

Horizontal Grid Size: 60km

Emission inventory: 1998

2.3 ChAQM Analysis Results

During a five-day period that was studied there were three high SO_2 concentration areas in China. The first one is in North China, including Inner Mongolia, Shanxi, Hebei, Henan, and Shandong provinces. The southern tip of this high concentration area covers the southern part of Shandong and the northern part of Jiangsu. The second one covers Chang Jiang River Basin and the area to the south of the Basin. The third high concentration area occurs in southwest China, including Chongqin and Guiyang. This area is relatively small but has very high concentrations.

During a five-day period that was studied, aside from the high concentration areas in China, areas in East Asia, Korea and the Yellow Sea to the north of Korea also showed high SO_2 concentrations. According to the wind patterns, these high concentrations seem to be the result of transboundary transportation from Chang Jiang River Basin to Japan and Korea. The local SO_2 concentrations in Korea should be caused by Korea's own emissions. There obviously exists a high concentration area in China and East Asia spanning eastward from the middle part of Chang Jiang River to southern Japan. Sulfate concentrations in the middle and down parts of Chang Jiang river also indicate long-distance transport. This possibly leads to the high concentration of sulfate in southern Japan.

Northwest China does not experience severe SO_2 pollution. Pollution in this area seems mainly local. This provides room for the plan of sending electricity from west to east in the development of the western part of the country. Building more coal-fired power plants in southwest China is an issue that needs further study because pollution control costs may be substantial in the long term due to the existing SO_2 pollution and acid rain as well as high sulfur content of coal in this area.

Given the complexity and challenges of modeling, another visual analysis tool has

recently been developed in the U.S. It was developed for the purpose of studying acid deposition and could provide valuable analysis insights for China. The U.S. EPA's Clean Air Mapping and Analysis Program (C-MAP) is a Geographic Information System (GIS) assessment tool being used to better understand and characterize the benefits of national and regional pollutant emission reduction programs. C-MAP allows the user to visualize and query a variety of emissions, concentration, deposition, and impact data. This analysis provides a compliment to the more in-depth modeling. The more complex modeling, of course, remains the necessary analysis tool for exploring future scenarios.

3. Scenarios for Sulfur Dioxide Emissions Reductions

Recent analysis (Wu, Wang and Meng, 2000) proposed scenarios for total amount reductions of SO_2 during the "Tenth Five-Year Plan" in China. This study recommended that the total load level of SO_2 emissions be controlled to 19 million tons by 2005. These estimates used the "Ninth Five-Year Plan" as a starting point. The plan indicated that the SO_2 emissions nationwide had to be controlled to 24.6 million tons. The study also provided an initial scenario for the total load control of SO_2 at national levels and for the SO_2 Control Areas and Acid Rain Control Areas (i.e., the "Two Control Areas"). Highest controls are indicated for Guangxi, Chongqing, and Guansu regions. Inner Mongolia, Sichuan, Guizhou, Yunnan, Qinghai, Ningxia, and Sinkiang are next in levels of required reductions. Lowest levels needed are indicated for Shaanxi and Tibet. These results will be helpful in setting permitted SO_2 emissions levels for the pilot regions where emissions trading of SO_2 are or will be conducted.

4. Next Steps

To evaluate strategies for dealing with the short and longer term impacts of SO_2 and related chemicals, the relationships among pollutant sources and impacts will need to continue to be assessed in detail. High quality data requirements remain an important pre-requisite for such assessments. A number of Chinese initiatives are underway or contemplated. In general, the next phases of work in China aim to broaden and deepen emissions inventories and expand monitoring of air quality and deposition as well as meteorological parameters.

The enhanced monitoring of air pollution and deposition, development of more accurate and integrated emissions inventories, increased use of GIS mapping to illuminate relationships through data analysis and use of more complex chemical/physical models will provide long term benefits in the development of even stronger analysis capabilities.

These capabilities, in turn, will enhance China's ability to develop an effective SO_2 emissions trading program.

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