Emissions Trading in China:
A Conceptual 'Leapfrog' Approach?

by Roger Raufer[*] & Shaoyi Li

Working Paper
For submission to: *Energy: The International Journal*

Affiliations:

Roger Raufer, Ph.D., P.E.
Independent Consulting Engineer
www.roger-raufer.com
& Lecturer/Senior Faculty Fellow
University of Pennsylvania

Shaoyi Li
Chief, Energy Resources Section,
Environment and Development Division,
United Nations Economic and Social Commission for Asia and the Pacific,
Bangkok, Thailand

Abstract

China is well aware of the advantages of quantity-based economic instruments (i.e., emissions trading) for domestic pollution control, but pilot studies and experimental programs in Taiyuan, Hong Kong/Guangdong, and other locations have not been successful. This paper proposes a very different type of emissions trading program, designed with Chinese implementation concerns in mind. It has three component parts: 1) a real-time intermittent control system (ICS) strategy designed to address public health concerns in the near term; 2) software-oriented Predictive Emissions Monitoring systems (PEMS) targeting process parameter (rather than emission) reporting from individual emission sources; and 3) real-time emissions markets responding to the ICS constraint. The technical and political difficulties associated with implementing such a system are recognized as daunting. However, such an approach would 'leapfrog' over existing systems, allowing the country to develop a comprehensive air pollution control strategy as economic growth occurs, continuously improving air quality in a cost efficient manner, utilizing both advanced technology and market-based control approaches in a manner consistent with China's unique environmental needs. It would also lay the groundwork for the eventual pricing of CO_2 and other greenhouse gases within China.

---

[*] Corresponding author: email address: rr@rogerraufer.com

Introduction

China has been undergoing significant changes across many fronts in recent decades. The country is experiencing accelerating urbanization, and the government has made this an important element of its economic development plan. Importantly, urban residents use about 3.5 times as much energy as their rural counterparts [1], and the environmental impacts of such increased energy use are also more concentrated. The country has seen extremely rapid economic growth, averaging 9.5% for the past two decades [2], and this growth has required an accompanying energy infrastructure. There have also been structural shifts in the economy in recent years, leading to even further increased energy utilization from heavy, energy-intensive industries such as steel and aluminum [3]. All of these factors have significant effects upon air quality, and according to the World Bank, China has 16 of the 20 most polluted cities in the world [4].

Just as the economic conditions have changed, the nature of air pollution in Chinese cities has also changed. In its early stages of economic development, heavy use of coal, coupled with inefficient boilers and combustion systems led to very high concentrations of both total suspended particulate (TSP) and sulfur dioxide in urban areas. A number of significant steps were taken to address these concerns, including fuel shifts (e.g., increased use of natural gas and town gas, increased use of LPG, etc.); prohibitions on open burning and other area emission sources; and better pollution control on major facilities. As a result of this, the coarser TSP levels have decreased over recent decades. Like other countries, however, China has increasingly focused on the finer PM-10 and PM-2.5 fractions, which have more significant health effects, and these are considerably more difficult to monitor and regulate. Chinese levels of fine particulate remain well above those in advanced economies.

Sulfur dioxide ambient levels have also decreased, although there has been a significant increase in emissions associated with increased power plant construction in recent years. These latter emissions occur from taller stacks, often at a distance from urban areas; and although their contribution towards urban SO_2 levels is not as significant, the secondary particulate they (along with NOx and VOC emissions) help to generate from chemical reactions in the atmosphere has become a noticeable element of China's air quality.

This has been exacerbated by new mobile source-related emissions in Chinese cities. Emissions of NOx and VOCs have led to high ground level concentrations of ozone in Chinese cities, and the increased rates of oxidation

---

[1] Economy E. The Great Leap Backward?, *Foreign Affairs*, Sept./Oct. 2007. (Shaoyi to confirm statistic and obtain governmental reference.)
[2] See http://www.chinability.com/GDP.htm. (Shaoyi to confirm statistic and obtain governmental reference.)
[3] Houser, T. et al., *Leveling the Carbon Playing Field: International Competition and US Climate Policy*, Peterson Inst. for International Economics and World Resources Inst., Washington, DC, May, 2008.
[4] Cited in “A Great Wall of Waste,” *The Economist*, Aug. 19, 2004

in the atmosphere have had a deleterious effect on previous traditional fuel-related emissions, leading to especially high levels of fine particulate.

As Shao et al. note: "While it is true that these processes are observed in many locations around the world, the conditions prevalent in China -- high concentrations of SO_2, oxidants, and their precursor components, as well as the comparatively high concentrations of suspended particles, etc. -- result in a level of aerial chemical interactions that is probably unique to the country." [5]

Tackling this unique air quality problem has been very difficult for the Chinese government. The country has invested heavily in fuel shifts, pollution control, and more stringent vehicle emission standards, but institutional and other factors play a key role in their implementation. Flue gas desulphurization technology has been mandated for all major power plants, for example, but non-compliance on the part of individual sources in the country is well known. SEPA itself noted that 60% of the installed FGD units in the country were not operated [6], since in many cases the pollution levy for non-compliance is lower than the operating costs of the equipment.

Shao et al. have argued that such measures might be effective for the abatement of some primary pollutants, and have, to some extent, slowed the rate of increase of pollutant emissions, but "they are insufficient for the control of secondary pollutants and the resulting chemical interactions that form the core of the air pollution complex model."[7]

China has explored the idea of using emissions trading [8], but given the unique chemical, institutional and economic development factors that are found in the country, it should not be surprising that traditional emissions trading approaches have not been successful to date in addressing air pollution concerns.

A Different Approach?

The Chinese government recently shut down major polluters in five provinces near Beijing for several weeks in order to have clean air during the Beijing Olympics. This was a "one-of-a-kind chance to study the large-scale effort in a uniquely urban laboratory," according to one media report [9], and the

[5] Shao M, Tang X, Zhang Y, Li W. City clusters in China: air and surface water pollution. *Frontiers in Ecology and the Environment* 2006; 4(7): 353-61
[6] Sun X. *Authorities Work on SO_2 Trade System*, CHINA DAILY, Sept. 14, 2006, see: http://www.chinadaily.com.cn/china/2006-09/14/content_688449.htm
[7] Shao et al. *op. cit.*, p. 358.
[8] See, for example, Wang J, Yang J, Ge C, Cao D, Schreifels J. Controlling Sulfur Dioxide in China: Will Emissions Trading Work?, *Environment*, 2004; 46 (5): 28-39; and Morganstern R, Abeygunawardena P, Anderson R, Bell, RG, Krupnick A, Schreifels J, Cao D, Wang J, Yang J, Larsen S. Emissions Trading to Improve Air Quality in an Industrial City in the People's Republic of China, Discussion Paper 04-16, Resources for the Future, Washington DC, April 2004.
[9] Tran T. Pollution curbs turn Beijing into urban laboratory, Associated Press, August 3, 2008.

result was "the best air quality in ten years" according to local environmental protection bureau officials [10].

The idea of controlling emissions in real-time is not new. In the U.S., for example, State Implementation Plans developed in the early 1970s for air pollution control were required to have 'emergency episode plans' which prescribed actions to be undertaken in the event of severe pollution episodes, and the topic has also received some academic attention [11].

More interesting, however, were the "intermittent control strategies" (ICS) proposed by some companies at that same time to meet the air quality goals (i.e., the National Ambient Air Quality Standards [NAAQS]). Under ICS, air quality impacts from individual sources were determined in two ways: 1) by conducting meteorological forecasting, and running those forecasts through dispersion models to estimate impacts; and 2) by establishing enhanced ambient monitoring networks around such facilities. If either the dispersion modeling or the ambient monitoring indicated that the NAAQS would likely be exceeded, then the individual facilities were required to undertake specific control activities. An overview of the 1970s ICS approach is outlined in Figure 1 [12].

ICS worked on the principal that ambient air quality standards were likely to be met under most meteorological conditions -- but that special control actions would be necessary at certain other times. For major emissions sources such as power plants or smelters, for example, worst case ambient concentrations were typically found under "B" stability trapping conditions (i.e., when the nearby atmosphere was unstable, with considerable vertical mixing, and with a temperature profile that resulted in a mixing height sufficiently low to "trap" the facility's plume).

ICS was typically applied to such major individual emission sources -- not cities -- but the underlying approach merits further consideration. If ICS was triggered, the facility might then be required to:

- shift fuels (e.g., for coal-fired facilities, shift to fuel oil or natural gas);
- shift to higher quality, same-type fuels (e.g., for coal-fired facilities, shift to lower sulfur/lower ash coals stockpiled on site);
- co-fire such higher quality fuels;
- if a power plant, shift the load to another type of low-emitting facility (e.g., hydropower or gas-fired units), or to a more distant location;
- curtail/reduce operations; or

[10] Ying T. Beijing's air quality is best in a decade, Government says, Bloomberg.com, August 19, 2008; see also Sanderson H. Beijing claims early victory over air pollution, Associated Press, December 1, 2008.
[11] See, for example, Kyan C, Seinfeld J. Real-Time Control of Air Pollution, *AIChE J.*, 19 (3), May 1973: 579-589.
[12] Adapted from PEDCO Environmental, *Assessment of Alternative Strategies for the Attainment and Maintenance of National Ambient Air Quality Standards for Sulfur Oxides*, Preliminary draft report to USEPA, December 6, 1974; cited in *Air Quality and Stationary Source Emission Control*, A Report by the Commission on Natural Resources, National Academy of Sciences, National Academy of Engineering, and National Research Council, Prepared for the Committee on Public Works, U.S. Senate, Washington DC, March 1975, p. 492

- shut down

ICS has been employed since the 1930s [13], but its best known application was in the early to mid-1970s when the Tennessee Valley Authority (a federal agency of the U.S. national government) undertook an extensive ICS program called the Sulfur Dioxide Emissions Limitation (SDEL) program at nine of its 12 coal-fired power plants [14]. At one of their large (2558 MW) coal-fired plants, SDEL control activities were triggered on 96 days over a 5½ year period, and included generation reductions ranging from 9 MW to 970 MW, for a period ranging from 0.2 to 6 hours [15].

Its application at industrial sites has required somewhat higher control action frequencies [16], and there have also been some broader, multi-facility applications [17]. But like the 'tall stacks' approach (which relied on dispersion of pollutants as a means of achieving NAAQS), the U.S. Congress ultimately disallowed the use of ICS as a permanent solution. The continued emissions of pollution under tall stacks or ICS policies would not be sufficient to address such problems as acid rain, which resulted from the total, cumulative loading of pollutants. Full-time controls were clearly necessary instead.

But ICS was allowed in the U.S. for certain sources that had employed it previously [18] and the approach also received consideration as an "interim" strategy [19] whereby firms would be required to use it to protect public health in the short term while full-time FGD or other control equipment was being constructed [20].

---

[13] Montgomery TL, Frey JW, Norris WB. Intermittent Control Systems, *Environ. Sci. & Tech*., 9 (6), 1975: 528-533.
[14] The other three met all primary and secondary NAAQS.
[15] Leavitt J, George L, Clark R. Sulfur Dioxide Emission Limitation (SDEL) Program at TVA Power Plants, *J. of the Air Pollution Control Assoc*., 26 (12): 1976: 1133-1140.
[16] The Horne smelter in Canada reduced its production capacity by about ten percent in a typical year in order to meet ambient standards. See Anonymous. Horne Smelter, *Canadian Mining Journal*, Jun/Jul, 2000, 121 (4): 15-17; Control actions were required on 43% of the days at one Dow Chemical plant employing ICS in Michigan. See Merlino R, Rocco V. An Operational Supplementary Control System for Industrial and Utility Applications, Proc., 5th Annual Conf. on State-of-the-Art of Air Pollution Control for Industrial Processes and Power Generation, Knoxville, TN, April, 1975. Cited in Norco J, Raufer R.. *The Air Quality and Economic Implications of Supplementary Control Systems in Illinois*. Illinois Institute for Environmental Quality Document No. 75/22, Chicago, IL, November 1975; Dispersion modeling for Illinois suggested that industrial facilities would require sulfur dioxide control on approximately 30-40% of days. See Norco J, Raufer R, Roberts P. The Air Quality and Energy Implications of Supplementary Control System Implementation, Proc., 68th Annual Meeting of the Air Pollution Control Assoc., Boston, MA June 1975.
[17] Crooks G, Ciccone A. A Computerized System to Measure and Predict Air Quality for Emission Control. Proc., 90th Annual Meeting of the Air & Waste Mgmt. Assoc., Toronto, CA, June, 1997; The primary author helped to design an ICS/SCS in central Illinois in the U.S. in 1975 that involved two power plants and a chemical plant.
[18] See 40 CFR 51.119
[19] *Air Quality and Stationary Source Emission Control*, supra note 13, p. 521.
[20] Accordingly, ICS are sometimes referred to as "supplementary" control systems.

From China's perspective, if applied broadly (with the significant implementation concerns discussed below), ICS might offer a means of protecting public health during the considerable (perhaps decades long?) "interim" period until the country can fully achieve its pollution control goals. In some respects the five province pollution control effort for the Beijing Olympics might be viewed as a rather draconian ICS, utilizing only shutdowns, to protect the health of visiting foreign athletes. It might be feasible to utilize much less onerous means -- with targets becoming increasingly stringent over time -- to protect the public health of its own citizens.

Obviously, ICS must not be seen as an excuse for back-sliding for those emission sources currently operating under mandated control requirements; full time controls are still necessary in China. Rather, the ICS approach could serve as a supplement to -- not a replacement of -- the existing pollution control requirements. If an emission source was fully operating its FGD, for example, its additional requirements under ICS should be minimal. Those 60% of facilities not operating their FGD when the ICS threshold was triggered might be required to stockpile better fuels for just such an occasion, in the event that the FGD was not operable at that time. The PEMS component discussed below is explicitly designed to ensure continued (and, in fact, increased) compliance for all existing regulatory requirements.

If employed in conjunction with the proposed components described below, and as a supplement to existing mandated requirements, ICS could offer an efficient and cost-effective means of accomplishing air quality goals.

Information/Communications Technology

Historically, firms have reported emissions based upon mass balances of fuel use, process material throughput, and similar measures. This began to change in the 1970s, when continuous emissions monitoring systems (CEMS) were introduced. CEMS typically take a sample of exhaust gas, run it though a specific emissions analyzer (e.g., for NOx, CO, etc.), and then determine actual emissions. These emissions data can then be cataloged in a data acquisition & handling system (DAHS) and reported on a mandated time-averaged basis (e.g., monthly or quarterly). Such data can also be delivered by telemetry to an environmental regulatory agency, and this is routinely done for certain types of major pollution sources such as municipal waste incinerators.

Like other information technology, the price of CEMS has continued to drop over the years, although their operations and maintenance costs can be high because they operate within a harsh physical environment, and need extensive calibrations and quality assurance/quality control efforts to maintain accuracy.

When the market-based approach for acid rain control was introduced in 1990, there was an increased focus on technological approaches to determining emissions, since both regulator and polluter have an interest in obtaining accurate data: regulators want to know the status of a facility's emissions in order to ensure that it holds sufficient allowances, while polluters are faced with the fact that all emissions cost money, in the form of surrendered allowances -- and so they too want to make sure that they aren't paying for inaccurate emissions.

As Henriquez notes, "the concept of a market in emission allowances was attractive in theory, but information technology made it happen"[21]. He suggests that there were three essential features of the digital infrastructure for allowance markets: 1) CEMS, which are mechanical devices that sampled, analyzed, measured and recorded emissions on a continuous basis at the power plants. Their capital and operating costs represented about 7% of observed compliance costs in the early part of the control program [22]; 2) EPA's Emissions Tracking System (ETS), which one senior EPA market-policy staffer termed "the backbone of the system." It analyzed the CEMS data being submitted, and assured the regulator that sources were complying with allowance requirements; and 3) EPA's Allowance Tracking System (ATS), which served as the central registry for allowances utilized for compliance with the program.

Any market-based pollution control system will require emissions and allowance tracking on the part of the regulator, as in the ETS and ATS above -- but the problems in China are more closely related to obtaining accurate information about emissions from individual polluters. CEMS are required for major facilities, but they too tend to work sporadically. Facilities usually blame the calibration and operations/maintenance requirements of the CEMS equipment, but operators would obviously be reluctant to make apparent and document their operating non-compliance.

As part of a new effort to strengthen its acid rain control program, China is putting renewed emphasis on CEMS, expanding the requirements to include smaller emissions sources, as well as providing new enforcement personnel to conduct environmental audits. But the rapid change in information/communications technology might offer an alternative solution for this concern as well.

This alternative approach does not place mechanical equipment in the exhaust gas, but instead goes to the control room of the facility. In order to operate, the plant operator must know and track a wide range of process information concerning temperatures, pressures, flow rates, damper positions, valve settings, and similar parameters at various points throughout the process. What if such data -- which have to be known anyway -- could be used to estimate the facility's emissions?

There are two general approaches for doing so. The first is usually referred to as parametric modeling, and it relies upon physical principles (e.g., the first and second laws of thermodynamics, etc.) and analytical methods (e.g., numerical analysis techniques) to describe the dynamics of the specific process occurring at the facility. Essentially it tries to "understand" what is going on in the process, and then attempts to estimate emissions accordingly.

---

[21] Henriquez B. Information Technology: The Unsung Hero of Market-based Environmental Policies, *Resources* (152) Fall/Winter, 2004: 9-12.
[22] Ibid., p. 11.

A second approach takes an artificial intelligence (or "adaptive") approach, and "trains" software (usually using neural network techniques) to estimate emissions based upon historical operating data and emissions testing results. It does not try to understand what is going on within the process, but rather looks for key process variables and patterns that offer a good fit for emissions data estimation.

These approaches utilizing process parameters (rather than exhaust gas samples) for estimating emissions are usually referred to as "predictive emissions monitoring" (PEMS) [23]. There are obviously a range of analytical approaches for developing PEMS systems, some relying on statistical regressions as well as the general approaches noted above. Some pollutants are difficult to estimate using parametric modeling -- notably NOx and CO -- because small differences in combustion and flame conditions can lead to significant differences in output [24]. But these pollutants have been successfully estimated utilizing other PEMS approaches [25], and have, in fact, become the two most prevalent pollutants addressed by PEMS [26].

More than 10,000 MW of power plants in the US and Europe have installed PEMS [27], and it has also been employed in Taiwan [28]. One promising aspect of this approach is that it can also be used in a wide range of other factories and manufacturing facilities as well (including iron and steel facilities [29], pulp and paper [30], and even maritime applications [31]). Proponents suggest that the better understanding of process conditions that occurs when such systems are implemented ultimately leads to improved productivity at the facility as well as better environmental management, and much of the marketing of process control software is directed at such purposes.

From China's perspective, however, the use of PEMS has a number of practical characteristics: 1) they can be as accurate and reliable as CEMS; 2) they can be considerably cheaper than CEMS [32] (i.e., most cost estimates put them in the one-third to one-half range [33]); 3) they can be applied to a wide range of emissions sources; and 4) sources have to know their process

---

[23] For an overview of this technology, see Reinermann P. The Maturation of a Technology: Predictive Emissions Monitoring, *Chemical Engineering*, July, 2006: 50-55.
[24] Sharpe P. Real-Time Monitoring System Optimizes Operation of Industrial Power Plant, *Power Engineering* 104 (9): 45-48.
[25] See, for example, Cheng A, Blankenship E. PEMS Meets Boiler NOx CEMS Requirements, *Power Engineering*, 102 (10) October, 1998: 40-45.
[26] Reienemann P. *op. cit.*, p. 50.
[27] Hadjiski M, Boshnakov K, Christova N. Simulation-Based Predictive Emissions Monitoring System, Proc., 19th European Conf. on Modelling and Simulation, 2005.
[28] Chien T, Chu H, Hsu W, Tu Y, Tsai H, Chen K. A Performance Study of PEMS Applied to the Hsinta Power Station of Taipower, *Atmospheric Environment*, 39, 2005: 223-230
[29] Ionescu A, Candau Y. Air Pollutant Emissions Prediction by Process Modeling -- Application in the Iron and Steel Industry in the Case of a Reheating Furnace, *Environ. Modeling & Software*, 22, 2007: 1362-1371
[30] Thé J, Walton, C. Predictive Emissions Monitoring for Advanced Environmental Management, *Pollution Engineering*, 37 (3), March, 2005: 57-58.
[31] Cooper D, Ekstrom M. Applicability of the PEMS Technique for Simplified NOx Monitoring On Board Ships, *Atmospheric Environment*, 39, 2005: 127-137.
[32] They essentially eliminate all of the annual O&M costs associated with CEMS.
[33] See for example, Ibid., p. 40; and Chien et al., op. cit., p. 1028.

conditions in order to operate [34]. But perhaps most importantly, process data could be transmitted to the regulator instead of emissions data; and if the source didn't know or understand the corresponding relationships between process parameters and emissions, it would be rather difficult to "game" the compliance system. Such an approach would introduce its own implementation concerns, as noted below -- but overcoming the issue of non-compliance is crucial for any (i.e., command/control, market or other) pollution control program's success within the country.

Real-time Emissions Trading

A third important component of the proposed 'leapfrog' approach is utilizing emissions markets to accomplish the environmental goal, but doing so in real-time.

ICS and PEMS have historically evolved within a "command/control" environmental regulatory framework, but there is no reason why these components could not be set within an environmental market. Any "cap and trade" program sets a collective quantitative constraint (or "cap") on emissions, and the trading provisions allow markets to respond with a corresponding price for emissions. While these have historically been employed on an annual basis (e.g., the EU ETS or the US acid rain program), or a seasonal basis (e.g., the US NOx Budget), if incorporated with an ICS such markets could operate in real-time.

While this might seem a radical departure, in fact it is consistent with existing trends in other environmental-related markets. Much of the initial infrastructure for environmental markets has evolved around the electric power sector, for example, which has historically been the major source of emissions [35]. Since power cannot be stored, sophisticated power trading systems have also evolved in the U.S. and Europe. As significant levels of intermittent renewable energy systems (such as wind energy) have been introduced, this is putting increased focus on real-time capabilities in system operations [36]. The market-based Renewable Energy Credits (RECs) verification systems are closely linked to power pooling systems [37], and the technical ability to measure the generation and emission attributes for any given MWh now exists (even if it is not routinely employed). The ability to bundle or unbundle those attributes for different local, regional, national and international environmental markets has already received attention, as has the linkage between RECs and environmental allowances/credits. Although

---

[34] For a discussion of the use of PEMS from a regulatory perspective, see Eghneim G. Thoughts on Predictive Emissions Monitoring from a Regulatory Perspective, *J. Air & Waste Mgmt. Assoc*., 46, Nov., 1996: 1086-1092; and Macak J. The Pros and Cons of Predictive, Parametric, and Alternative Emissions Monitoring Systems for Regulatory Compliance, Proc., 89th Annual Meeting of Air & Waste Mgmt. Assoc., Nashville, TN, June, 1996.

[35] The SO_2 market for acid rain, the NOx Budget, etc. in the U.S.

[36] See, for example, Reid B, Thornton A, Ngo B, Adib P. Wind resource integration information for the future, APX Inc., Santa Clara, CA, 2008. At http://www.apx.com/documents/Wind-Resource-Integration-in-Grid-Operations.pdf

[37] See Musier R. U.S. Mandatory REC Markets -- An Established Environmental Infrastructure, APX Inc., Santa Clara, CA. 2006. At http://www.apx.com/documents/Whitepaper--US-Mandatory-REC-Markets.v.Final.pdf

no environmental emission markets have yet moved towards real-time, it is ultimately likely to happen.

There are several powerful advantages for employing such a real-time market approach:

- *Economic efficiency*. Markets achieve the pollution control in an efficient manner, since all sources face the same marginal costs of control necessary to achieve the environmental goal. Polluters respond by considering their own economic situation; if they are continually paying for excessive emissions, or having to curtail operations, or shutting down under the ICS, then switching fuels or adding pollution control equipment becomes quite economically attractive.
- *Distributive elements of design*. As market proponents know, a key advantage of quantity-based market systems over Pigouvian taxation is that the former allows market regulators a wide range of distributive properties, without significantly changing economic efficiency. At one extreme, regulators can give away pollutant allowances for free to the polluters (typically called 'grandfathering'); at the other, they can auction off all of the allowances, resulting in a significant wealth shift from the private to the public sector. Since the distributive effects can be manipulated without affecting efficiency, Asian market designs could use such distributive properties to address sustainable development concerns (including energy access concerns).
- *Gradual achievement of goals*. Another important advantage is that the regulator can gradually tighten the constraints over time (much like air pollutant markets such as RECLAIM in Southern California have done), and therefore allow for economic growth while the goals are accomplished. China could thus continually improve its air quality over time, in an economically efficient manner.

Implementation of Conceptual Approach

A fully integrated ICS/PEMS/ET program is shown in Figure 2. It is certainly recognized that each component of the proposed approach presents daunting technical and political challenges; integrating them into a coherent, functioning air quality management system is likely to take years -- or, more likely, decades. It will be necessary to take a step-by-step approach [38], tackling each of the components in a phased approach, and perhaps introducing ICS and PEMS together before introducing real-time ET market components.

Major implementation considerations that would have to be addressed include the following:

---

[38] The difficulties associated with implementing market-based strategies in developing countries are discussed in Bell RG, Russell C. Environmental Policy for Developing Countries, *Issues in Science and Technology*, Spring, 2002: 63-70; and Blackman A, Harrington W. The Use of Economic Incentives in Developing Countries: Lessons from International Experience with Industrial Air Pollution, Discussion Paper 99-39, Resources for the Future, Washington DC, May 1999.

1. Intermittent Control Systems

Air quality in China tends to be best in the Southern part of the country, and worst in the Northwest, with the latter due in part to climatic conditions (including coal combustion for heating) as well as significant industrial emissions (including those from extractive industries). Even in Northwestern cities, however, days with "good or excellent air quality" occur more than two-thirds of the time [39], so there is considerable opportunity to take cognizance of meteorological conditions in developing strategies to address worst-case public health episodes.

But there are a number of very significant implementation problems that ICS must address, and feasibility studies may very well limit its applicability accordingly:

- ICS has historically been implemented near individual emission sources, rather than in urban areas. This is because the pollutant impacts from such major sources were deemed significant, but also reflected the fact that responsibility for exceeding the ambient threshold could be clearly established. This is not likely to be true in an urban area.

- ICS has historically dealt almost exclusively with one primary pollutant -- sulfur dioxide -- which is directly emitted from an individual source. As noted earlier, China has a primary pollution control program (with implementation and compliance concerns), but much of the air quality concern is associated with secondary pollutants resulting from atmospheric chemistry.

- ICS has not historically been used in developing countries, because the technical requirements of such systems -- dispersion modeling, emissions and ambient monitoring, load shifting opportunities, etc., all operating in real-time -- have not usually been readily available.

Each of these problems is likely to serve as a constraint in developing an ICS program in China. It may be necessary to initially develop the system including only major emission sources; the dispersion models are not likely to be sufficiently robust to address the problem, particularly given its secondary nature; it will be extremely difficult to assign relative responsibilities for control; and the necessary investment -- and economic impact of operational curtailments -- might prove to be significant.

On the other hand, the air quality problem is severe, and it causing tremendous economic damage to the country and its citizens; any actions undertaken under ICS would address the most severe, short-term problems, and improve the situation over time. Dispersion modeling, computing and

---

[39] World Bank, *China; Governance, Investment Climate, and Harmonious Society: Competitiveness Enhancements for 120 Cities in China*, World Bank Report No. 37759-CN, Beijing, 8 October 2006.

information systems have improved dramatically in recent decades, and China would be well-served by trying to utilize such advancements to tackle its environmental problems. ICS is fully compatible with China's centralized administrative and political system, and it is also one that could be implemented at the urban or regional level.

And while the cost might be significant for a developing country, it is typically much lower than the economic damage caused by the pollution. A conservative analysis of control efforts in the power sector in China found that "the quantifiable health and non-health benefits of controlling SO_2 emissions from existing power plants will outweigh the costs by a ratio of more than 5 to 1 with significant additional benefits that were not assessed."[40] Since ICS was originally proposed as a less expensive means of achieving air quality goals, and could potentially address pollutants beyond sulfur dioxide, the benefits are likely to be quite significant.

2. Predictive Emissions Monitoring

PEMS is likely to face technical and political implementation problems of comparable magnitude, and here again feasibility studies may well limit its applicability.

When applied in the West, PEMS have usually been developed by individual emission sources seeking an alternative to CEMS or other monitoring requirements. These sources have therefore borne all of the development and "training" costs associated with the PEMS approach, and have also typically integrated the system with their control room data flows and functions.

The PEMS approach outlined in this paper is quite different. It is essentially a "hostile" one, with the environmental regulator saying to emission sources: "We don't believe your emissions reports, so we're coming in to your control room to find out what is really happening."

This obviously leads to numerous technical and political concerns:

- Who develops the PEMS? Since these are sophisticated and analytically rigorous efforts, typically requiring considerable unit-specific testing and development, emission sources are unlikely to be willing proponents of PEMS -- especially so if the regulator controls the model and the outputs. Could the government apply "generic" PEMS

---

[40] US-China Joint Economic Research Group. Economic Analyses of Energy Saving and Pollution Abatement Policies for the Electric Power Sectors of China and the United States: Summary for Policymakers, US-China Joint Economic Study, 2007; The U.S. received approximately $45 of value in terms of reduced mortality, morbidity, and other negative impacts for every dollar spent on air pollution control over the period 1970-1990. See Davies J, Mazurek J. *Pollution Control in the United States: Evaluating the System*, Resources for the Future, Washington, DC. 1998.

to smaller sources? [41] Would a gradation of performance specifications be acceptable in a government-run program?

- Who runs the PEMS? If the PEMS model (whether parametric or adaptive) is seeing a data stream in real-time, and the regulator wants to assure that the polluter cannot 'game' the system, then it should control the model and resulting output. This obviously increases the regulator's administrative burdens considerably.

- How would a PEMS program be integrated with the existing CEMS program already in place in China? Should PEMS estimates be required if CEMS data recovery fell below certain required levels? PEMS already serve an auditing function for CEMS, and its use -- for major sources, in any event -- might well lie in this area instead.

3. Real-time Emissions Trading

Like ICS and PEMS, the development of real-time emissions markets represents a considerable leap, in both technical and political terms. Conceptually, one would ultimately hope to design a system whereby polluters faced a price for all of the individual pollutants they emitted. Initially, they might pay less on clear, windy days than on days with calm, low level inversions; over time, as the goals became increasingly stringent, they would change their operations and make investment decisions that would reflect the higher costs associated with these more stringent societal air quality targets.

It seems likely that market development would lag the introduction of both ICS and PEMS. The former could be implemented quite quickly under the command/control framework, as it has operated in other countries; the latter over time as technical and political concerns are addressed, increasing compliance within China's existing regulatory system. Both of these programs could be employed across a wide range of emission sources within the country.

When markets are subsequently introduced, they are likely to focus initially on primary pollutants (e.g., SO_2 and NOx); major emission sources (such as power plants, cement plants, and similar facilities); and annual (rather than real-time) compliance period (like the existing US acid rain market, and the proposed SO_2 system for acid rain that China is now exploring). This would allow the country to develop the market infrastructure and regulatory experience it needs, supported by the 'interim' ICS protection of public health and PEMS attention to compliance.

Such a graduated implementation plan introduces its own implementation concerns:

---

[41] In the early stages of the program, many sources might find generic applications acceptable -- but as market-oriented emissions trading constraints began to take effect, they might decide that investing in better-trained software was a more cost effective option.

- What are the proper steps and incremental timing for the individual components, in terms of pollutants and affected sources? How long should planners assume it will take to meet current ambient air quality goals?

- What are the geopolitical boundaries for different market structures (e.g., national, provincial, city, etc.) and pollutants?

- How might the distributional aspects of market design be employed to address sustainable development concerns (e.g., poverty)?

- Should the markets be expanded (or parallel markets established) to include RECs and/or white certificates for energy efficiency?

Obviously, one of the major reasons for structuring domestic environmental markets would be to ultimately introduce market constraints (and prices) for CO_2, and other greenhouse gases. This would enable China to enter the international carbon market, in a manner consistent with its own development and environmental goals. It currently supplies certified emission reductions (CERs) under the Clean Development Mechanism of the Kyoto Protocol, but demand for such CERs is essentially European. If European or potential U.S. reliance on such credits is reduced in the near term (either due to disagreement over the form of post-Kyoto agreements, or economic factors currently affecting emissions markets), the significant problems associated with Asian emissions growth does not go away. Ultimately, Asia needs demand for carbon reductions as well as supply -- and the domestic emissions markets will provide the framework for developing that demand.

Finally, over time, one would hope that the real-time program would evolve into a vibrant energy/environmental marketplace, operating in several tiers. Pollutants such as particulates would have relatively small, localized trading; sulfur dioxide and NOx would trade over a larger, regional (and potentially national) scale; and CO_2 could trade in international markets. RECs, white certificates, and real-time power pooling/trading -- which do not yet play a major role in China -- could eventually come to play a significant role in meeting environmental concerns as well [42].

And while any "interim" solution such as ICS should ideally put itself out of business over time (as sources came to be fully controlled), experience suggests that this is not likely to happen, for two reasons: 1) societies tend to make their environmental goals more stringent over time (i.e., by tightening ambient standards); and 2) even in a "post-control" world, urban areas tend to face risks from toxic pollutants (what the U.S. EPA terms "residual risk" [43]) which could be addressed in such a manner. The scale of environmental concerns within China suggests that the transition period is likely to be of considerable duration in any event.

---

[42] The on-going development of a complex, multi-tiered environmental commodity marketplace in the U.S. is noted in Shults B, Musier R. Managing the Mosaic, *Environmental Finance*, April 2007: 518.
[43] See U.S. EPA, *Residual Risk: Report to Congress*, EPA-453/R-99-001, RTP, NC, March, 1999.

Next Steps

As the discussion above makes clear, there are daunting implementation concerns associated with the proposed ICS/PEMS/ET program. These would have to be fully explored in a feasibility analysis, and it would be useful to begin at the pilot scale -- much like previous efforts to introduce ET in the country.

Certainly the cities which have already introduced emissions exchanges -- Beijing, Shanghai, Tianjin, and Changsha -- would appear obvious candidates for such a pilot project. Tianjin has the advantage of working with the Chicago Climate Exchange, which already has experience with U.S. trading efforts in SOx and NOx. As noted earlier, Beijing has already implemented a form of ICS for the 2008 Olympcis, and has taken steps to continue some of those efforts.

Another approach would be to try a pilot project in areas which have already had unsuccessful efforts. The Asian Development Bank invested considerable resources in establishing the Taiyuan ET system, and officials there are already well schooled in the benefits of trading. The air quality in that city remains a significant environmental concern. Hong Kong and Guangdong also developed the infrastructure for emissions trading of SO_2, NOx and respirable particulates in early 2007, but no trades have taken place to date. That location similarly has a significant air quality concern, with a cross-border situation well adapted to ET (i.e., a wealthy urban region with a strong legal and regulatory infrastructure, bordered by a poorer but rapidly growing area with compliance concerns).

Conclusions

The recent establishment of emissions exchanges in China suggests that there is considerable interest in implementing emissions trading within the country, but efforts to develop domestic emission trading programs have not been successful. This paper holds that the establishment of such markets could play an important role in addressing air quality concerns within the country, but that market designs based upon U.S. or European approaches are not necessarily relevant for the conditions found in China.

Instead, a three component air quality management approach is proposed:

1) Real-time intermittent control systems (ICS), designed to protect public health during episodes of severe air quality. This will have significant economic impacts, since much of the economic damage is associated with significant public health impacts. By tackling severe impacts, ICS will allow the country to achieve its air quality goals over time, developing a more sophisticated and comprehensive control program over time;

2) Software-oriented Predictive Emissions Monitoring (PEMS) approaches designed to monitor targeted process parameters (rather than reported emissions) from individual emission sources. Emissions will then be estimated utilizing parametric or adaptive modeling

approaches. By going into the control room, regulators will be able to address the significant compliance concerns now evident in the country; whenever the facility is operating, emissions will be determined; and

3) Real-time emissions markets designed to accomplish increasingly stringent air quality goals over time, in an economically efficient manner, with sustainable development concerns addressed through distributional characteristics of the market design.

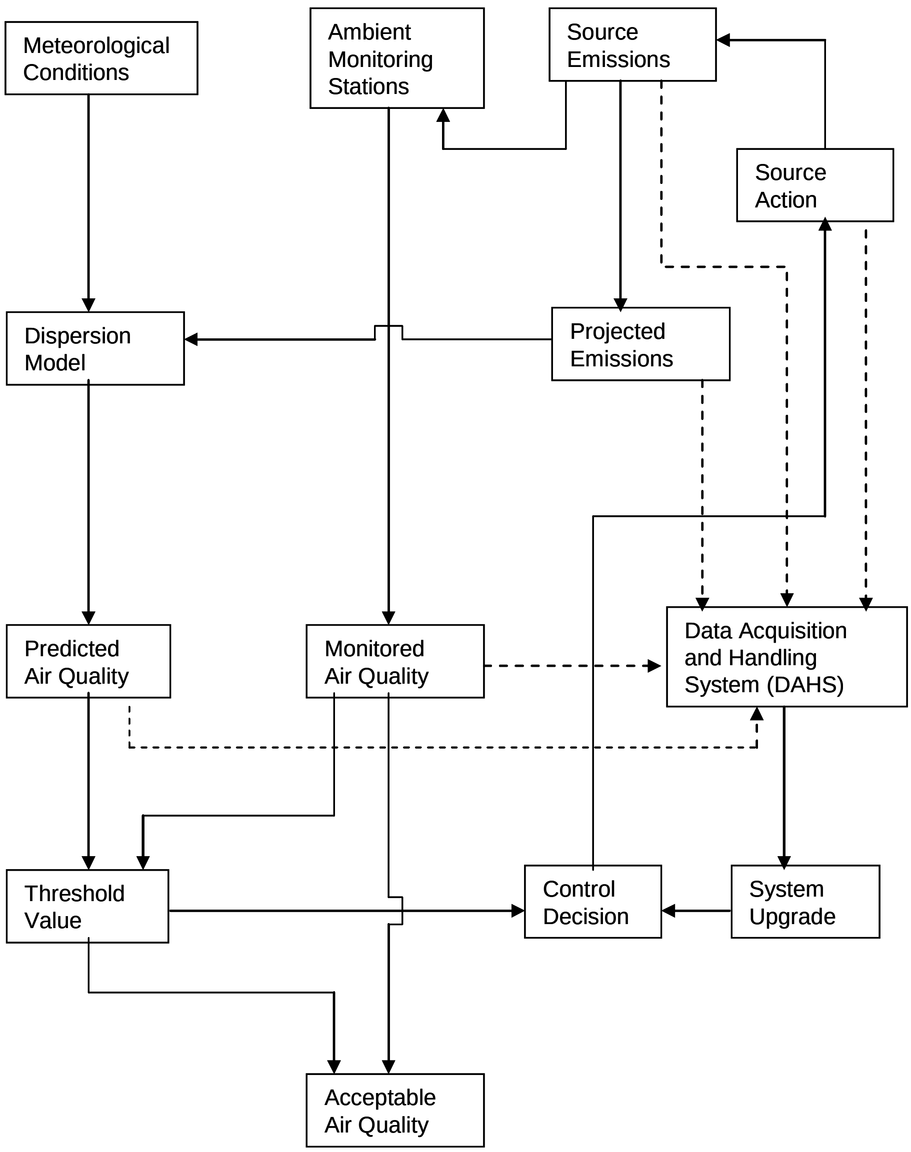
There are myriad technical and political difficulties associated with implementing such a system, and it is fully recognized that the path forward will be very difficult. Feasibility studies may well restrict the viability of any or all of the individual components, and their integration is likely to take considerable time.

However, such an approach has some powerful advantages as well. It utilizes advanced, knowledge-based technologies -- dispersion modeling; real-time ambient monitoring; parametric and adaptive predictive emissions monitoring; emissions and allowance management information systems; computerized trading systems; etc. -- to tackle the severe environmental conditions evident within the country. This exploits the radical transformation of computers, information and communications technology in recent decades, targeting them towards environmental improvements. It is congruent with the political and regulatory system that exists within China. It is economically efficient, achieving air quality goals over time, in a manner that utilizes markets. It allows the country to target sustainable development goals through market design, recognizing the importance of economic growth.

From the international perspective, it lays out a pathway for China to realistically address the severe environmental impacts of its localized pollutants, which already are having important international impacts on neighboring countries, as well as more distant ones through long range transport. It also, very significantly, lays out the pathway for China to ultimately put a price on CO_2 and other greenhouse gases, joining the international community on the 'demand' side of the carbon reduction effort.

Perhaps most importantly, however, it represents an air management system designed for China's unique institutional and environmental problems, utilizing markets in a manner designed for its own rather than external requirements.

Figure 1. Intermittent Control System



Intermittent Control System

Figure 2. Integrated ICS/PEMS/ET System