The Ancillary Carbon Benefits of SO_2 Reductions from a Small-Boiler Policy in Taiyuan, PRC

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September 2002 • Discussion Paper 02–54

RESOURCES FOR THE FUTURE

Resources for the Future
1616 P Street, NW
Washington, D.C. 20036
Telephone: 202–328–5000
Fax: 202–939–3460
Internet: http://www.rff.org

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Abstract

To reduce carbon emissions worldwide, it makes sense to consider the possibility of developed countries paying for carbon reductions in developing countries. Developing countries may be interested in such activities if the ancillary air pollution benefits are large.

This paper reports on an RFF survey of the emissions benefits (and costs) of reducing sulfur dioxide (SO_2) emissions from small, coal-burning boilers in Taiyuan, an industrial, northern Chinese city that recently banned uncontrolled coal combustion in certain small boilers in the downtown area.

We find significant carbon benefits in percentage terms—on the order of 50% to 95% reduction—associated with this SO_2 control policy, with large reduction potential elsewhere in Taiyuan and China. While the cost for boilers that switched out of coal was almost $3,600 per ton of SO_2 reduced, these ancillary carbon reductions are truly "free" from a social cost perspective.

Key Words: Carbon, air pollution, informal sector, ancillary benefits, abatement costs, survey

JEL Classification Numbers: O12, O2, Q12, Q25, Q48

Acknowledgments

The authors would like to acknowledge EPA's Office of Air and Radiation, and our project officer, Krishna Chivukula, for their support of this project. The survey would not have been possible without the dedication and hard work of Yuqi Xie of the Taiyuan Environmental Protection Bureau, who led the survey team. We would also like to thank Dan Millison for his work on estimating coal consumption at district heating plants, and Dong Cao of the Chinese Research Academy of Environmental Sciences for his help in various phases of the project.

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I. Introduction

It is well understood that greenhouse gas (GHG) reduction policies, which create incentives to alter the use of fossil fuels, can yield near-term environmental gains quite distinct from the long-term benefits directly associated with climate change. Significant ancillary reductions in local air pollution are predicted in studies of the U.S. economy, and even larger reductions are estimated for developing countries experiencing high pollution levels (IPCC, 2001). Despite the findings of net benefits when the ancillary gains are included, proposals for GHG reductions have been met with widespread skepticism in the developing world (Jin, et. al., 2000).[1]

A promising approach, particularly relevant for developing countries, is to reverse the policy logic and consider the ancillary carbon benefits of local air pollution control policies. A compelling case can be made to focus on local pollution first: large health benefits can often be obtained at relatively modest cost, particularly in areas where air pollution levels grossly exceed international standards,. The key questions are whether there are any carbon benefits associated with the local air pollution policies, and, if such benefits do exist, are they large enough to justify a closer look at policies that take air pollution policies as their starting point?

Referring to the first question, conventional wisdom holds that pollution abatement, e.g., the control of SO_2 emissions, requires additional energy to operate scrubbers or other equipment, thereby leading to an increase in carbon emissions. This concern, however, ignores the possibility of reducing SO_2 emissions without energy-using end-of-pipe controls, e.g., by fuel substitution or greater combustion efficiency. As to the second question, skepticism about the size of the tangible, near-term benefits available to the local citizenry is understandable. Sources

[1] A key concern is that credits associated with inexpensive options for carbon reductions would benefit developed countries today while developing countries would be left with more expensive options in the future.

of significant carbon reductions in developing countries are often small, inefficient and highly polluting, and found in the "informal" service and manufacturing sectors. Such sources are typically a challenge to regulate (Blackman, 2000). According to a World Bank (1996) report, for example, as of 1990, 35% of China's coal use was in small- and medium-sized boilers with an average size of 2.3 tons per hour.

This paper examines the case of Taiyuan, an industrial, northern Chinese city heavily dependent on coal as a source of primary energy, which recently banned uncontrolled coal combustion in certain small boilers in the downtown area as part of its overall SO_2 control strategy. Because the implementation of the policy has been underway for two years (2000-2001), it is possible to go beyond the typical *ex ante* calculations and examine the actual *ex post* operation of the policy. SO_2 and carbon reductions are estimated via analysis of a recent survey of individual boilers designed and conducted by Resources for the Future and the Taiyuan Environmental Protection Bureau (EPB).

Overall, large reductions in both SO_2 and carbon occurred as a result of the decision to ban uncontrolled coal combustion in certain classes of establishments in the central city of Taiyuan that use small boilers. The size of the estimated reductions depends on assumptions made about the future operation of recently shut-down facilities, and about the incremental emissions from large, centralized facilities used as replacement sources of energy. Not surprisingly, the SO_2 marginal abatement costs for banning uncontrolled coal combustion in small boilers are relatively high. Yet, these costs are calculated to be less than the value of the marginal health benefits based on standard exposure, dose-response, and valuation assumptions. Adjustment for the indoor exposures associated with the use of small boilers in commercial establishments, or attributing any positive value to the carbon reductions, would clearly increase net benefits.

Section II of the paper reviews the literature on ancillary benefits and examines the rationale for reversing the policy logic by considering the ancillary carbon benefits of local air pollution control. Section III introduces the specific policy adopted in Taiyuan in 1999 to close small boilers in certain classes of establishments and describes the conduct of the boiler survey, including the survey instrument used. Section IV presents estimates of the SO_2 and carbon emissions, both before and after implementation of the small boiler policy, along with estimates of the marginal abatement costs for the SO_2 reductions. Section V integrates the survey results with other information on damage costs associated with uncontrolled coal combustion, both indoor and outdoor. The final section explores the potential gains from expanding this policy to other classes of establishments and other locales in Taiyuan, as well as to other geographic areas.

Given the evolving interest in using the Clean Development Mechanism[2] to obtain carbon reductions from small-scale projects, this broader assessment may have particular salience.

II. Reversing the Policy Logic

An extensive literature has developed on the ancillary benefits of GHG reduction policies (see Davis, Krupnick, and McGlynn, 2001 for a collection of papers and IPCC, 2001 for a section on this topic in the Working Group III report). The predominant conclusion from this work is that those benefits, which primarily consist of improved health from reduction in conventional air pollutants, can offset a significant fraction of carbon mitigation costs. Indeed, in some cases, carbon reductions can be justified on the basis of the ancillary air pollution improvements alone. These optimistic conclusions are more applicable to developing nations than developed nations, owing to lower costs of reducing carbon in developing nations, as well as the relative values assigned to health improvements in developed versus developing countries.

While these conclusions hold for China, in particular, they have not proven compelling. Although China was among the first nations to ratify the United Nations Framework Convention on Climate Change (in 1993), its official position in the international climate negotiations has been characterized as "conservative." (Buen, 2000). In the Kyoto negotiations, China has emphasized "common, but differentiated responsibilities" for developing nations and has strongly argued that it should not be expected to limit its GHG emissions until its economy has reached the level of a developed country.

Notwithstanding its firm stand in the Kyoto negotiations, China's Agenda 21 adopted in 1994 established climate policy objectives, such as formulating a national program for controlling GHG emissions by afforestation and energy development.[3] Since 1995, China has adopted measures to reduce its carbon emissions, including participation in cooperative projects with Norway, Japan, the Netherlands, and the United States. For a variety of reasons, China's

[2] The Clean Development Mechanism was established under the Kyoto Protocol for project level activities to be carried out in developing (non Annex I) countries.

[3] As noted in China's Agenda 21, China "will actively seek investment from the international community for projects which assist in the slowing of climate change. These include projects for coal-fired power plants, hydroelectric power stations, coal gas projects, coal methane utilization and tree planting." (European Parliament, (1996.).

carbon emissions fell by almost 4% from 1995 to 1998 at a time when its GDP increased by 36%.

China has some of the highest pollution readings in the world for particulates and SO_2 (which converts to fine particulates in the air)—pollutants that are most significantly implicated in premature death and serious morbidity. The World Bank (1997) listed Taiyuan among the most polluted cities in the world in terms of ambient concentration of total suspended particulates and SO_2, based on 1995 data. In 1996, the Chinese government initiated a policy of "One Control and Two Compliances," which set emissions standards in mass rather than concentration terms and required cities to implement so-called Total Emissions Control (TEC). Each province and city was required to bring its total emissions of particulates, SO_2, and other pollutants within the levels designated by the national government. The policy also required some key Chinese cities to meet the national ambient air quality standards by 2000, which was later extended until 2002.

Given the strong interest in reducing local air pollution, and the clear reluctance to directly address carbon emissions, it seems reasonable to reverse the policy logic implicit in the ancillary benefits literature. That is, we consider whether the local air policies that the Chinese are already undertaking also may generate (ancillary) carbon benefits. If they do, how large, how cost effective, and how cost beneficial are these policies? What is the potential for expanding such efforts?

III. The Policy to Shut Down Small Boilers in Taiyuan City

The Policy

In June 1999, the Taiyuan City Government issued the *Bulletin Controlling Air Pollution,* which covered a wide range of air pollution sources in the area, including both stationary and mobile sources (Appendix I contains the full *Bulletin*). Among the issues covered in the *Bulletin* was a decision, supported by further administrative guidance, to shut down existing small coal-fired boilers operated by certain classes of establishments in a central zone established by the Taiyuan City Government; "small boilers" were defined as those with a rated capacity of 2 tons or less of steam per hour.

All the heating boilers operating in areas served by central heating were required to hook up to the district heating system. In addition, all the restaurants, entertainment centers, and public bathhouses located in the designated central zone were required to switch to less polluting fuels such as coal gas, diesel oil, electricity, and liquid petroleum gas (LPG). The central zone was comprised of high population density areas in each of the six districts in Taiyuan City. The policy was administered by the Taiyuan Environmental Protection Bureau (EPB).

The Survey

In cooperation with the Taiyuan EPB, we developed a survey instrument to assess the impact of the small boiler policy in the designated control zone. Specifically, we collected information on the boiler equipment in place prior to implementation of the new policy, the types, quantities, and costs of fuels used and hours of operation (before and after implementation of the new policy), and new investments undertaken to upgrade or replace the boilers in 2000-2001. The survey format is displayed in Appendix II.

The survey was administered in November and December 2001 in the six districts supervised by the Taiyuan EPB.[4] In an initial meeting, the Taiyuan EPB reviewed the survey forms with the staff of the district EPBs. Each district EPB, in turn, designated "street" environmental personnel, who were individually in charge of administering environmental regulations on the specific streets and visiting all the establishments with small boilers covered by the 1999 *Bulletin* in both 2000 and 2001. Each district EPB completed a survey form for these years.

In total, data were collected for 308 boilers that operated in the designated control zone at the end of 1999. It is our understanding that this number represents all the small boilers in the restaurants, entertainment centers, and public bathhouses in the designated zone, as well as those boilers used for (winter) heating purposes located in the sub-zone where district heating became available in 2000-2001. As a form of quality control, a number of internal consistency checks were carried out.[5] Forty boilers were removed from the data set for a variety of technical reasons, leaving a total of 268 boilers for further analysis.[6]

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[4] The six districts are: Jinyuan, Yingze, Jiancaoping, Wanbolin, Xiaodian, and Xinghualing.

[5] For example, we regressed the reported investment costs on a series of variables representing size, fuel type, and location (the sub-district). Overall, the signs of the variables were as expected. The R^2 for the equation was 0.65.

[6] Twenty-two boilers were replaced by larger units as part of a voluntary conversion for technological improvement and were thereby exempt from the 1999 Bulletin. Key information on energy use by the replacement units was missing for 18 of the boilers (primarily for electric powered replacement boilers).

IV. The Survey Results

SO2 and Carbon Emissions

Estimates of SO_2 and carbon emissions from the 268 boilers before and after implementation of the small-boiler shut down policy are displayed in Table 1. Ninety-nine of the enterprises reconfigured their boilers to burn other fuels, 98 reportedly stopped operation completely, and 71 switched to central heating. Among the 99 boilers that switched fuel, the fuels of choice were: oil (69%), coal gas (21%), electricity (5%) and liquid petroleum gas (4%). For all boilers in the sample, SO_2 emissions were about 1,900 metric tons at the end of 1999. By way of comparison, the Taiyuan EPB estimates total SO_2 point source emissions for the whole city, not just the zone designated for shutting down small boilers, at 258,000 tons in 1999 (Morgenstern, et. al., 2001). Thus, the emissions affected by the small boiler shutdown policy implemented in 2000-2001 represent less than 1% of total point source SO_2 emissions in the entire city.

Table 1: SO_2 and Carbon Emissions, Before and After Policy Implementation, Small Boilers in Taiyuan (2000-2001)

	Number of Boilers	Emissions before shut down (tons)		Emissions after shut down (tons)			
				Case A		Case B	
		SO2	Carbon	SO2	Carbon	SO2	Carbon
All Boilers	268	1,916.80	112,336.32	651.13	55,766.42	25.78	5,197.65
Boilers continuing to operate	99	532.20	2,1434.70	25.68	5,197.65	25.68	5,197.65
Boilers stopped operation	98	515.36	2,0636.82				
Centralized heating boilers	71	869.25	7,0264.80	625.35	5,0568.77		

Note: 1. Case A counts SO2 and carbon emissions of centralized heating as 72% of emissions before shutdown.

2. Case B counts SO2 and carbon emissions of centralized heating as zero.

Among the key issues when estimating emission reductions of the new policy is accounting for those boilers reported as “shut down” and those switching to central heating. If one assumes that shut-down boilers are not subsequently re-opened after the administration of the survey, and that the services they perform are not taken up (with corresponding emissions increases) in the remaining facilities, then a 100% emission reduction is implied.

We examined this issue by including in the survey a question on the motive for the shutdown. Three of the 98 “shut down” boilers were reported as going bankrupt. Eight of them were reported as combining with others while five were reported as being removed from the premises. The large majority of the boilers (82) were reported as simply “shut down.” With the possible exception of the 8% of the boilers in the survey reported as “combining with others,” there is no credible basis to assume anything other than a complete cessation of operations, i.e., zero emissions. If the 8% of the boilers reported as combining with others were in establishments covered by the *Bulletin*, their emissions would already be accounted for. If the boilers reported as combining with others were not in establishments covered by the *Bulletin* we would be over-counting the emission reductions. We acknowledge some uncertainty on this point, but we report the results separately, according to the reason for the boiler shutdown.

The situation involving centralized heating is somewhat more complicated. Based on a feasibility study developed for a district heating project in a nearby city (Datong), plus a site visit to Power Plant #1 in Taiyuan, Millison (2002) has estimated that central heating facilities generate 72% of both the SO_2 and carbon emissions of the typical small boiler per unit of output. (The Millison memorandum is reproduced as Appendix 3). Using the Millison emissions estimate for central heating, along with fuel-specific emission estimates developed by the Taiyuan EPB, we calculate that, across all 268 small boilers in the survey, SO_2 emissions were reduced by two-thirds, to about 650 tons per year as a result of the small boiler shut down policy.[7, 8] (These results are shown in Table 1 as Case A). Based on comparable assumptions, carbon emissions were reduced by 50% as a result of the small boiler shut down policy. For those boilers that switched fuels, higher reductions were obtained: 95% for SO_2 and 76% for carbon.

Taiyuan city officials reported that the energy source that replaced the 71 shut-down boilers was derived from waste heat, not from additional coal combustion as assumed in Case A. Accordingly, we developed another case to reflect the assumption of zero emissions from the replacement district heating. Based on this assumption, we calculate that total SO_2 emissions

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[7] Assumptions used to calculate SO2 emissions for replacement fuels (source: Taiyuan EPB):

a. Oil-burning boilers: Taiyuan city usually uses light diesel oil, the polluting coefficient is 20 S/m^3 SO2 emissions = fuel consumption * 20. 0.2 is the sulfur content of light diesel oil;

b. the polluting coefficient of oil-burning boilers is 20 * 0.2/0.8 = 5kg/ton; and

c. Gas-burning boilers: the polluting coefficient is 630kg/10^6 m^3. SO_2 emissions = fuel consumption * 630kg/10^6 m^3.

[8] Assumptions used to calculate carbon content for replacement fuels. (Source: Millison (2002)
Carbon content estimation:
a. Coal: ton * 0.8
b. Oil (diesel oil): m^3 * 0.94 * 0.85
c. Gas (coal gas): m^3 * 0.1125 * 0.75/1000
d. Electricity: kwh * 375 * 0.8/1000000
e. LPG: m3 * 0.542 * 0.807
f: Centralized heating: kwh * 375 * 0.8 * 0.9/1000000 [*same as for electricity, but heat transmission efficiency of 90% is assumed*]

were reduced by more than 98% as a result of the small-boiler shut down policy. Based on comparable assumptions, carbon emissions were reduced by 95% as a result of the small-boiler shut-down policy. (These results are shown in Table 1 as Case B).

V. SO_2 Marginal Abatement Costs

Marginal abatement costs represent the incremental costs per ton of emission reductions. Unfortunately, we only have complete cost information on a subset of 44 boilers that switched fuels in response to the policy to shut down uncontrolled combustion of raw coal.[9] Table 2 shows the distribution of fuels chosen by this subset of 44 boilers. More than 60% switched to oil; 30% switched to coal gas; and 10% switched to LPG. This distribution of (cleaner) fuels is similar but not identical to that of the full group of 99 boilers that fuel switched.[10] For this subset of 44 boilers we summed the annualized investment costs for the new equipment and the *incremental* fuel costs.[11] This sum, divided by the reported emission reductions represents the average SO_2 marginal abatement costs of the 44 boilers for which we have complete data. As shown in Table 2, total investment in the 44 boilers amounted to 4.8 million RMB (at about 8 RMB per U.S. dollar) in 2000-2001. Annual fuel costs increased by more than a factor of five, from 1.2 million RMB to 6.6 million RMB. Note that the SO_2 marginal abatement costs vary almost a third from the lowest (coal gas) to the highest (diesel oil) fuel type. LPG is only slightly more expensive than coal gas per ton of SO_2 abated.Across the full group of 44 boilers, the average SO_2 marginal abatement cost is about 29,200 RMB per ton or $3572.[12] Of course, this policy also resulted in the incidental reduction of more than 8,700 tons of carbon for these 44 boilers.

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[9] We also have (nominally) complete data for 8 additional boilers. However, because of internal inconsistencies in the responses, we eliminated them from the data set.

[10] The full group had more oil and less coal gas and LPG. In addition, five percent of the full group switched to electricity, while none in this sub-sample did so.

[11] Annual investment costs are taken to be 0.1 of total investment costs.

[12] Weighting the average based on the distribution in the full sample of 99 boilers versus the 44 in this sub-sample raises the marginal abatement cost by 2.9% to about 30,000 RMB per ton.

Table 2: Marginal Abatement Cost of SO2 Reduction by Fuels

		Emissions before shut down		Emissions after shut down				Energy Cost ($)		
	Number of boilers	Total SO2 (tons)	Total carbon (tons)	Total SO2 (tons)	Total carbon (tons)	% SO2 reduction	Investment after ($)	Before	After	Average Marginal Abatement Cost ($/ton)
Coal gas	13	15.49	4,287.36	.18	709.95	96.38	212,875	60,963	265,500	3,013
(Diesel) Oil	27	38.45	6,036.10	.35	1,412.31	94.69	336,250	83,388	515,300	4,007
LPG	4	5.32	736.00	.69	178.37	95.50	53,250	5,813	41,625	3,295
Total	44	69.26	11,059.46	2.23	2,300.63	95.46	602,375	150,163	822,425	3,648

VI. Implications

The findings reported in the previous section are striking: emissions of carbon fell by 50% to 95% from a baseline of 112,000 tons as a result of a policy to shut down small boilers in one city center, and only boilers in one of three categories of establishments. The availability of waste heat to support district heating determines whether the percentage reductions are on the upper or lower end of these ranges. If reproducible in other parts of Taiyuan and/or in other urban areas, these results could have profound implications for carbon reductions in China.

Of course, a policy that requires boilers to shut down is, on its face, likely to be inefficient. The cost for boilers that switched fuel was almost $3,600 per ton of SO_2. This cost can be compared to other approaches for reducing SO_2 in Taiyuan, which we have estimated to be in the range of $60 (Taiyuan district heating) to $1,160 (coal washing) (Morgenstern, et. al. 2001). Estimated abatement costs for other parts of China developed by Liang et. al. (1998) range from $75-$250 per ton. Thus, the cost-effectiveness of the small-boiler ban is not particularly attractive. Nevertheless, apart from differences across fuels, marginal (as opposed to average) costs for shut-down boilers were not estimated; neither was the cost of linking to a district heating system. These costs may well be lower than \$3,600 per ton. A better-designed, more-flexible policy could doubtlessly lower marginal costs even further but perhaps at the cost of the policy being harder to enforce.

These cost-effectiveness estimates also may be overestimated when considered in terms of "effective tons" reduced. When a boiler in a restaurant is replaced with district heating, for example, emissions from a short stack venting on the side or roof of a building, or perhaps even leaking into inhabited rooms, are eliminated. In its place are emissions from a tall stack of an electric power plant or some other large facility. Recent air quality modeling for point and surface NOx emissions and their effects on PM2.5 concentrations (Russell et al, 2002) shows that PM2.5 concentrations in the local area are 60% larger per ton of emissions from the surface sources. If SO_2 has similar properties, then 1 ton of SO_2 eliminated from a small boiler is likely "worth" considerably more than a ton increased from a tall stack.

Another measure of whether this policy makes economic sense—again, even before accounting for the "free" carbon reductions—is to compare the costs of SO_2 reductions to the benefits. We performed a very simple comparison using the results for the 44 boilers for which we had complete data. Total costs for reducing SO_2 by 257 tons per year are \$732,500. Benefits are calculated based on an air quality model, which related SO_2 emissions to ambient concentrations (Morgenstern, et al, 2001). This emissions-concentration relationship was then used, along with an estimate of the value of the health benefits from reducing SO_2 concentrations from current levels to Class II standards (Morgenstern et al, 2001), to arrive at a total benefit per ton of SO_2 emissions reduction. Estimated benefits ranged from \$4,677 to \$21,740 per ton SO_2 reduction. depending on which of two epidemiological studies of the effects of SO_2 on health are utilized. Multiplying this figure by the 257 tons of SO_2 emissions reduction yields a total benefit of \$1.2 million to \$5.59 million. Thus, net benefits are positive for Taiyuan's smallboiler control policy, based on the 44 boilers for which data are available.

Another way of considering Taiyuan's small-boiler policy is to calculate the break-even value of carbon reductions that would offset the SO_2 abatement costs even without counting any health benefits. This calculation involves dividing SO_2 abatement costs (\$732,500 per year) by the ancillary carbon reduction of 8,759 tons per year, for a break-even carbon reductions value of about \$84 per ton of carbon. These figures are in the range of the values for marginal damages found in the literature. For example, the Union of the Electricity Industry (2001) lists damage values per ton of carbon ranging from 74 -170 Euros per ton (1 Euro = about \$1). Note, however, that SO_2-related health benefits more than offset the full cost of the SO_2 emissions reductions without counting carbon reduction benefits.

VII. Conclusion

Ancillary carbon benefits from local air pollution control – particularly by the "informal sector"—have not been widely explored in the literature. Given the reluctance of developing (and some developed) countries to adopt strong carbon-reducing policies for their own sake, however, it is not unreasonable to consider other potential policy drivers. This *ex post* analysis of an actual policy to shut down certain classes of small boilers in the central area of a highly polluted Chinese city indicates significant carbon benefits in percentage terms—on the order of 50%-95% reduction—associated with a SO_2 control policy.

We estimate that extending the small boiler SO_2 control policy adopted in downtown Taiyuan beyond restaurants, entertainment centers, and public bathhouses, as well as to other areas and to slightly larger boilers, could eliminate as much as 15% of total carbon emissions in the larger Taiyuan area.[13] If the estimates of 1990 coal use in small- and medium-sized boilers previously cited by the World Bank were representative of today's patterns, the potential savings could be considerably higher. Thus, although this small-boiler policy does not involve innovative technologies or major sources, the carbon reductions potentially achievable by such policies are non-trivial. Given the demonstrated action of the city government to reduce SO_2 emissions from small boilers, these ancillary carbon reductions are truly "free" from a social cost perspective.Of interest to policymakers is the shape of the supply curve of this untapped reservoir of potential carbon reductions—not just in Taiyuan, but in all of China. We have demonstrated that considerable reductions are available without cost, but how would more emission reductions be attractive to the city government if there was a market for the carbon?

Of particular interest is the status of ongoing efforts to control small sources of SO_2 in other cities in Shanxi, as well as in other provinces. Conventional wisdom is that uncontrolled coal combustion from small sources is being phased out all over China. Our survey in one city questions this view. Only a small fraction of the eligible boilers in Taiyuan have been subject to regulation. Informal discussions with Taiyuan officials indicate that it may be many years before they are able to control all such sources. As noted, the economics of the small-boiler control

[13] Yuqi Xie of the Taiyuan EPB estimated that, in 1995, the total boiler population in the six EPB districts was about 4,000. From the 4,000 figure, one must subtract the 1,000 boilers already shut down and boilers exceeding 10 tons, leaving about 2,800 boilers that potentially could fall under an expanded shutdown policy. This does not count so-called tea stoves, which may number 700 in Taiyuan.

policy are complex. Our estimates indicate that it is clearly not the most cost-effective way to achieve ambient SO_2 reductions in Taiyuan. However, when one considers the possible reductions in indoor exposures, or even the (conservatively) estimated benefits of ambient SO_2 reductions, the policy looks more attractive.

The extent to which policies are already in place to reduce emissions from small boilers in China is a key issue in determining the baseline for potential support of such activities under the Clean Development Mechanism. While not offering results as dramatic as those produced by plant-by-plant reductions, small boilers may represent relatively low-hanging fruit, particularly as the Clean Development Mechanism Board has recently issued guidelines favoring small sources (UNFCCC, 2002). Overall, we believe that further investigation is warranted of the potential for small boiler control policies to contribute to improving local air pollution and to reducing carbon emissions. Incremental changes to ongoing policies with demonstrated local benefits may be an extremely effective way of starting down the long road of carbon mitigation, especially in developing countries.

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Appendix I: Taiyuan People's Government Bulletin on Controlling Air Pollution

In order to conscientiously carry out "Decision on Several Environmental Protection Issues" issued by State Council, realize the "one control and two compliances" goal in 2000, and quickly improve the serious air pollution condition in Taiyuan, the Taiyuan Government issued this bulletin.

1. The units located in the centralized heating zone must implement centralized heating, stop running scattered heating boilers, and remove boiler chimneys. The units already entered in the centralized heating system are prohibited from withdrawing. The units that currently are not provided with centralized heating must build temporary heating boilers and use clean fuel such as city coal gas, LPG, or petroleum. The districts outside the centralized heating zone must adopt united heating method.

2. The residential households, which are located in the zone from west of Dongshan highway, east of Xiwai ring road (planned road), north of Nanwai ring road (planned road), south of Xinlan road, and in the Jing Temple scenic spot, must use city coal gas or LPG and are prohibited from dispersing burning raw coal.

Service businesses of eating houses, entertainment, and public bathhouses within the above zone can not build new coal-burning boilers. The currently running boilers up to 2 tons capacity must be converted to gas-burning, electricity-burning, or oil-burning boilers before December 31, 1999. Before remolding, industrial casting coal must be used. The boilers larger than 2 tons should use clean fuel such as industrial casting coal and refined coal.

3. The tea stoves, eating house stoves, dining room stoves, and food booths that are located in the zone from north of Xuefu street, south of Shengli street, west of Jianshe road, and east of Heping road, must switch to clean fuel such as gas, electricity, and oil. Building new coal-burning facilities is prohibited and outdoor barbecue are banned.

4. Power-plant boilers must use high-quality coal (sulfur content is below 1.0% and ash content is below 10.0%). Coal-burning boilers for production and heating must gradually use high quality coal, the ones smaller than 1 ton capacity must use industrial casting coal. Industrial cave stoves must gradually use clean fuel such as gas, electricity, and oil and are strictly prohibited from dispersing burning raw coal after 2000.

5. The new boilers above 4 tons (including 4 tons) must install dust removal and desulfurization facilities. The currently running ones should install desulfurization facilities. The installation must be completed before the end of 2000.

6. Industrial enterprises (including village and township enterprises) must strictly implement the # (1998) 33, 34 City Government documents to achieve environmental compliance. The ones that do not comply within the specified time period will be closed or have their operations stopped according to the requirements from State Council and Shanxi Provincial Government.

7. Strengthen management of motor vehicles with new license plates. Starting from July 1, 1999, the city environmental protection bureau will examine and verify tail-pipe gas emissions of motor vehicles sold in Taiyuan. The model list of motor vehicles for which sales are permissable will be publicized. The new cars applying for license plates must meet the model list requirement. Otherwise, the police and communication departments will not issue license plates.

8. Strengthen the examination of tail-pipe gas emissions during the annual examination of motor vehicles. The motor vehicles that meet the standard of tail gas emissions will be issued motor vehicle emission certificates. The ones whose tail gas emissions exceed the national standard will be ordered to install tail gas purifying facilities. City environmental protection bureau will re-examine their tail-pipe gas emissions and issue motor vehicle emission certificates if its emissions meet the standard. The motor vehicle management sector of the police department will then carry out motor vehicle annual examination.

9. Strengthen on-road tail gas examination of motor vehicles.

10. Motor vehicles must be scrapped strictly according to national requirements. The scrapped motor vehicles cannot be sold or transferred.

11. Starting from July 1, 1999, all gas stations and oil distribution sectors in Taiyuan city must sell unleaded gas.

12. Spread the application of LPG to public buses and taxis in Taiyuan city.

13. Adopt control measurements to treat secondary dust.

14. All Taiyuan citizen should take initiatives and strive to improve Taiyuan air quality. The relevant governmental agencies must strengthen supervision and examination methods according to the Bulletin requirements. To guarantee the full implementation of these measurements, units and individuals violating the Bulletin will be punished according to the relevant regulation and rules.

Taiyuan People's Government

June 1, 1999

Appendix II: Survey Form

The boilers shut down								
Name	Type	Size (tons)	Efficiency	District located	Operation time	Yearly coal consumption (tons)	SO_2 emission (tons)	Notes

Alternative Boilers						Cost comparison (10,000 RMB)		
Type	Size (tons)	Efficiency	Sources of energy use & consumption (tons)	SO_2 emission (tons)	Notes	Investment	Energy Consumption	Operation Cost

Appendix III: Millison Memorandum on District Heating

MEMORANDUM

TO:Zhang Xuehua, Dick Morgenstern, Alan Krupnick, RFF

FROM:Dan Millison

DATE:3 April 2002

SUBJECT:Taiyuan District Heating Network Coal Consumption (#2)

I have reviewed the information provided (attached) on the Taiyuan space heating and have done some estimates on the energy use and coal consumption required to provide the necessary heat. Using the Datong City district heating project as an example, and notes provided by the Taiyuan No.1 Power Plant during our March 2001 visit, I have estimated that about 65,000 Tons of coal is required for the heating season (approximately 4 months), generating about 190,000 tons of CO_2.

DATONG Specifications

- 3.38 Million GJ heat for 5 Million m2 space per season (approximately 4 months), or approximately 0.676 GJ/m2 or 676 MJ/m2.
- Heat is provided by the large power plant on south side of Datong City urban area; replaces a large number of small-scale boilers (> 1000) throughout the central urban area; estimated coal savings is 486,700 T/y.

TAIYUAN Estimate

Coal used to produce heat for the new Taiyuan heating network is estimated as follows[14]:

610,000 m2 space x 0.676 GJ/m2 = 412,360 GJ

Assuming a heating value of coal of 17.6 GJ per ton (the value used in our spreadsheet for small boiler conversions), then the amount of coal required to generate and deliver the required heat is as follows:

Energy required/energy per mass = mass fuel / boiler efficiency = total fuel required

Assume boiler efficiency = 40% and distribution efficiency is 90%

Total fuel required = 412,360 GJ/17.6 GJ per ton/0.4/0.9 = **65,082 tons coal**

Assuming 80% carbon content in the coal, the equivalent CO2 emissions are **190,907 Tons.**

Working from the power plant side, we can check and make sure this makes sense. The No. 1 Power plant is rated at 1200 MW (4 x 300 MW), and consumes about 250,000 tons coal per month during winter (about 8333 Tons/day). The equivalent energy consumed is:

8333 T/d x 17.6 GJ/T = 146,660 GJ

Converting GJ to GW-hr: GJ/3600 = GW-hr (GW-hr x 3600 = GJ)

146,660 GJ/3600 = 40.7 GW-hr per day (total energy consumed)

If we assume 40% efficiency in simple cycle mode the plant will generate 16.3 GW-hr electricity per day, which is equivalent to the 1200 MW plant operating at about 57% capacity; **the waste heat is available "<u>for free</u>."** Assuming 80% efficiency in cogeneration mode we get 32.6 GW-hr total power equivalent (electricity + heat). Assuming the plant actually operates at around 80% of optimum efficiency, the deliverable power should be:

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[14] This area is relatively small compared to that cited for Datong, so I assume that the 610,000 m2 is only a small portion of the total service area.

1200 MW/1000 (MW/GW) x 24 h/d x 0.8 = 23.04 GW-hr

If 16.3 GW-hr are being delivered as electricity (a generous assumption), then about 6.7 GW-hr is available for steam and heat[15]. This number is consistent with the Datong design.

Working back from delivered space heat of 0.676 GJ/m2 for 610,000 m2, we get

412,360 GJ /3600 GJ/GW-hr = **114.54 GW-hr**

For a 4-month heating season, we need about 1 GW-hr per day for space heat.

The equivalent coal required from a large power plant, assuming 100% transmission efficiency is:

114.54 GW-hr x 375 Tons coal/GW-hr = 47,952 Tons coal

Actual transmission efficiencies will vary; at best it will be around 90% and can be much lower (30 – 60%) depending on the total system demand. If the power plant is the heat source, then the required transmission efficiency is:

Tons equivalent coal (heat delivered) / Tons coal consumed at power plant = 23,430/47,952 = 49%

This is consistent with variable demand and transmission efficiency over the heating season.

Remember the heat is "free" because it is waste heat from the power plant. The delivery cost is based on the heat exchanger, transmission/distribution system, meters, etc.

The attached spreadsheet illustrates the system parameters and efficiencies of various types of heat delivery systems. For a simple, dedicated "community boiler" the combined boiler and transmission efficiency will be about 36%. If heat is taken from a large power plant (as in Taiyuan and Datong cases), the efficiency is theoretically much higher, maybe as much as 72% (80% boiler thermal efficiency x 90% transmission efficiency). A modern industrial

[15] This is not a truly robust set of calculations, but the intent is to illustrate the overall electric power and heat balance.

cogeneration system might be the most efficient in terms of fuel efficiency, etc., but might also be more expensive on a unit cost basis, depending on the size of the units constructed.

If we want to know the difference in coal use for a large power plant system versus small, inefficient community boilers, we can make an educated guess by taking the different efficiencies and equivalent amount of coal required to deliver the required heat.

On the example sheet, we see that the dedicated boiler scenario requires about 65,000 Tons of coal vs. about 47,000 Tons for heat supplied by Taiyuan No. 1 power plant. We can take this difference as the typical coal savings, or about 18,000 Tons for the heating season. Assuming further that the district heating system is designed to cover 5 to 6 million square meters (as in the Datong case), then we can multiply the 610,000 m2 times ten to get about 6 Million m2, for which the total coal savings would be 180,000 Tons per year. If we take the difference between 36% and 72% efficiency as the theoretical maximum achievable, the coal savings is about twice as high, (again consistent with the Datong case).