ACHIEVING SULFUR DIOXIDE REDUCTION THROUGH COAL-SWITCHING

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This memorandum discusses the environmental effects of coal-switching by electric utilities. The discussion only considers emission reductions achievable in those situations where coal switching remains cheaper than wet scrubbing. The Congressional Budget Office's analysis indicates that economic emission reductions through coal-switching could total at least 8 million tons of sulfur dioxide (SO_2) annually, and probably as much as 10 million tons (as measured against 1980 utility emission levels). An attached set of tables provide the basis for the discussion.

The economic potential for achieving SO_2 emission reductions through coal switching in electric utility boilers is governed primarily by the price of the alternative techniques considered (in this analysis wet scrubbing) and the relative prices of high and low sulfur coal. When estimating these reductions, the relative prices of scrubbing and of high and low sulfur coal will change as the demand for them is affected by acid rain policies. This shift in price complicates the analysis of alternative approaches, since current prices may give misleading estimates of the absolute and relative costs of different polices. To account for these effects, the Congressional Budget Office has employed a model of regional coal markets to simulate the output and price movements experienced under a wide variety of acid rain control options. This model, the National Coal Model, predicts outcomes based on the assumption that individual utilities will react to control policies by finding the lowest cost method of abatement. The methodology is explained in detail in *Curbing Acid Rain: Cost, Budget and Coal Market Effects* (Congressional Budget Office, June 1986), and the results discussed in this paper are based on analyses contained in that report.

Two assumptions used in that analysis will largely determine the amount of emission reduction that could be expected by fuel switching alone. The first assumption is that only one technological abatement alternative is considered--wet scrubbing. The second assumption regards the cost of that technique, which will be discussed in the final section of this paper.

Although wet scrubbing is currently the most widely utilized retrofit SO_2 removal technology, several emerging technologies may play an important role in the future. These alternatives included dry scrubbing, fluidized bed combustion, limestone injection multistage burners, and possibly integrated gasification combined cycle generation. Physical coal cleaning could also become more prevalent under acid rain control policies. These tech-

nologies are in various stages of development, and hold the eventual promise for lower capital and operating costs compared to those encountered with pulverized coal plants equipped with wet scrubbers. However, their potential for retrofit applications, the ultimate removal efficiencies of some techniques, and their rates of future usage remains uncertain.

To the extent that these techniques become available and compete with wet scrubbing in the future, then the results of the CBO simulations that consider only wet scrubbing will tend to understate the role of technological abatement options and overstate the potential for fuel switching as the preferred abatement choice. Combined with the relatively high assumed costs for retrofit scrubber installation, these simulation results should be interpreted as the upper bound of emission reductions achievable solely through fuel switching.

Emission Reductions from Coal Switching

For policies intended to achieve SO_2 reductions in the range of 8 million tons or less annually, coal switching remains the least cost technique for virtually all utility sources. The technical characteristics of scrubbers, the choices faced by individual plants, and coal market economics of fuel switching support this conclusion. On a plant-specific level, coal switching is generally cheaper when modest emission reductions are sought, and when low sulfur coal is only moderately more expensive than high sulfur coal. Scrubbing becomes more cost effective when significant percentage emission reductions are sought--in the 90 percent range for an individual boiler--and when the price of high sulfur coal is much lower than low sulfur coal. These conditions lead utilities to maintain relatively low emission rates by scrubbing cheaper high sulfur coal. Prevailing market conditions in most regions of the country, however, do not show large enough price differentials among coals of varying sulfur contents, and enough low sulfur coal is available for utility use as the primary abatement choice under moderate emission reduction policies. In fact, recently weakened demand (in part attributable to lower oil and gas prices), chronic overcapacity, and advances in mining productivity advances suggest that in most regions, low sulfur coal will continue to be supplied at fairly low prices.

The desirability of low sulfur coal under a modest emission reduction policy will force up the relative price of low sulfur coal compared with high and medium sulfur coals. This raises the important question of when shifts in coal use patterns would drive the price of low sulfur coal high enough to encourage the installation of scrubbers instead. In the previous CBO analysis of options that did not subsidize or otherwise promote scrubbing, this

"crossover" point was not reached until roughly the 10 million ton reduction level. For reductions lower than that level, virtually all of the emission reductions occurred as a result of coal switching. In contrast, various analysis by ICF, Inc., have indicated that scrubber use will increase dramatically between eight to nine million tons of annual SO_2 reductions. The primary difference between the two analyses lies in the assumed cost of retrofit scrubbers. Compared with the ICF, Inc. analysis, CBO has assumed relatively higher retrofit scrubber costs. If CBO estimates overstate actual scrubber costs or if new abatement technology became competitive, the "crossover" point might occur at a point less than 10 million tons reduced, but most likely not below 8 million tons. A more detailed discussion of scrubber costs is provided later.

In addition to achieving reductions in emissions, a coal switching policy could have a substantial impact on markets for coal. The enclosed Tables 1, 2, and 3 show the predicted coal market effects of an 8 and 10 million ton reduction as compared with the base case. Under an 8 million ton reduction, high sulfur coal production would decline by 53 million tons per year, while low sulfur coal production would rise by 117 million tons. These effects are even more pronounced under the 10 million ton reduction, where high sulfur coal would drop by 80 million tons annually and low sulfur coal production would rise nearly 190 million tons annually over predicted base case levels.

Under higher emission reduction goals, the role of scrubbing would grow. For example, to achieve a 12 million ton reduction, utilities would equip a substantial fraction of generating capacity with retrofit scrubbers because such technology currently represents the most economical and, in some cases, the only feasible method of attaining this emission reduction. The likely coal market effects may be virtually identical if utilities scrub existing plants, or build new plants subject to the current New Source Performance Standards while retiring old ones. Although these decisions would affect the control costs, the end result would still be a substantial fraction of generating capacity equipped with scrubbers. Paradoxically, these higher emission reduction goals would protect a large segment of the high sulfur coal market. CBO has analyzed the effects of a 0.7 pound of SO_2 per million Btu emission limit, which attained slightly more than a 12 million ton reduction. The results of the analysis are shown in Table 4. Under that policy, high sulfur coal production could be roughly the same as under an 8 million ton annual reduction, as a result of the level of retrofit scrubbing necessitated by the emission reduction policies.

The Design of Emission Reduction Policies and Coal Use

In the region of 8 to 10 million ton reductions, the design of a rollback policy can also affect the point at which scrubber use would become attractive. Rollback policies that lead to emission reductions in this "crossover" range may have substantially different effects on the market for all coals--including coal of medium sulfur content--depending on how emission targets are assigned.[1]

These coal market effects can be illustrated by examining two widely proposed approaches to assigned emission reductions: statewide average emission targets and uniform boiler emission standards. To illustrate the differences, consider a state currently emitting SO_2 from burning high sulfur coal in unscrubbed plants, faced with an emission reduction target based on achieving a statewide average of 1.2 pounds of SO_2 per million Btus, compared with the same state faced with a uniform emission limit of 1.2 pounds of SO_2 for each source. These alternatives essentially describe the two major provisions contained in the Waxman proposal (H.R 4567) introduced into the 99th Congress, and form the basis for Table 5 and Table 6.

Given the 1.2 pound statewide average under the first scenario, scrubbing would not be utilized to any great degree, since coal switching would remain the least cost abatement method at this level of emission reduction. Low sulfur coal in most regions would be substituted for high sulfur coal, but medium-sulfur coal could still be burned without a scrubber as long as sufficient low sulfur coal or scrubbed plants elsewhere in the state were utilized to yield a statewide average of 1.2 pounds. This is not the case for the second policy, however. Plants burning medium sulfur coal would be forced to either switch to low sulfur coal or install scrubbers, which would allow them to burn virtually any coal. According to the CBO results, both techniques would be adopted, thereby lowering overall emissions through a combination of additional scrubbing and coal switching. Compared with a statewide averaging policy, high sulfur coal use could remain roughly constant (because of increased scrubber use), low sulfur coal production would be slightly higher, while medium sulfur coal production would be less by about 20 million tons nationally. This result illustrates a general conclusion about policies that stipulate reductions based on specific emission limits: the demand for coals with sulfur content slightly in excess of the allowed emission limit could be significantly reduced. In order for utilities to burn these

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1. Medium sulfur coal here refers to coal emitting more than 1.2 pounds of SO_2 per British thermal unit (Btu) burned, but less than 5.0 pounds.

coals without scrubbers, they would have to blend them with coal significantly lower in sulfur content than the standard requires, a practice that incurs additional costs. This effect would be mitigated somewhat if new abatement technologies become less expensive to install and operate than current scrubbers.

As emission reduction targets approach the 12 million ton level, the difference between allowing statewide averages or insisting on uniform emission limits in practice would probably narrow, since emission rates low enough to offset higher than average emission rates would become increasingly less feasible and almost certainly uneconomical.

The Role of Scrubber Costs in Coal Switching Analysis

As mentioned above, the relative prices of three factors--low sulfur coal, high sulfur coal, and scrubbers--determine the choice and costs of abatement methods. These choices in turn affect the "crossover" point--the level of emission reduction at which scrubber installation becomes economical. In the CBO model, coal prices are allowed to vary according to supply and demand conditions in the coal markets, but scrubber costs are assumed to remain constant, although some regional variation exists to account for differences in prevailing construction prices. How accurately does the assumption of constant scrubber prices portray the choices utilities might face under acid rain control legislation?

Actual scrubber costs vary widely, especially when retrofitting an existing plant. Detailed retrofit analyses often find extremely wide retrofit penalties (costs incurred over typical new scrubber installation) which can range from zero to values that render retrofit scrubbers economically infeasible, as in sites where insufficient space exists for the scrubber unit. The methodology used by CBO, however, allows only "average" scrubber costs, including the assumed retrofit penalty. Therefore, the simulation results for moderate emission reduction policies may understate actual scrubber utilization in a few cases where a combination of favorable siting conditions and coal prices facing an individual plant may make retrofitting economical. Without a strict boiler-by-boiler analysis, however, such omissions are inevitable.

The cost of building retrofit scrubbers in the CBO model is fairly high compared with other analyses (notably ICF, Inc.). This is the result of financial assumptions (primarily real interest rates and expected asset lifetimes) as well as the assumption of extensive boiler refurbishment--"life extension"--that utilities would likely undertake if scrubbing were deemed desir-

able. The CBO assumed that the average combined retrofit penalty and boiler refurbishment costs would be $125 per installed kilowatt, roughly a 50 percent retrofit penalty on the basic scrubber cost of $240 per kilowatt. Such an assumption becomes critical at this stage of the analysis, since many of the relevant boilers will be reaching the end of their expected useful lifetimes during the period in which utilities must decide on the choice of abatement strategy under current acid rain proposals.

It is reasonable to assume that utilities installing a scrubber would refurbish the boiler as well, in order to enhance the operational efficiency of the combustion unit and to match the lifetime of the boiler to the expected lifetime of the scrubber. Also, the cost of doing both at the same time would be lower than performing both tasks separately. Thus, the financial decision would have to take into account the combined cost of life extension and scrubber installation. The combined cost may still be lower than building a new plant, but be more expensive than scrubber installation alone as typically accounted for in emission control literature. 2/

But this approach attributes all of these refurbishment costs to the emission reduction policy when utilities may perform life-extension activities without the imposition of acid rain control policy. For most utilities, life extension is currently a cheaper way to maintain capacity compared with retiring old plants and building new ones, and several utilities are developing and implementing life extension programs. To the extent that these costs would occur in the absence of additional SO_2 control policies, then the estimates of control costs under policies that rely heavily on scrubbers will be somewhat overstated. The CBO plans to examine this issue in more detail in an upcoming paper.

Finally, the historic costs of retrofit scrubbers may not provide a perfect predictor of future costs. It is likely that the 45 retrofit scrubbers operating as of December 1985 were constructed on the most favorable utility sites, and that higher costs may characterize many of the remaining boilers. On the other hand, lower costs resulting from technical improvements of the scrubber units themselves might help counter this, although wet scrubbing is a fairly mature technology. And, as discussed previously, emerging combustion and post-combustion SO_2 removal technologies hold the promise for lower costs as well, but this possibility remains uncertain.

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2. See D. B. Garvey, D. G. Streets, and T. D. Vaselka, The "Control-or-Retire" Strategy for Reducing Sulfur Dioxide Emissions from Power Plants (Argonne National Laboratory for the U.S. Department of Energy, October, 1984) for a thorough discussion of scrubbing and life extension costs, especially Chapter 3.

ADDENDUM

These tables show estimated 1995 steam coal production (in millions of tons per year) under several policy options. These options are discussed in detail in *Curbing Acid Rain: Cost, Budget and Coal Market Effects*, (Congressional Budget Office, June, 1986).

Table 1 shows projected steam coal production in 1995 under the base case assumptions, that is, production expected under current policy. Low sulfur coal is defined as coal that would emit up to 1.2 pounds of sulfur dioxide (SO_2) per million British thermal units (Btus) burned. Medium sulfur coal has sulfur content greater than 1.2 pounds of SO_2 emitted per million Btus, but less than 5.0 pounds of SO_2. High sulfur coal would emit 5.0 pounds of SO_2 or more per million Btus.

Tables 2 and 3 display the differences in production levels from these regions under an 8 million ton annual emission reduction and a 10 million ton reduction, respectively (as measured against 1980 utility emission levels). These options correspond to Options II-1A and II-2A in the previous report. The emission reductions are governed by the "excess emission formula" applied to 48 states, and assume that extensive coal-switching would be allowed. Since these reductions are stipulated as statewide emission targets in 1995, states are allowed to chose the least cost manner to attain the targets. These reductions, therefore, are similar to other policies under which statewide averaging of emissions from different sources would be allowed. Table 4 shows the expected coal market changes under a 12 million ton reduction achieved through a uniform emission rate of 0.7 pounds of SO_2 per million Btus applied to all utility sources. This is similar to S. 2203, introduced into the 99th Congress by Senator Stafford, and analyzed in the CBO report as Option VI-3.

Finally, Tables 5 and 6 correspond to the analysis of H.R. 4567 (introduced into the 99th Congress by Representative Waxman), and are referenced in the previous report as Option VI-1 and Option VI-2. Table 5 shows expected coal production shifts under the assumption that all states submit efficient abatement plans that would achieve a statewide average emission rate of 1.2 pounds of SO_2 emitted per million Btus of heat input burned. Table 6 shows the coal production changes expected under the default provisions of H.R. 4567, under which all individual utility sources must achieve a 1.2 pound of SO_2 limit by 1995. The reader is urged to consult the report for additional detail that may be helpful in interpreting these figures.

The regions used in these tables are composed of the following states:

Northern Appalachia: Pennsylvania, Ohio, Maryland, Northern West Virginia

Central Appalachia: Southern West Virginia, Virginia, Eastern Kentucky, Tennessee, Alabama

Midwest: Western Kentucky, Illinois, Indiana

Central West and Gulf: Iowa, Missouri, Kansas, Arkansas, Oklahoma, Texas

Great Plains: North Dakota, South Dakota, Montana, Wyoming, Northern Colorado

Rocky Mountains: Southern Colorado, Utah

West: Arizona, New Mexico, Washington, Alaska

TABLE 1. BASE CASE STEAM COAL PRODUCTION IN 1995
(In millions of tons)

Region [a]	Low Sulfur	Medium Sulfur	High Sulfur	Total
Northern Appalachia	22.6	93.5	67.5	183.6
Central Appalachia	155.2	159.7	12.7	327.6
Midwest	0.0	18.4	93.1	111.5
Central West and Gulf	2.5	101.9	24.2	128.6
Great Plains	123.0	64.7	0.2	187.9
Rocky Mountains	37.0	10.7	0.6	48.3
West	27.4	19.2	0.0	46.6
Total	367.7	468.1	198.3	1,034.1

SOURCE: Congressional Budget Office, based on *Curbing Acid Rain: Cost, Budget, and Coal Market Effects*, (June 1986)

NOTE: 1995 sulfur dioxide emissions from electric utilities are estimated at 18.4 million tons under current policy

a. See accompanying text for a list of states included in each region.

TABLE 2. DIFFERENCES FROM BASE CASE OF STEAM COAL PRODUCTION IN 1995 UNDER AN 8 MILLION TON REDUCTION WITHOUT RESTRICTIONS ON COAL SWITCHING (In millions of tons)

Region [a]	Low Sulfur	Medium Sulfur	High Sulfur	Total
Northern Appalachia	8.0	-19.4	-22.8	-34.2
Central Appalachia	84.9	-23.5	-4.5	56.9
Midwest	0.0	-2.8	-19.2	-22.0
Central West and Gulf	0.0	-2.8	-6.0	-8.8
Great Plains	16.6	-3.3	0.0	13.3
Rocky Mountains	5.5	-3.9	-0.1	1.5
West	2.2	0.0	0.0	2.2
Total	117.2	-55.7	-52.6	8.9

SOURCE: Congressional Budget Office, based on Option II-1A described in *Curbing Acid Rain: Cost, Budget, and Coal Market Effects*, (June 1986).

NOTE: Under this policy, 1995 sulfur dioxide emissions from electric utilities are estimated at 11.2 million tons. The annual cost to utilities of this policy is expected to be $1.9 billion (in 1985 dollars). Utilities would purchase $1.2 billion worth of scrubber equipment, which would provide roughly 0.4 million tons of SO_2 reduction.

a. See accompanying text for a list of states included in each region.

TABLE 3. DIFFERENCES FROM BASE CASE OF STEAM COAL PRODUCTION IN 1995 UNDER A 10 MILLION TON REDUCTION WITHOUT RESTRICTIONS ON COAL SWITCHING (In millions of tons)

Region [a]	Low Sulfur	Medium Sulfur	High Sulfur	Total
Northern Appalachia	8.0	-22.7	-33.5	-48.2
Central Appalachia	112.7	-56.3	-6.1	50.3
Midwest	0.0	-3.4	-34.1	-37.5
Central West and Gulf	0.0	-2.9	-6.0	-8.9
Great Plains	56.9	-4.2	0.0	52.7
Rocky Mountains	9.6	-3.8	-0.2	2.3
West	2.3	0.0	0.0	2.3
Total	189.5	-93.3	-79.9	16.3

SOURCE: Congressional Budget Office, based on Option II-2A described in *Curbing Acid Rain: Cost, Budget, and Coal Market Effects*, (June 1986).

NOTE: Under this policy, 1995 sulfur dioxide emissions from electric utilities are estimated at 9.2 million tons. The annual cost to utilities of this policy is expected to be $3.2 billion (in 1985 dollars). Utilities would purchase $1.7 billion worth of scrubber equipment, which would provide roughly 0.5 million tons of SO_2 reduction.

a. See accompanying text for a list of states included in each region.

TABLE 4. DIFFERENCES FROM BASE CASE OF STEAM COAL PRODUCTION IN 1995 UNDER A 12 MILLION TON REDUCTION, WITH ALL PLANTS MEETING A 0.7 LB SO_2 PER MILLION BTU STANDARD (In millions of tons)

Region [a]	Low Sulfur	Medium Sulfur	High Sulfur	Total
Northern Appalachia	2.0	-22.9	-19.8	-40.7
Central Appalachia	42.9	-54.0	-5.2	-16.3
Midwest	0.0	-4.0	-19.3	-23.3
Central West and Gulf	0.0	-2.8	-5.1	-7.9
Great Plains	82.3	-16.3	0.0	66.0
Rocky Mountains	36.5	0.1	-0.4	36.2
West	10.2	0.0	0.0	10.2
Total	173.9	-99.9	-49.8	24.2

SOURCE: Congressional Budget Office, based on Option VI-3 described in *Curbing Acid Rain: Cost, Budget, and Coal Market Effects*, (June 1986).

NOTE: Under this policy, 1995 sulfur dioxide emissions from electric utilities are estimated at 6.9 million tons. The annual cost to utilities of this policy is expected to be $8.8 billion (in 1985 dollars). Utilities would purchase $24.4 billion worth of scrubber equipment, which would provide roughly 7.2 million tons of SO_2 reduction.

a. See accompanying text for a list of states included in each region.

TABLE 5. DIFFERENCES FROM BASE CASE OF STEAM COAL PRODUCTION IN 1995 UNDER A STATEWIDE AVERAGE EMISSION RATE OF 1.2 LBS SO_2 PER MILLION BTU (In millions of tons)

Region [a]	Low Sulfur	Medium Sulfur	High Sulfur	Total
Northern Appalachia	8.0	-22.0	-25.7	-39.7
Central Appalachia	106.2	-48.7	-4.5	53.0
Midwest	0.0	-3.4	-25.8	-29.2
Central West and Gulf	0.0	-2.9	-6.0	-8.9
Great Plains	32.4	-1.6	0.0	30.8
Rocky Mountains	8.5	-4.0	-0.1	4.4
West	0.5	0.0	0.0	0.5
Total	155.6	-82.6	-62.1	10.9

SOURCE: Congressional Budget Office, based on Option VI-1 described in *Curbing Acid Rain: Cost, Budget, and Coal Market Effects*, (June 1986).

NOTE: Under this policy, 1995 sulfur dioxide emissions from electric utilities are estimated at 10.1 million tons. The annual cost to utilities of this policy is expected to be $2.5 billion (in 1985 dollars). Utilities would purchase $1.9 billion worth of scrubber equipment, which would provide roughly 0.6 million tons of SO_2 reduction.

a. See accompanying text for a list of states included in each region.

TABLE 6. DIFFERENCES FROM BASE CASE OF STEAM COAL PRODUCTION IN 1995 WITH ALL PLANTS MEETING A 1.2 LBS SO_2 PER MILLION BTU STANDARD (In millions of tons)

Region [a]	Low Sulfur	Medium Sulfur	High Sulfur	Total
Northern Appalachia	14.5	-25.8	-26.3	-37.6
Central Appalachia	125.1	-60.3	-5.5	59.3
Midwest	0.0	-3.8	-28.5	-32.3
Central West and Gulf	0.0	-1.1	-5.9	-7.0
Great Plains	27.5	-12.0	0.2	15.7
Rocky Mountains	1.6	-0.3	2.6	3.9
West	-0.4	-0.1	0.0	-0.5
Total	168.3	-103.4	-63.4	1.5

SOURCE: Congressional Budget Office, based on Option VI-2 described in *Curbing Acid Rain: Cost, Budget, and Coal Market Effects*, (June 1986).

NOTE: Under this policy, 1995 sulfur dioxide emissions from electric utilities are estimated at 9.3 million tons. The annual cost to utilities of this policy is expected to be $3.3 billion (in 1985 dollars). Utilities would purchase $3.9 billion worth of scrubber equipment, which would provide roughly 1.1 million tons of SO_2 reduction.

a. See accompanying text for a list of states included in each region.