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Achieving Air Quality Goals at Minimum Cost

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ACHIEVING AIR QUALITY GOALS AT MINIMUM COST*

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This paper sets forth the economic criteria for pollution reduction, given a permissable level of emissions. To achieve proposed air quality goals for sulfur dioxide in the St. Louis urbanized area, the Public Health Service recommended a maximum of 35,500 tons of sulfur dioxide emissions in a three month period in the 400 square miles including and surrounding St. Louis and East St. Louis.[1]

THE METHOD

Table 1 indicates the emissions in the winter of 1963-64.[2] Because of the long term nature of the control plan, it was necessary to project these figures (as shown in Table 2) to some future date; 1975 was selected as an appropriate year.

Reducing a large quantity of emissions at the least possible cost is accomplished first by considering various sectors of control. An individual marginal cost curve is constructed for each of these sectors; this curve charts the cost of reducing a ton of sulfur dioxide from one to the maximum possible reduction. From the individual curves, a total cost curve is derived. Each point on the curve indicates the minimum cost for this level of pollution reduction.

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** Robert E. Kohn holds an Air Pollution Special Fellowship awarded by the National Center for Air Pollution Control, U.S. Public Health Service, Department of Health, Education, and Welfare. Mr. Kohn is currently completing a doctoral dissertation which extends this one-pollutant, sulfur dioxide model into a multi-pollutant, linear programming model.

1. Robert A. Taft Sanitary Engineering Center, *A Proposal for an Air Resource Management Program*, Section VIII, INTERSTATE AIR POLLUTION STUDY (Cincinnati, Ohio; June, 1966) (Draft Copy) [hereinafter cited as IAPS]. James D. Williams, Guntis Ozolins, and Jack W. Sadler prepared this Section.

2. *Id.*, Section VIII, Table 12, at 72.

TABLE 1

Source	*Emissions for Urban Area Dec. 1963-Jan., Feb. 1964*
Transportation (principally road vehicles)	900 tons
Combusion of Fuels	
Industry	28,820 tons
Steam-electric utilities	24,540 tons
Residential	18,910 tons
Commercial and institutional	6,435 tons
Refuse Disposal	90 tons[3]
Sulfuric Acid Plant Emissions	5,000 tons
Total	84,790 tons

TABLE 2

Sector	*Source*	*Projected Emissions for Urban Area Dec. 1974-Feb. 1975*
S_1	Transportation	1,440 tons
S_2	Existing Sulfuric Acid Plants	6,381 tons
S_3	New Sulfuric Acid Plants	2,601 tons
S_4	Open Burning of Refuse	144 tons
S_5	Industrial Combustion of Coal	41,168 tons
S_6	Industrial Combustion of Oil	4,920 tons
S_7	Residential Coal Burning	1,891 tons
S_8	Commercial and Institutional Combustion of Fuels	4,426 tons
S_9	Utilities in the Urbanized Area	6,877 tons
S_{10}	The Portion of Outlying Utility Emissions Affecting Air Quality in the Urbanized Area	25,000 tons
	Total	94,848 tons

Consider the hypothetical chart shown in Figure 1. Line A is the cost of reducing pollution in sector A from zero to a maximum of 2 tons. Line B is the cost of reducing pollution in sector B from zero to 4 tons. Line A+B is a horizontal summation of the two and goes from

3. IAPS, Section VIII, Table 12 does not include the 90 ton figure but states "negligible" for this value. However, it does indicate that 60 tons are emitted in the City of St. Louis alone in refuse disposal. Table 11 shows that over a year's time St. Clair County emits half as much as the City of St. Louis from this source. Adding an estimated winter output of 30 tons for St. Clair County to St. Louis' 60 tons gives the 90 ton total.

zero to 6 tons. Total pollution is indicated by the arrowed line at 9. If allowable emissions are 4, the reduction of 5 will cost 3 x $1 + 1 x $2 + 1 x $3 = $8, which is the integral of the A+B curve from zero to 5. The chart also indicates the division of reduction between sector A and sector B. Both must reduce as much pollution as possible at $3 a ton or less. Reading across from the $3 figure on the marginal cost scale, it will be seen that two tons can be reduced at this price or less in A and three tons in B. This is the "least cost" solution.

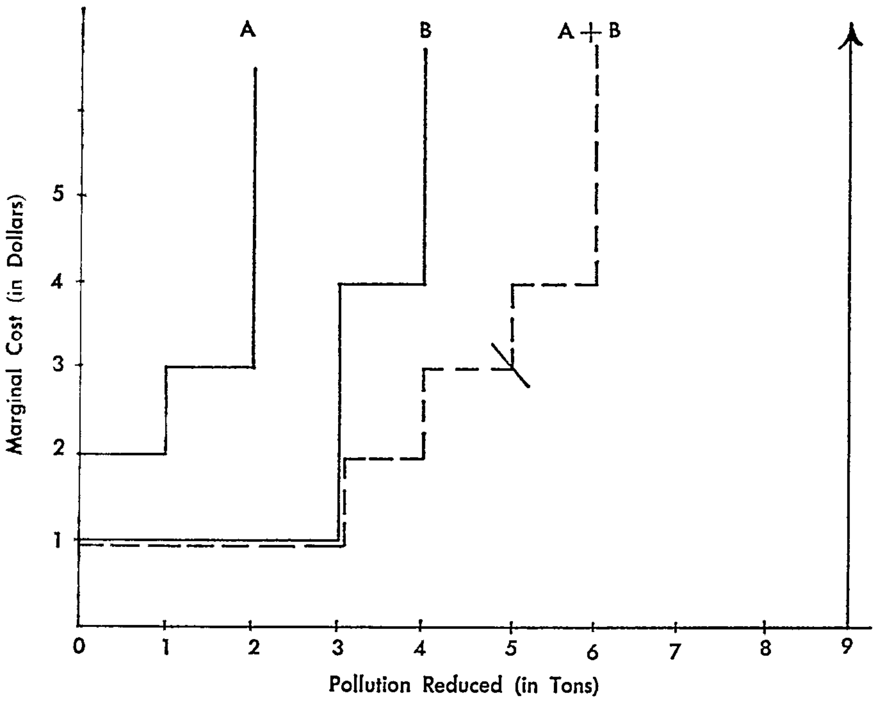

FIGURE I
GRAPHICAL ILLUSTRATION OF METHODOLOGY

The cost curves illustrated above (and those used in this paper) are step functions because only a limited number of pollution reduction methods were considered feasible, and each was presumed to have constant marginal cost. If the cost curves were continuous, curvilinear, and positively sloped, then the least cost solution for any level of reduction would be achieved by carrying pollution reduction in each sector to the point where marginal cost is equal in each sector.

Certain simplifications should be noted:

1. Emissions in each sector are considered to affect air quality

equally. The *Interstate Study* notes, however, that some reductions are more significant than others. For example,

> A sizable reduction in residental emissions is expected to have a more pronounced effect on the reduction of the ambient air concentrations of sulfur dioxide than comparable reductions in other source categories. This is primarily due to the proximity of the source to the receptor, the wide geographical distribution of sources, and of the generally low elevations of emissions.[4]

In the case of certain utility installations, the concentration of emissions has an effect on air quality proportionally greater than more diffused sources. In such cases a higher marginal cost of control for these sources would be consistent with minimum cost of obtaining the air quality goal.

2. Emissions in each sector are considered to affect air quality equally at any point in time. Meteorological conditions are most adverse to atmospheric dissipation of pollutants during ten or twenty days of a three month winter period. There is a minimum cost of control theory that an air quality goal can be most economically achieved by drastically reducing pollution during this period. By curtailing emissions on these days only, and not the remaining days, it is presumed that the air quality goal can be achieved at less cost than a program which depends on permanent reductions.

This type of program depends on a different range of control methods than those described in this paper. The methods are short-run, and include such measures as temporary substitution of natural gas for coal, temporary cessation of manufacturing which contributes heavily to pollution, temporary prohibition of non-essential automobile use, etc. Part of the cost of this program is the cost of predicting in advance those days in which such measures must be instituted; and there is the risk that such predictions may be faulty.

3. It is possible that the air quality goal for sulfur dioxide could be achieved with less reduction if emissions were more evenly spread out over the urbanized area. The *Interstate Study* notes, "if the sources were uniformly distributed throughout the urbanized area, the existing air quality would approximate the air quality goals."[5]

4. The marginal cost in any sector is the cost to a representative firm in the industry. If, for example, a particular firm with poor credit had to pay more for abatement, the marginal cost for this firm, being

4. IAPS, Section VIII, at 87.
5. *Id.*, Section VIII, at 80 (this statement pertains to the 1963 level of emissions).

higher than others, would not be the representative marginal cost for the reduction alternative.

5. The marginal cost of enforcement has not been included, although it should be. In some cases the difficulty of enforcing a relatively stringent regulation would make a significant addition to the marginal cost of that regulation.

6. Various dynamic, long run effects have been ignored. If pollution abatement restricts the expansion of certain industries or causes some firms to relocate to avoid controls, there will be social costs which should be taken into account. (It is possible that pollution control will attract new industry; however, this is part of the benefits of a clean air program.)

7. The reduction methods used in this paper were essentially those considered or adopted by the Missouri Air Conservation Commission. Clearly, other degrees of control, both more and less stringent, could have been included if data had been available. Although in some respects this study represents an incomplete model, it nevertheless illustrates the kind model that could be constructed by a community having the advantage of more adequate research facilities than exist at present.

I. TRANSPORTATION

As noted in Table 1, transportation contributed 900 tons of sulfur dioxide in the three winter months of 1963. Over 80 percent of this was from road vehicles, the remainder from aircraft, vessels, and railroads. Approximately nine pounds of sulfur oxides are emitted from the exhaust of gasoline engines for every thousand gallons of fuel consumed. The emission is more than four times as great in diesel engines.[6]

The *Interstate Study* includes a projection of carbon monoxide emissions, if uncontrolled, for the next 30 years. This same projection can be applied to sulfur dioxide, which will not be controlled even if carbon monoxide is. According to the projection, emissions in 1975 will be 160 percent above the 1963 level.[7] Assuming that this projection applies to diesel vehicles and aircraft, sulfur dioxide emissions for three winter months, in the urbanized area, will be 1440 tons in

6. *Id.*, Section II, Table 7 of the Appendix.
7. *Id.*, Section VIII, at 123.

1975.[8] Consequently, there is no feasible cost curve for reducing sulfur dioxide from this source.

II. Sulfuric Acid Plant Emissions

Table 1 attributes 5,000 tons of sulfur dioxide to industrial plant emissions.[9] These are vented from the stacks during the manufacture of sulfuric acid. Assuming an annual increase in sulfuric acid production of five percent per year, pollution from this source will increase from 5,000 tons in 1963 to 6381 tons five years later; the 1975 total will be 8982 tons. Because the costs of sulfur dioxide control are higher when added to existing equipment, this sector is subdivided into existing plants and new plants.

A. *Costs of Sulfur Dioxide Control in Existing Facilities for Producing Sulfuric Acid*

Meeting a 500 parts per million (ppm) standard in existing sulfuric acid facilities reduces sulfur dioxide emissions from 45 to 7.5 pounds per ton of acid produced. An engineer of a large producer of sulfuric acid in the St. Louis area, who requested that his name and company not be stated, had cost estimates for meeting a 500 ppm standard.[10] According to the engineer, an additional 40 percent in capital equipment would have to be incorporated into existing facilities.

Capital equipment cost for producing 350,000 tons of sulfuric acid annually under current process:	$2,400,000
40 percent addition:	960,000
Annual depreciation of the 40 percent addition; 15%[11]	144,000
Imputed interest cost of the 40 percent addition; 10%	96,000
Property taxes, insurance, and factory indirect expenses assigned to overhead; 7½%	72,000
Additional maintenance cost of the 40 percent addi-	

8. *Id.*, Section II, Table 1 of the Appendix; Section VIII, at 123.

9. Table I shows that 5,000 tons of sulfur dioxide arise from industrial process emissions. Two-thirds of these emissions occur in the production of sulfuric acid, the remainder in other processes. A correct analysis would include a separate sector and marginal cost curve for each process. Owing to lack of data on the breakdown of emissions into other processes, however, the cost information for sulfuric acid will be used to represent a single industrial process emission sector.

10. Private communication on April 25, 1967.

11. Accelerated depreciation to account for the fact that a capital addition is being added to older equipment.

tion (5% of additional capital requirement) 48,000

$360,000

Costs per ton of acid produced is $\frac{\$360,000}{350,000}$ or \$1.03.

Attaining the 500 ppm standard costs \$1.03 per ton of acid produced. The sulfur dioxide reduction is 37.5 pounds. The cost per ton of sulfur dioxide reduced is:

$$\frac{(2,000 \text{ pounds})}{(37.5 \text{ pounds})} (\$1.03) = \$54.93.$$

The reduction of 83⅓% permits the elimination of 5317 tons of sulfur dioxide at a marginal cost of \$54.93. Figure II illustrates this result.

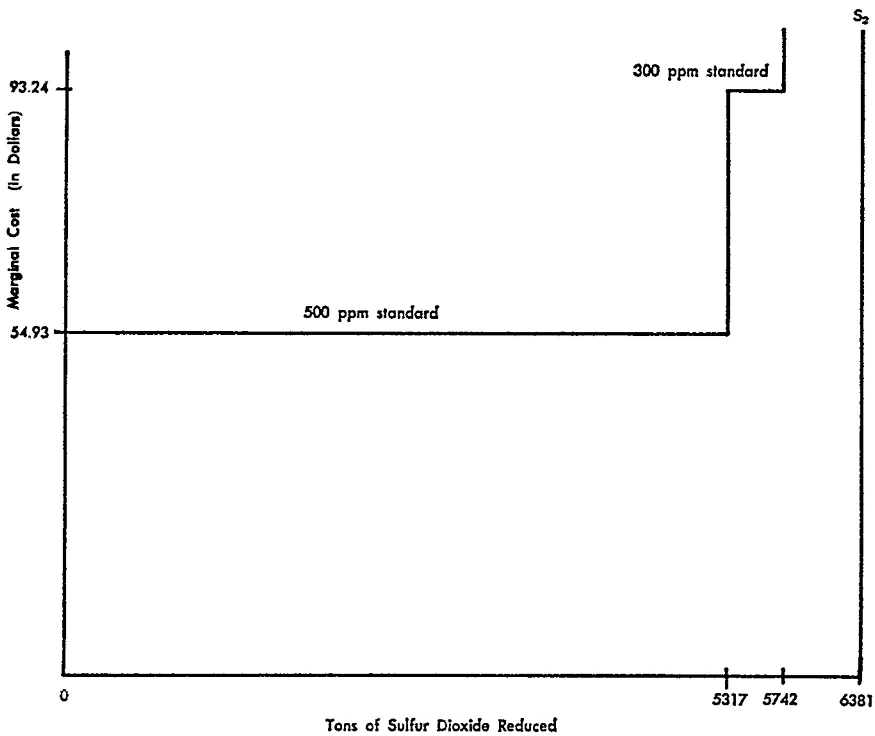

FIGURE II
MARGINAL COSTS OF SULFUR DIOXIDE REDUCTION IN EXISTING SULFURIC ACID FACILITIES

A standard of 300 ppm, as will be explained in the next section, would entail marginal costs of \$93.24 per ton.

B. *Costs of Sulfur Dioxide Control in Sulfuric Acid Plants Constructed After 1967*

Sulfuric acid facilities constructed after 1967 in the Interstate Area, if uncontrolled, would be emitting 2601 tons of sulfur dioxide by 1975. A 500 ppm regulation will reduce this amount by 83 percent to 442 tons. What is the cost of eliminating these 2159 tons of sulfur dioxide:

According to the authority on sulfuric acid production, the 500 ppm standard can be achieved by either of two methods, both of which are comparable in cost: the Ammonia Scrubbing Process and the Bayer Double Catalyst Contact Process. The Bayer process requires 15 percent more capital than current sulfuric acid plants. The cost per ton of acid is computed as follows:

Capital equipment for producing 350,000 tons of sulfuric acid annually under current process:	$2,400,000
15 percent addition	360,000
Annual depreciation of the addition; 7½%	27,000
Imputed Interest cost of the 15 percent addition; 10%	36,000
Property taxes, insurance and factory indirect expenses assigned to overhead; 7½%	27,000
Additional maintenance cost of the 40 percent addition; 5%	18,000
	$108,000

Costs per ton of acid produced is

$$\frac{\$108{,}000}{350{,}000} \text{ or } \$.31.$$

(There is a steam loss in this process, but it is offset by a saving in the quantity of sulfur input.)

Reducing sulfur dioxide emissions from 45 to 7½ pounds per ton of acid by this process represents a cost of $16.53 per ton of sulfur dioxide eliminated $\left(\frac{2000}{37.5} \times \$.31 = \$16.53\right)$.

A 300 ppm standard for new plants would reduce sulfur dioxide emissions an additional 40 percent, from 7½ pounds to 4½ pounds. This additional 3 pound reduction would be obtainable with the new Bayer process by replacing 25 percent of the catalyst annually. For a 350,000 ton a year plant, this would increase catalyst costs $50,000 a year, or 14¢ a ton. The 3 pound additional reduction at a cost of 14¢ a ton of acid produced, represents a marginal cost of $93.24 per ton of sulfur dioxide emissions eliminated. Figure III illustrates the marginal cost of sulfur dioxide controls.

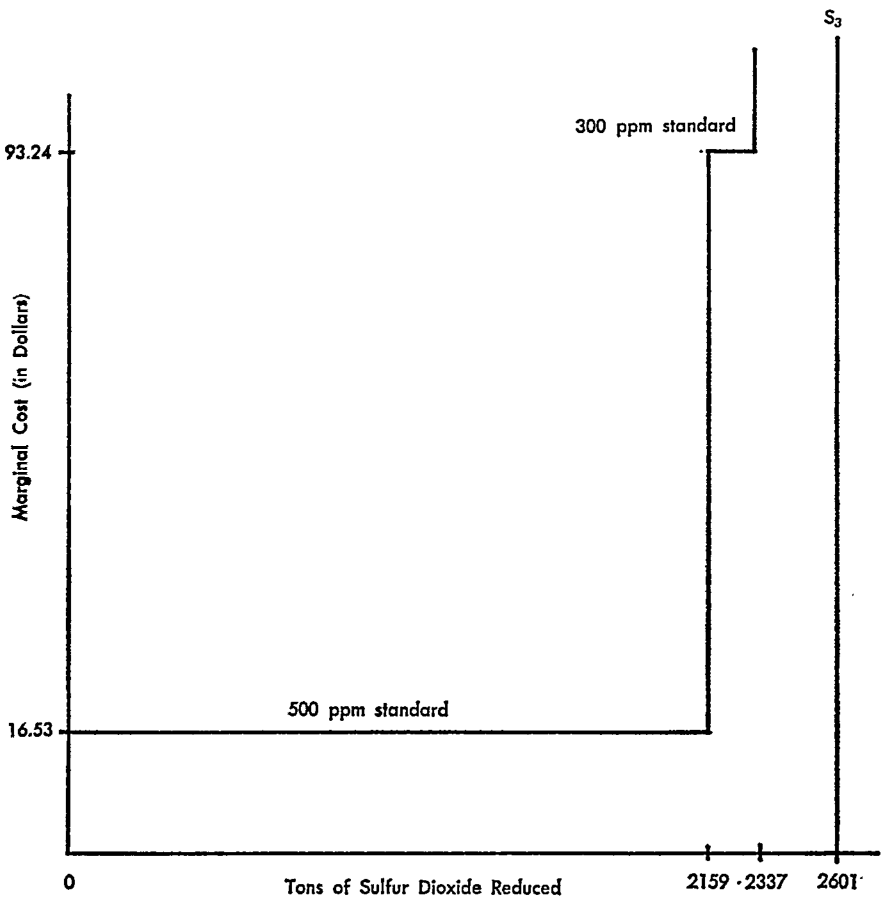

FIGURE III
MARGINAL COSTS OF SULFUR DIOXIDE REDUCTION IN NEW SULFURIC ACID FACILITIES

III. OPEN BURNING OF REFUSE

As noted in Table 1, 90 tons of sulfur dioxide were released in the winter of 1963-4 from refuse disposal. Estimating this output to increase, along with industrial expansion, at a rate of 4 percent per annum, the 1975 output of sulfur dioxide from this source will be 144 tons. The greatest part of these emissions is from open burning,[12] and can be eliminated by removing rubbish from the area.

According to Mr. M. Corman, President of AAA Disposal Co. of St. Louis, which operates a rubbish disposal service for industry, the cost of rubbish pick-up and removal is approximately $2.00 per cubic yard. Mr. Corman estimated that a truck load of 25 cubic yards will have an average weight of 8 tons.[13] This indicates a cost of $50 for 8 tons or $6.25 per ton, as the cost of eliminating the burning of refuse and rubbish.

A ton of refuse, burned in a dump, emits 328 pounds of pollutants, including sulfur dioxide.[14] For an average cost of $6.25, these emissions can be avoided. Thus, for $37.50, a ton of pollutants can be eliminated by this method of pollution reduction. Figure IV illustrates this cost function.

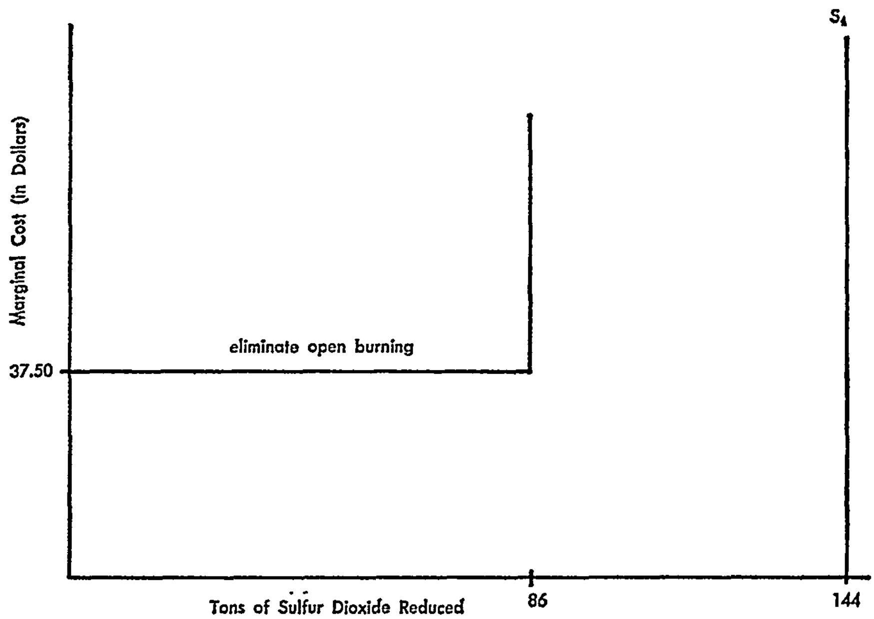

FIGURE IV
MARGINAL COST TO REDUCE SULFUR DIOXIDE EMISSIONS FROM REFUSE DISPOSAL

12. IAPS, Section II, Table 1. This table indicates that 60 percent of Refuse Disposal emissions are from open burning. The remainder of SO_2 is from incineration and cannot be significantly reduced.

13. Private communication with Mr. Max Corman on May 4, 1967.

14. IAPS, Section II, Table 5 of the Appendix. (In this case, all pollutants are costed as being equivalent to sulfur dioxide.)

IV. Combustion of Fuels

A. *Sulfur Dioxide from Industrial Combustion of Coal*

According to Table 1, sulfur dioxide emissions from industrial combustion of fuels were 28,820 tons. Of these approximately 3090 tons were from the combustion of fuel oil, while the remaining 25,730 tons were from coal.[15]

Assuming an annual rate increase of 4 percent[16] for industries using coal, emissions in 1975 will grow from 25,730 tons in 1963 to 41,168 tons in 1975.

Mr. James R. Jones, Chief Combustion Engineer of Peabody Coal Co., speaking on behalf of the Mid-West Coal Producers' Institute, stated that industrial coal combustion in the Interstate Area will remain relatively stable because "increases in such usage will be outside of the (urbanized) area (and) plants such as Anheuser-Busch, which has converted part of its facilities to gas, and McDonnell Aircraft, which has converted to gas entirely, will be offsetting factors for any increase."[17]

Mr. Jones' prediction may prove to be correct. However, there is no reason to presume a shift of industry away from the 400 square mile urbanized area into the relatively unpopulated area. Although the industrial growth in the latter areas may well prove to exceed 4 percent, the 4 percent growth rate for industry in the urbanized area also seems to be a reasonable projection.

Mr. Jones' suggestion of conversion from coal to natural gas is convincing. Let us assume that of the increase in projected emissions for 1975, from 25,730 tons to 41,168 tons, half of the increase will be avoided by conversion of some coal users to natural gas. The elimina-

15. IAPS, Section VIII, Table 16, at 85. This table shows omissions for industry and utilities together. However, since the utilities in 1963 used a small proportion of the total fuel oil (see Table 3), the fuel oil emissions from Table 16 are ascribed to industry combustion alone.

16. Bureau of the Census, Long Term Economic Growth, Chart 17, Part A, at 107 (October, 1966), indicates a 4.2 percent growth rate of real Gross National Product of the United States for the period 1960-65. The growth rate for 1955-65 is 3.4 percent. Professor Harold Barnett advises that whereas the 3.4 percent rate might apply to the country as a whole, for industrial areas and for manufacturing in particular, in the industrial areas, the growth rate is in excess of 4 percent. Union Electric Company's 1965 Annual Report noted that for the metropolitan St. Louis area, "Manufacturing output for the year increased 12 percent, as compared with the national increase of 7 percent" (at 17). The 4 percent growth rate is used in this paper as a reasonable but conservative expectation of industrial growth of the Interstate Area.

17. Letter from James R. Jones to Robert E. Kohn, May 2, 1967.

tion of 7719 tons of sulfur dioxide emissions by conversion to natural gas represents a cost which must now be examined.

1. *Reducing Industrial Emissions of Sulfur Dioxide by Using Gas*

Table 3 shows the sulfur content of coal burned in the Interstate Area over twelve months, 1963-1964.

TABLE 3[18]

Source of Coal	*Quantity Burned (in tons)*	*Percent sulfur, by weight, as received*
Belleville District	5,411,600	3.3
Southern Illinois	1,724,000	1.5
Miscellaneous	250,000	3.0
	7,385,600	

The 7,385,600 tons of coal used for combustion have an average sulfur content of 2.85 percent.

The atomic weight of sulfur is 32, while that of oxygen is 16. Sulfur dioxide (SO_2) includes one atom of sulfur and two of oxygen and consequently weighs twice as much as the sulfur component. If a ton of coal has a 2.85 percent sulfur content, it contains (2.85 percent of 2000 lbs.) 57 pounds of sulfur, which during combustion unites with oxygen to produce 114 pounds of sulfur dioxide. Since complete combustion usually does not occur, however, the emission rate conforms to a formula.

$$\text{Pounds of } SO_2 = 3800 \times \text{Sulfur Content} \times \text{Tons of Coal.}$$

For example, the combustion of one ton of coal of 2.85 percent sulfur content produces $3800 \times .0285 \times 1$, or 108.3 pounds of sulfur dioxide. The formula indicates that 95 percent of the sulfur content is converted to sulfur dioxide.

For each ton of coal replaced by the BTU equivalent of natural gas, 108.3 pounds of sulfur dioxide emissions are avoided. What is the cost of this substitution? The Mid-West Coal Producers' Institute estimated costs to replace coal with natural gas in the greater St. Louis area. At 1050 BTU's per cubic foot of natural gas, it requires 21,900 cubic feet to produce 23,000,000 BTU's, which is the approximate

18. IAPS, Section VIII, Table 10, at 69. This table does not include 876,000 tons of coal (1.5 percent sulfur content) used for cooking. See IAPS, Section II, Table 13, at 24, "Air Pollutant Inventory."

heating value of a ton of coal.[19] For large industrial users, the Mid-West Coal Producers' Institute estimated an average price of 41.1 cents per one thousand cubic feet of natural gas.[20] A particular firm in St. Louis, which preferred that its name be withheld, supplied the following comparative cost estimates. This firm uses both fuels in its operation.

	Cost per 1,000,000 BTU's	*Cost for 23,000,000 BTU's (the heat output of 1 ton of coal or 21,900 cubic feet of gas)*
Coal	$.248	$5.30
Gas	.375	8.62

These figures make no allowance for the economies of burning gas, e.g., no storage costs, greater cleanliness. Mr. Richard Horner, Administrative Vice-President of Mississippi River Transmission Corporation estimates that in comparing fuel costs, 10 percent should be added to the price of coal to include the diseconomies which are avoided by burning gas.[21] Using this "rule of thumb," the increased cost of burning 21,900 cubic feet of gas rather than one ton of coal is $8.62—($5.30 + .53) or $2.79.

Assuming that this is representative of the cost to industrial coal users of switching to natural gas, $2.79 can be estimated as the cost of eliminating 108.3 pounds of sulfur dioxide, the emissions attributable to a ton of 2.85 percent sulfur content coal.

The shift from coal to natural gas reduces other pollutants as well as sulfur dioxide. This is illustrated in Table 4. It is apparent that $2.79 spent on this form of pollution control reduces many pollutants, including benzo (a) pyrene, a chemical capable of causing cancer. Since this cost should not all be assigned to sulfur dioxide, half of this figure, or $1.40, will be used as the cost of eliminating 108.3 pounds of sulfur dioxide. This is equivalent to a cost of $25.90 per ton of sulfur dioxide eliminated, and will be applied to the 7,719 tons of sulfur

19. Statement by John McGrath on behalf of Mid-West Coal Producers Institute, Inc., before the East-West Gateway Coordinating Council, East St. Louis, Illinois, October 19, 1966, at A-19.

20. *Id.*, at A-18.

21. Private communication with Mr. Horner on April 25, 1967.

dioxide which were previously estimated to be the 1975 sulfur dioxide emissions avoided by industrial firms shifting from coal to natural gas.

2. *Reducing Industrial Emissions of Sulfur Dioxide by Burning Lower Sulfur Coal*

It was estimated earlier that industrial sulfur dioxide emissions in 1975 would be 41,168 tons. Deducting the partial shift to natural gas leaves 33,449 tons.

TABLE 4
POLLUTANT EMISSION FOR INDUSTRIAL COMBUSTION OF EITHER COAL OR GAS TO PRODUCE 23,000,000 BTU's[22]

Pollutant	*One ton of coal, (sulfur content = 2.85% per ton)*	*21,900 cubic feet of natural gas, (sulfur content = .0008%)*
Carbon Monoxide	3 lbs.	.09 lbs.
Hydrocarbons	1 lb.	negligible
Nitrogen Dioxide	20 lbs.	5.09 lbs.
Sulfur Dioxide	108.3 lbs.	.02 lbs.
Particulates	128.0 lbs.[23]	.38 lbs.
Benzo (a) Pyrene	640 micrograms	452.4 micrograms

These emissions could be substantially reduced by a requirement that no coal with more than a two percent sulfur content be burned. The *Interstate Study* estimated that the incremental cost of two percent sulfur requirement would represent an additional cost to coal users of $1.35 a ton.[24] The increased cost of two percent sulfur coal over 3.3 percent reflects the fact that low sulfur coal is obtained in Illinois from shaft mines rather than from strip mines, which are a cheaper method of production.[25] It reflects the fact that until mines

22. IAPS, Section II, Apendix Tables 1 and 3. The natural gas emissions listed in Table 3 are in pounds per ton. To convert to pounds per 21,900 cubic feet, a factor of .5655 is applied, utilizing the fact that the density of natural gas is .05165 pounds per cubic foot.

23. The particulates are an increasing function of the ash content of coal. This figure is based on the 8 percent ash content of Southern Illinois coal rather than the 10 percent ash content of Belleville coal.

24. *See* IAPS, Section VIII, at 95.

25. Although coal can be recovered more cheaply from strip mines than from shaft mines, the debate over the strip mining control bill in the Illinois Legislature indicates that strip mining involves a social cost that has been ignored. Strip mining contributes to water pollution and renders tens of thousands of acres of land unsightly and unusuable for agriculture unless restored. *Cf.* Pensoneau, Strip Mining Control Bill Wins Approval, St. Louis Post Dispatch, April 2, 1967, § C, at 9, col. 3.

are opened in St. Clair and Madison Counties, the freight from Southern Illinois fields will be over $1.00 more than from the Belleville fields.

Mr. S. L. Leichtle, St. Louis District Manager of Old Ben Coal Corporation (until his retirement on April 30, 1967), advised the writer that his company was constructing a 3,000,000 ton mine in Southern Illinois, to open in 1968.[26] Although most of the capacity had been sold, approximately 750,000 tons per year had not been committed. The sulfur content of this coal would meet the two percent requirement. Mr. Leichtle's quoted price for this coal was $5.85 per ton plus $2.47 transportation charges,[27] a total of $8.32. This compares to a delivered price of approximately $6.30 per ton for high sulfur coal,[28] indicating that low sulfur coal from Southern Illinois would cost industrial users approximately $2.00 more a ton than high sulfur coal.

William Pritchard, vice-president of Randall Fuel Co., of Atlanta, Georgia, with large coal mining facilities in Kentucky, while on a recent trip to St. Louis to sell low sulfur coal, advised the writer that industrial users would pay an estimated increase of $2.50 a ton (including transportation costs) for Kentucky coal than they are currently paying for high sulfur coal. This estimate was based on the premise that new freight rates into the St. Louis area would be obtained equal to special rates which are already in effect for other markets equidistant from Kentucky.

The estimated increase of $2.00 a ton for Southern Illinois coal and $2.50 a ton for Kentucky coal are partly offset by low sulfur coal's higher heating rating in British Thermal Units. Table 5 gives these ratings.

TABLE 5

AVERAGE HEATING VALUE PER POUND OF COAL IN BRITISH THERMAL UNITS.[29]

Coal Source	*Sulfur Content*	*BTU's*
Belleville District	3.3 percent	11,300
Southern Illinois	1.5 percent	12,200
East Kentucky	1.0 percent	13,500

26. Private communication with Mr. Leichtle on March 12, 1967.

27. Rail charges from Southern Illinois are $2.07 for 20 car shipments, which require the purchase of 1250 tons of coal for a single delivery.

28. For instance, the City of St. Louis placed a contract for 30,000 tons of 3.2 percent sulfur coal for its Howard Bend station, with Consolidation Coal Company, at $6.29 per ton. St. Louis Globe-Democrat, February 21, 1967, at 1A, col. 4.

29. IAPS, Section II, Table 13.

Approximately 0.93 tons of 12,200 BTU coal has the same heating value as a ton of 11,300 BTU coal. This indicates a cost offset in using low sulfur coal, since a smaller amount of coal is required. As a rule of thumb, each one hundred BTU differential is worth six cents. This would reduce the $2.00 estimated cost increase for Southern Illinois coal by $.54 to $1.46, and the $2.50 estimated cost increase for Kentucky coal to $1.18. However, in the latter case, according to Ralph P. Vollmer, Chairman of the St. Louis Chapter of the Midwest Coal Producers Institute, the greater heat value of Kentucky coal is partially offset by different volatility, ash and swelling characteristics.[30]

Assuming a net cost increase of $1.50 for either Southern Illinois coal or Eastern Kentucky coal gives a cost increase roughly 10 percent higher than the original estimate of the *Interstate Study.* Although the cost might be temporarily above this level while new mine capacity is being added, the cost of $1.50 a ton should be realistic for our 1975 analysis.

Assuming that 75 percent of the low sulfur coal is obtained in Illinois and 25 percent in Eastern Kentucky, the reduction in sulfur dioxide emissions for each ton of 3.3 percent sulfur coal replaced will be

$$.75\,[(3800)(.033)(1) - (3800)(.02)(.93)] \\ + .25\,[(3800)(.033)(1) - (3800)(.010)(.93)],$$

which is 63.6 pounds. This is equivalent to a cost of $46.50 per ton of sulfur dioxide emissions eliminated.[31]

To carry the marginal cost analysis one step further, we might question the advisability of a 1.5 percent sulfur limit on coal; this is the limit that was originally recommended in the *Interstate Study.*[32] This would have ruled out Southern Illinois coal and given the Kentucky producers as well as the Louisville and Nashville Railroad an unchallenged position in the Interstate Area market. Union Electric Company's estimate that the price of low sulfur coal might be as high as $4.00 per ton more than Belleville coal is a conservative estimate.[33] The additional reduction in emissions per ton of coal burned, approximately (3800) (.020) — (3800) (.015) or 19 pounds of sulfur dioxide, purchased at the incremental price of ($4.00-$1.50) or $2.50 would represent a marginal cost of $262.50 per ton of sulfur dioxide reduction.

30. *Cf.* St. Louis Post-Dispatch, February 20, 1967, at 3A, col. 1.

31. This figure incorporates a slight mathematical error.

32. IAPS, Section VIII, at 94-95.

33. Union Electric Company, *Effect of Missouri Air Conservation Regulations on Union Electric Company and Community* (March, 1967).

3. Cleaning the Stack Gases

That some industrial firms (other than public utilities) might find it feasible to burn high sulfur coal and then remove the sulfur dioxide from the smoke stacks has become a very real possibility. At the American Power Conference, held in Chicago on April 25-27, 1967, Combustion Engineering, Inc. announced a new process for separating sulfur dioxide from the flue gases.

Mr. A. L. Plumley, Senior Project Engineer of Combustion Engineering, Inc., who is lead author of the paper, *Removal of SO_2 and Dust From Stack Gases,* which was presented at the American Power Conference, advised the writer that this process would work as efficiently for small combustion units as for large power plants. The three processes which have been known to the public, the Reinluft Process, the Alkalized Alumina Process, and the Catalytic Oxidation Process, all would require such a great capital investment that they could only be economical for large utility power plants.[34] Mr. Plumley stated that the cost for operating the Combustion Engineering process would range from $.361 to $.631 per ton of coal burned. Mr. Plumley had no way of estimating what proportion of the industrial firms in the St. Louis area might be using this, or competitive processes should they be developed, in the year 1975. However, he felt that a range of 15 to 25 percent of the firms would be a reasonable prediction.[35]

The Detroit Edison Company has been testing this process, in which dolomite reacts with sulfur dioxide to form an easily disposable solid waste material, and their results indicate that 90 percent or more of the sulfur dioxide was removed from the stacks under a variety of conditions, and under optimum conditions, 98 percent.[36] Assuming 90 percent efficiency, this process would reduce sulfur dioxide emissions (3800) (.0285) (.90), or 97.5 pounds per ton of coal burned. At a removal cost of $.631 per ton of coal, this process eliminates a ton of sulfur dioxide for $12.94.

It was estimated earlier that after allowing for conversion to natural

34. S. Katell, An Evaluation of Dry Processes for the Removal of Sulfur Dioxide from Power Plant Flue Gases, 14 (unpublished paper presented at the Symposium on Economics of Air Pollution Control, Columbus, Ohio, May 15-18, 1966, on file with the Department of Economics, Washington University).

35. Private communication with Mr. A. L. Plumley, May 5, 1967.

36. A. Plumley, Removal of SO_2 and Dust from Stack Gases, 9 (unpublished paper presented at the American Power Conference, Chicago, Illinois, April 25-27, 1967, on file with the Department of Economics, Washington University).

gas, the 1975 emissions of sulfur dioxide from industrial sources would be 33,449 tons. This would represent the combustion of

$$\frac{(33{,}449)(2000)}{(3800)(.0285)},$$

or 617,700 tons of coal in a three month winter period in 1975.[37]

Assuming that 15 percent of the firms will be using stack-cleaning equipment, and that these 15 percent of the firms burn 25 percent of the coal,[38] then 25 percent of 617,700 tons of coal or 154,425 tons would be burned in plants using processes to remove sulfur dioxide from the flue or stack gases. This will reduce sulfur dioxide emissions by

$$\frac{(3800)(.0285)(.90)(154{,}425)}{(2000)},$$

or 7520 tons. A 2 percent sulfur requirement on coal for the remaining 463,275 tons of coal will reduce emissions

$$\frac{[(3800)(.0285) - (3800)(.0175)(.93)]\,463{,}275}{2{,}000}$$

or 10,760 tons.[39]

Figure V illustrates the marginal cost of reducing sulfur dioxide emissions from industrial combustion of coal. The lowest cost reduction is from stack cleaning which is predicted to eliminate 7520 tons at a cost of $12.94 per ton. Conversion to natural gas eliminates an additional 7719 tons at $25.90, while the 2 percent sulfur content limitation eliminates 10,760 tons of sulfur dioxide. This leaves 15,169 tons of sulfur dioxide still emitted from industrial combustion of coal in 1975.

37. Solving for T, tons of coal in the formula

(tons of SO_2) (2000 pounds) = (3800) (Average sulfur content) (T).

38. According to Mr. Leichtle, the top 15 percent of area firms, ranged in order of coal tonnage burned, probably consume 50 percent of the coal. This does not include the two utilities nor the coal they burn. However, we are not assuming that it is these same 15 percent that adopt the stack cleaning process; hence the 25 percent compromise. Private communication with Mr. Leichtle, May 5, 1967.

39. The (.93) represents the reduction in tons of higher BTU coal burned to acheive equal heating value of 2.85 percent sulfur coal. The reader may question why 2.85 percent sulfur content is used in the equation for source reduction while 3.3 percent sulfur content is used in equations to determine marginal cost. This explanation is that for cost purposes, it is the 3.3 percent sulfur coal that is being replaced by low sulfur coal; the reduction in emissions must start with the 2.85 percent average sulfur content, since fuel consumption in 1963 included a portion of the more expensive, low sulfur coal.

A sulfur content limitation of 1½ percent instead of 2 percent, would reduce sulfur dioxide emissions an additional

$$\frac{(3800)(.0175 - .0125)(463{,}275)}{2{,}000},$$

or 4401 tons.[40]

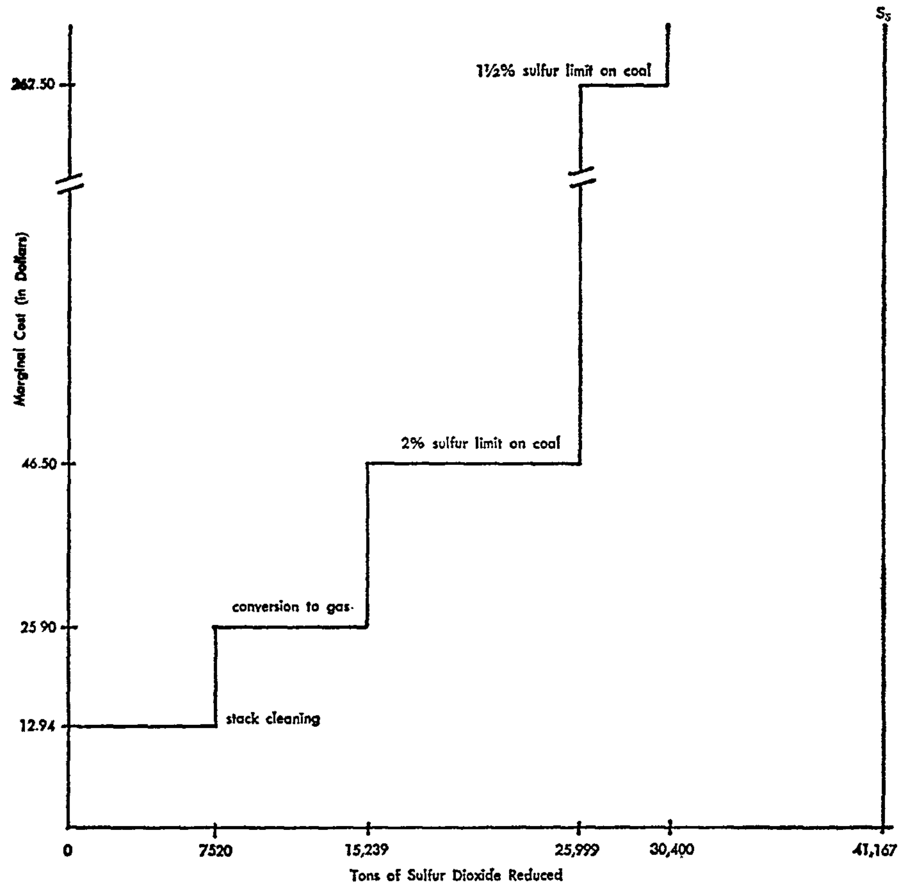

FIGURE V
MARGINAL COSTS TO REDUCE SULFUR DIOXIDE EMISSIONS FROM INDUSTRIAL COMBUSTION OF COAL

For this analysis to be valid, each component cost curve must be a least cost function. In Figure V, for example, this cost curve would shift to the right if a greater number of firms would either install stack cleaning equipment or convert to natural gas. Stack cleaning is the

40. A mixture of 1½ and 1 percent sulfur coal assumed here in the .0125 figure.

most economical method of reducing industrial emissions both for the individual firm and for society. The higher price of coal will be an inducement for firms to install stack cleaning equipment, and the only limitation will be the limited supply of the new equipment, plus problems of whether or not it can be adapted to a particular firm's operation. The federal government will probably promote a speed-up in the development and marketing of new equipment since President Johnson has already agreed to subsidize private industry in developing stack control technology.[41]

Referring again to Figure V, the cost curve is not a minimum cost curve unless as many tons of sulfur dioxide as possible are removed at $25.90 per ton. Here the limitation is the scarcity of natural gas. Although new reserves are continually being discovered, the available reserves are seldom more than a twenty or thirty year supply. The Federal Power Commission is very much concerned that the limited reserves be protected both for current users of natural gas and additional users expected as a result of the normal market growth. The Commission recently rejected a petition from New York City which sought to alleviate its air pollution problem by generating a portion of their electricity with gas instead of coal. Mr. Richard Homer, Administrative Vice President of Mississippi River Transmission Corporation, the company that supplies gas to Laclede Gas Company and many large industrial firms, confirmed the fact that it was very unlikely that additional pipe line facilities into the St. Louis area would be permitted for the purpose of controlling air pollution.[42]

4. *Cost of Reducing Sulfur Dioxide Emissions from Industrial Combustion of Residual Oil*

During the three winter months of 1963-4, 3094 tons of sulfur dioxide emissions were attributed to the combustion of fuel oil by industry and utilities.[43] Approximately 98 percent of these emissions are from the burning of residual fuel oil rather than distillate fuel oil. While distillate fuel represents less than 8 percent of the total oil burned by industry, its sulfur content averages only 25 percent of the sulfur content of residual oil.[44]

41. St. Louis Post-Dispatch, April 2, 1967, § A, at 2.

42. Information on the natural gas supply provided by Mr. Richard Homer in personal communications on April 25, 1967.

43. IAPS, Section VIII, at 85.

44. *Id.*, Section II, Tables 9 and 13.

Projecting a growth rate of 4 percent per year for industries using residual fuel oil, by 1975 these emissions will increase to 4920 tons for the three month winter period. One possible control would be a 2 percent sulfur content limitation on fuel oil. The only residual fuel oil with sulfur content over this limit is an imported #6 heavy oil. According to Mr. Robert Siegler, Sales Manager of Hartog Oil Co., approximately 20 percent of the residual oil burned in the Interstate Area is #6 oil.[45] Table 6 indicates the price, average sulfur content, and heating value of several grades of oil.

TABLE 6
FUEL OIL[46]

Type of Oil	*Average Sulfur Content*	*BTU per gallon*	*Price per gallon*
#6 heavy residual oil	2.5%[47]	151,000	$.0689
#5 industrial, residual oil	1.6%	149,000	.0760
#2 furnace, distillate fuel oil	.4%	142,000	.0985

The sulfur dioxide emission formula for fuel oil is as follows:[48] Pounds of sulfur dioxide = (3985) (sulfur content) (1 ton of oil). At a density of 8 pounds per gallon, this formula can be converted to pounds of sulfur dioxide = (3985) (sulfur content) (1 unit of 250 gallons of oil).

The cost of switching from #6 to #5 oil for 250 gallons is $1.77½. The reduction in emissions is (3985) (.025 − .016) or 35.86 pounds. This represents a cost of [(2000)/(35.86)] ($1.775) or approximately $99.40 to eliminate one ton of sulfur dioxide emissions.[49]

By reducing the average sulfur content from 1/5(4 x 1.6 + 1 x 2.5)% or 1.78 percent to 1.60 percent, or approximately 10 percent, a 10 percent reduction in the 1975 estimate of 4920 can be achieved. This is illustrated in Figure 6.

It is interesting to estimate the cost of reducing emissions from oil combustion still further. The remaining emissions could be reduced 75% by limiting the sulfur content of fuel oil to .4 percent. This would

45. Private communication with Mr. Siegler, April 26, 1967.

46. Information from this table, with the exception of the sulfur content of #6 oil, was obtained in part from Mr. Siegler and in part from IAPS, Section II, Table 13.

47. Chopey, *Sulfur Puts Squeeze on Heavy Fuel Oil*, CHEMICAL ENGINEERING, April 24, 1967, at 92.

48. IAPS, Section II, Appendix Table 2.

49. There is an additional cost involved in the slightly lower BTU value of the #5 oil. However, this is offset by the economies of maintenance in burning the #5 oil. Mr. Siegler supplied this information.

reduce emissions (3985)(.016 — .004) or 47.82 pounds for each 250 gallons of oil burned. The additional fuel cost for this quality of #2 oil, over #5, would be ($.0225 a gallon x 250) or $5.62½. Thus, the net cost of reducing emissions would be $235.00 per ton of sulfur dioxide.

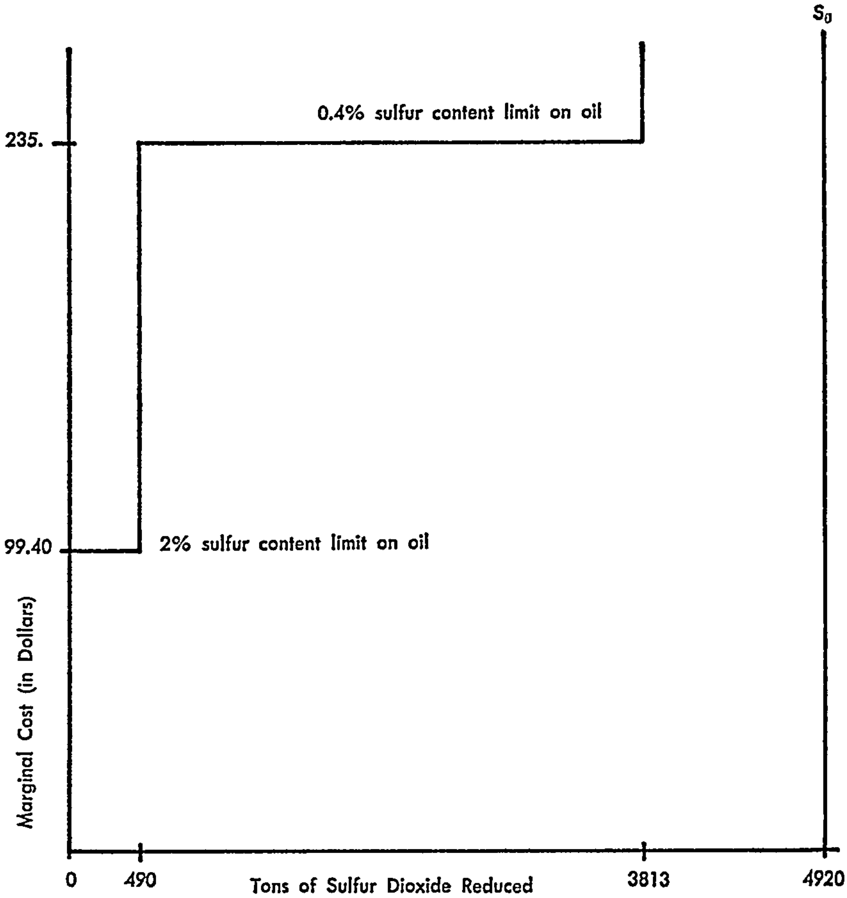

FIGURE VI
MARGINAL COSTS TO ELIMINATE SULFUR DIOXIDE EMISSIONS FROM INDUSTRIAL COMBUSTION OF COAL

B. *Residential Coal Users*

Table 1 indicates a three winter month emission rate of 18,910 tons of sulfur dioxide. Despite population growth, this figure is expected to decline as households convert to gas. The increased cost of low sulfur coal will probably accelerate this rate of conversion; however, no cost will be assigned to this changeover. Mr. Robert Davis, Manager of

Area Development of Laclede Gas Co., states that the cost of a conversion unit pays itself off over five years' time in lower fuel costs;[50] in addition, the individual who converts to gas discovers many conveniences in this simpler, cleaner method of heating.

The Mid-West Coal Producers Institute has estimated that residential emissions of sulfur dioxide will be reduced 90 percent by 1975,[51] to 1891 tons of emissions for a three-month winter period. Thus $S_7 = 1891$.

Emissions of 1891 tons indicate the combustion of

$$\frac{(1891)(2000)}{(3800)(.0285)}$$

or approximately 34,900 tons of coal. A 2 percent sulfur content regulation would reduce these emissions by[52]

$$\frac{[(3800)(.0285) - (3800)(.0175)(.93)][34,900]}{[2000]}$$

or 811 tons of sulfur dioxide.

As noted previously, the use of low sulfur coal reduces emissions of sulfur dioxide by 63.6 pounds for each ton of 3.3 percent sulfur coal replaced by 2.0 percent and 1.0 percent sulfur coal. This 63.6 pound reduction will cost residential users the estimated $1.50 a ton increase in coal prices, plus approximately $.90 in increased dealer mark-up,[53] a total increase of $2.40 a ton of coal.

The marginal cost of this reduction method is

$$\frac{(2000)}{(63.6)}(\$2.40), \text{ or } \$75.47.$$

Figure VII illustrates this cost.

C. *Commercial and Institutional Sources*

According to Table 1, commercial and institutional emissions were 6,435 tons in 1963. Combustion of fuel by this source was for heating

50. Private communication with Mr. Davis, April 28, 1967.

51. Mid-West Coal Producers Institute, *Coal Industry Statement on Emmissions of Sulfur Dioxide in the Interstate Air Pollution Study Area* (unpublished statements Jan. 18, 1967).

52. *See* text accompanying notes 37-38 *supra*.

53. Mr. S. L. Leichtle of Old Ben Coal Corporation advised the Writer on April 28, 1967, that the coal dealer's mark-up on residential coal is approximately 60 percent of cost.

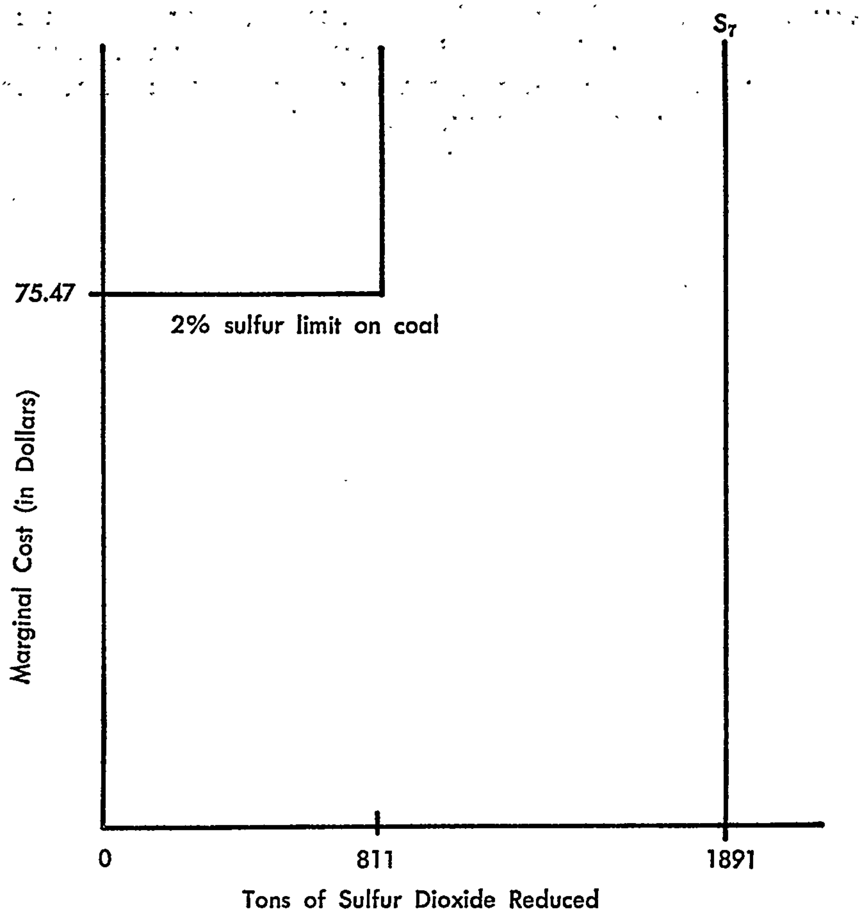

FIGURE VII
MARGINAL COST OF REDUCING SULFUR DIOXIDE EMISSIONS FROM RESIDENTIAL COMBUSTION OF COAL

purposes and 6435/13,900 or 46 percent of their fuel was burned during the three winter months.

The fuels used were coal, 102,000 tons; distillate fuel oil, 2,950,000 gallons; and natural gas, 1,368,000,000 cubic feet.[54]

To project emissions for 1975, we will:

54. IAPS, Section II, Table 9. The table gives the annual consumption figures. These were multiplied by .46 to derive the three-month totals. The figures in Table 9 are for the entire Interstate Area. However, almost all of the fuel used by this source was burned in Urbanized Area.

(1) ignore the insignificant amount of sulfur dioxide from the natural gas;

(2) assume no change in distillate fuel oil consumption;

(3) assume an arbitrary 2 percent annual decline in coal consumption, so that in 1975, commercial and institutional combustion of coal will be 80,000 tons.

Sulfur dioxide emissions from 80,000 tons of coal, averaging 2.85 percent in sulfur content will be

$$(1/2000)\ (3800)\ (.0285)\ (80{,}000),\text{ or }4332\text{ tons.}$$

Emissions from 2,950,000 gallons (11,800 tons) distillate fuel oil will be

$$(1/2000)\ (3985)\ (.004)\ (11{,}800),\text{ or }94\text{ tons.}$$[55]

Projected emissions for 1975, assuming that there were no control regulations, would be 4426 tons of sulfur dioxide, which expresses the value of S_8.

A 2 percent sulfur limit on coal will reduce this projection by

$$\frac{[(3800)(.0285) - (3800)(.0175)(.93)][80{,}000]}{[2000]},$$

or 1860 tons.

As noted previously, the use of low sulfur coal in place of that portion of commercial and institutional coal averaging 3.3 percent in sulfur content reduces sulfur dioxide reduction 63.6 pounds per ton of coal burned. Assuming that the average commercial or institutional user pays a price increase for coal midway between the $1.50 estimate for industrial users, and the $2.40 estimate for residential users, the price increase for low sulfur coal will average $1.95 a ton.[56] The marginal cost of this reduction method will be

$$\frac{(2000)}{(63.6)}(\$1.95)\text{ or }\$61.32.$$

Figure VIII illustrates this marginal cost.

55. *See* IAPS, Section II, Table 2.

56. Private communication with Mr. Ralph P. Vollmer, sales manager of Consolidation Coal Co., May 9, 1967.

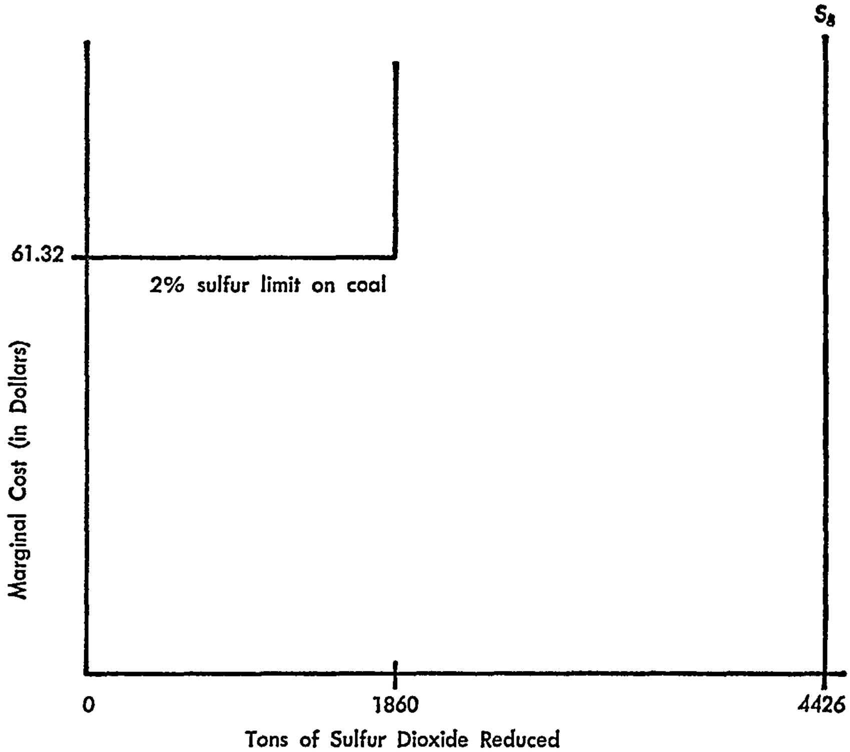

FIGURE VIII
MARGINAL COST OF REDUCING SULFUR DIOXIDE EMISSIONS FROM COMMERCIAL AND INSTITUTIONAL SOURCES

D. *Steam-Electric Utilities*

1. *Electric Utility Emissions in the Urbanized Area*

Utilities are the largest source of sulfur dioxide emissions. Table 1 reveals that 52 percent of this pollutant in the Interstate Area is a by-product of steam generation of electricity by public utilities.

Table 1 indicates that 24,540 tons of sulfur dioxide were emitted in three winter months of 1963. The source of these emissions were the Cahokia, Venice, and Ashley plants of Union Electric. In 1975, sulfur dioxide emissions from these sources will be reduced to 6,877 tons,[57] provided Union Electric expansion program goes on schedule and it is able to supply projected power needs from the more efficient plants it is building at Portage des Sioux and Labadie and from their Meramec plant, which has been in operation since 1953.

57. See note 51 *supra*.

The emission rate of 6,877 tons of sulfur dioxide indicates the combustion of

$$\frac{(6877)(2000)}{(3800)(.0285)},$$

or approximately 127,000 tons of coal. A 2 percent sulfur limit on coal would reduce emissions from the source by[58]

$$\frac{[(3800)(.0285) - (3800)(.0175)(.93)][127,000]}{[2000]}$$

or 2953 tons of sulfur dioxide.

Figure IX shows the cost curve for this reduction of 2953 tons, using the cost of $46.50 derived above.

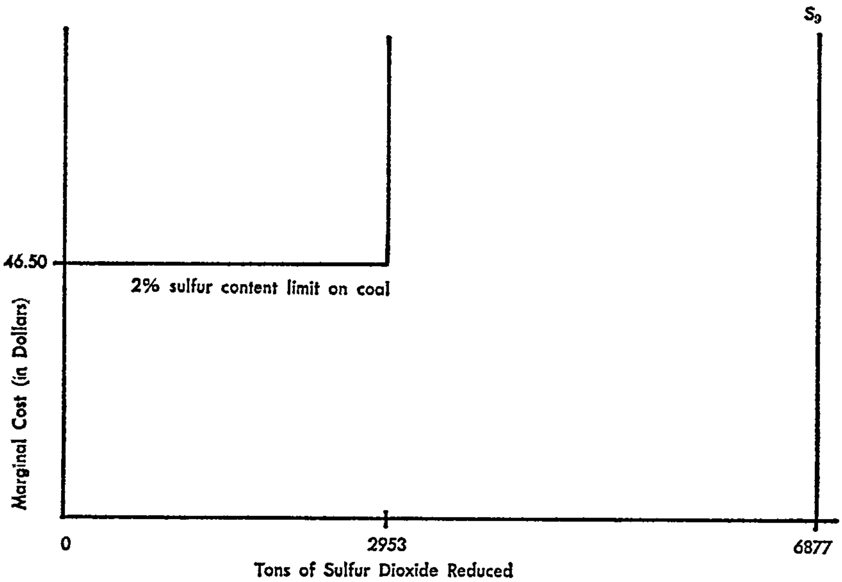

FIGURE IX
MARGINAL COST TO REDUCE SULFUR DIOXIDE EMISSIONS FROM STEAM ELECTRIC UTILITIES IN THE URBANIZED AREA

2. *Utility Emissions of Sulfur Dioxide in Outlying Areas Expected to Affect Air Quality in the Urbanized Area*

While 77 percent of all sulfur dioxide emissions, other than from steam-electric utilities, originate in the urbanized area, only 37 per-

58. *See* text accompanying notes 37-38 *supra.*

cent of utility emissions are from the urbanized area. By 1975, this percentage will decrease even further.

The *Interstate Study* referred to these outlying concentrations of emissions (in twelve months of 1963, 137,000 tons of sulfur dioxide were emitted from Union Electric's Meramec Power Plant, some ten miles south of the outlying portion of the urbanized area):[59]

> The emissions from these sources affect the air quality of the City of St. Louis and its immediately surrounding area only at times of specific meteorological conditions and thus cannot be considered in the same manner as the emissions from the sources located in the area.[60]

The *Study* later stressed that the air quality program "should consider any steam-electric utility plant that may contribute pollutants to the *Study* area."[61]

In the preceding projections of pollutant emissions, we have only considered those originating within the urbanized area itself. In the case of utilities, we will consider emissions from outside the urbanized area, although still within the Interstate airshed.

In the preceding projections, we used the three-month emission rate as a basis. However, contrary to the experience in 1963, the proportion of electricity consumed in the winter months has declined somewhat. Therefore, we will estimate annual sulfur dioxide emissions from power plants for 1975, and then take half of 47.7 percent as a three month winter output.[62]

Table 7 indicates that the average rate of growth for Union Electric Company over the past ten years has been 6.4 percent. Since Union Electric's share of the utility pollution was 75 percent in 1963, data for this utility will be used to project the pollution figures for the entire Interstate area. A total of 235,000 tons of sulfur dioxide were emitted during 1963. In that year Union Electric steam-generated 9,101 million kilowatt hours, but purchased 1,331 kilowatt hours outside of the Interstate Area.[63] Since the company plans to generate all of its own

59. IAPS, Section VIII, at 67.

60. *Id.* at 71. The bracketed numbers refer to the figures and table in this paper.

61. *Id.* at 97.

62. In a letter to the writer dated April 17, 1967, Mr. J. F. McLaughlin, Jr. advised that in 1966, 47.7 percent of Union Electric's electrical power was generated in January, February, March. October, November, and December. Mr. McLaughlin stated that the 47.7 percent figure would be a good estimate for 1975 winter consumption of electricity.

63. Union Electric Company, 1966 Annual Report, at 28.

power by 1971, the pollution emitted elsewhere to generate these 1,331 kilowatt hours must be added to the Interstate base. This is an additional $\frac{1331}{9101}$ or 15 percent, of union Electric's share of the utility pollution, which was 175,000 tons.[64] The total 1963 base after adding $.15 \times 175{,}000$ or 26,250 tons is 261,250 tons. By 1975, this output will be 556,462 tons of sulfur dioxide.

TABLE 7
GROWTH OF ELECTRICAL POWER SALES OF UNION ELECTRIC CO.[65]

Year	*Kilowatt Hours Sold*	*Increase Over Preceding Year*	*Percent Increase Over Preceding Year*
1956	7410	—	—
1957	7601	191	.026
1958	7401	—200	—.026
1959	8296	895	.120
1960	8618	322	.039
1961	8798	180	.021
1962	9548	750	.085
1963	10407	859	.090
1964	11337	930	.089
1965	12325	988	.080
1966	13707	1382	.112
		Total	.636
		Average percentage increase	.064

Fifty-five percent of new generating capacity ordered in the United States in 1966 was nuclear.[66] Mr. McLaughlin predicted that if there are no unforeseen cost increases in nuclear energy, 20 percent of Union Electric's generating capacity in 1975 will probably come from nuclear fuel.[67] Although nuclear generation emits a small amount of krypton and creates a great problem of storing radioactive wastes, it does not emit sulfur dioxide.[68] Reducing the 1975 emissions by 20 percent leaves 445,170 tons of sulfur dioxide. Estimating a three-month's winter emission at one-half of 47.7 percent of this total gives 116,173 tons.

64. Of the 235,000 tons of utility in emissions in 1963, 175,000 are attributed to Union Electric and 60,000 to Illinois Power. IAPS, Section VIII, at 71.

65. Union Electric Company, 1966 Annual Report, at 28-29.

66. Karsh, *The Air Pollution Argument*, SCIENTIST AND CITIZEN 34 (February, 1967).

67. Private communication with Mr. J. F. McLaughlin, Jr., May 2, 1967.

68. Peterson, *Krypton 85—Nuclear Air Pollutant*, SCIENTIST AND CITIZEN 54-55 (March, 1967).

What portion of the 116,173 tons will mix in with sulfur dioxide in the urbanized area? According to Union Electric,

> Tall stacks on new plants will prevent high level ground concentration in the area near the plants. Sioux stacks are 600 feet high and Labadie stacks will be 700 feet high. New plants are so remote from existing high pollutant areas that they will not significantly contribute to existing levels of pollution.[69]

A more pessimistic memo by a U.S. Public Health official notes,

> although the emissions are being reduced in the plan area, the projected emissions from the Portage des Sioux power plant will greatly affect the ambient concentrations in the plant area. Some predicted three winter month average concentrations due to the Portage des Sioux plant range from .005 ppm in south St. Louis to 0.01 ppm in north St. Louis. This is one-fourth to one-half of the air quality goal.[70]

On the basis of these calculations, the projected 1975 three month winter emissions of 116,173 tons are the equivalent of 25,000 tons of urbanized emissions.

For large power plants, the outlook is for removal of sulfur dioxide from the stack gases. As explained earlier, news of a dolomite process of Combustion Engineering Co. has been made public.
As noted in a recent article:

> The company will guarantee the units will meet all applicable air pollution control laws and be in operation late this year or early next year. If the units work as expected, full scale marketing operations will begin. The process works by air-injection of powdered dolomite limestone into power plant furnaces. A reaction between the dolomite and water scrubbing of the smoke removes the gases. The process can be installed in any existing or future oil and coal fired plant.[71]

Union Electric Company has studied the dolomite process, estimated costs for installing the equipment, and announced that it will be installed. In installations where it would be included with existing precipitators, the cost would average about $1.00 per ton of coal used. In installations to be installed in the 1970's, this process can be used in place of precipitators. By allocating part of the costs to particulate re-

69. Union Electric Company, *Effect of Missouri Air Conservation Regulations on Union Electric and Community* 5 (March, 1967).

70. Farmer, unpublished memorandum of a meeting with U.S. Public Health Service officials and representatives of the Mid-West Coal Producers Institute, Jan. 17, 1967.

71. Wall Street Journal, April 29, 1967, at 12.

moval, the net cost is \$.50 per ton.[72] Actually, the cost of operating the dolomite system varies according to the percent of capacity at which an installation is operating. Utility systems are planned so that operating capacity can be varied to supply minimum power needs or peak loads. Therefore, the above costs represent estimated averages for a range of capacities.

Assuming that the dolomite process is in operation in all Interstate Area steam generating plants in 1975, half in conjunction with separate precipitators (at an average operating cost of \$1.00 per ton of coal burned) and half, performing the double function of sulfur dioxide and particulate removal, at an average operating cost of \$.50 per ton, what will be the emission removal cost? The projected emissions for three winter months in 1975 of 116,173 tons of sulfur dioxide represent the burning of approximately

$$\frac{(116{,}173)(2{,}000)}{(3800)(.0285)},$$

or 2,240,000 tons of coal. Figuring the \$1.00 cost for half of this coal would produce a total cost of \$1,120,000, the other half at \$.50 represents \$560,000 in total costs. Assuming 90 percent efficiency for the process, the projected 116,173 tons would be reduced by 90 percent. However, what we are calculating is the cost of reducing urbanized emissions, which were estimated at 25,000 tons. Reducing the 116,173 tons by 90 percent would thereby reduce the 25,000 tons by 90 percent, an urbanized reduction of 22,500 tons.

To assign the entire \$1,120,000 and \$560,000 costs to removing the 22,500 tons of urbanized pollution would be incorrect. While urbanized pollution is more serious than pollution in outlying areas, the prevention of pollution in suburban and rural areas is also desirable. Although the sulfur dioxide concentration in these areas is below the air quality goals, incremental emissions still have impact. The immense growth of emissions on the perimeter of the urbanized area poses a threat to livestock and agriculture in the surrounding areas. Ecologist Frederick Sargent II is concerned with the plant-damaging effect of sulfur dioxide, which could lead to a serious imbalance in the human ecosystem. He has warned that although atmospheric oxygen is a renewable resource,

72. Private communication with Mr. J. F. McLaughlin, Jr., May 4, 1967.

its abundance in the air depends upon the photosynthetic action of chlorophyll. When plant damage by air pollutants is combined with other continuing human aggressions on vegetation, an eventual reduction of atmospheric oxygen is not inconceivable.[73]

Biologist Barry Commoner has opposed establishment of air quality standards because they imply a threshhold level, below which the pollutant is harmless. Professor Commoner has asserted that any level of pollution does some damage.[74]

On the basis of these intangibles, it is difficult to estimate what portion of control costs should be assigned to reducing the portion of outlying utility emissions that affect the urbanized area. An arbitrary 50 percent will be used, implying that for society as a whole, $840,000 spent for reducing 91,173 tons of sulfur dioxide in rural and suburban areas produces the same benefit as $840,000 spent reducing 25,000 tons of urbanized pollution.

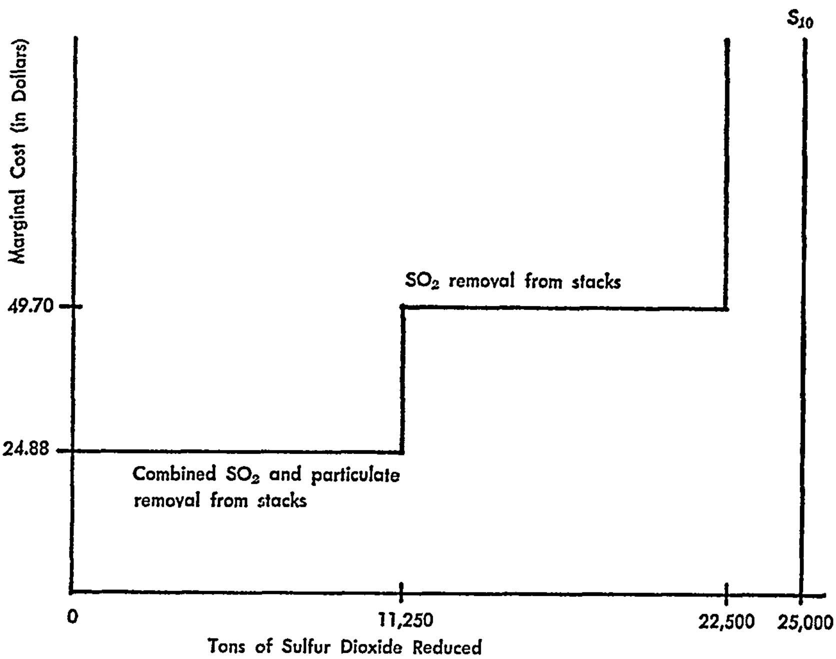

FIGURE X
MARGINAL COSTS OF REDUCING THE PORTION OF OUTLYING UTILITY EMISSIONS ASSUMED TO AFFECT SULFUR DIOXIDE AMBIENT AIR CONCENTRATIONS IN THE URBANIZED AREA

73. Sargent, *Air Pollution—A Problem of Human Ecology*, 14 ARCHIVES OF ENVIRONMENTAL HEALTH 37 (1967).

74. Private communication with Professor Commoner, March, 1967.

Half of the 22,500 ton reduction, or 11,250 tons of sulfur dioxide will be eliminated from power plants where the dolomite system is used in conjunction with a separate precipitator system. The cost allocated to this reduction is half of $1,120,000, or $560,000. Eliminating 11,250 tons of urbanized emissions at a cost of $560,000 represents a cost of $49.70 a ton of sulfur dioxide.

The reduction of 11,250 tons in power plants where the dolomite and precipitator system are combined gives a cost of $24.88 per ton. Figure X illustrates the marginal costs of reducing that portion of outlying power plant emissions presumed to affect sulfur dioxide concentrations in the urbanized area.

Aggregating The Sector Cost Curves

Table 8 illustrates the various methods of sulfur dioxide reduction, ranged in order of marginal cost. The aggregate cost curve is a horizontal summation of the individual cost curves. Table 8 contains the step-by-step summation, which is then illustrated in Figure XI. Figure XI also includes the summation of projected emissions for each sector. This is the total, 94,848 tons, on the horizontal axis.

Table 8

Reduction Method	*Tons of SO_2 Eliminated*	*Marginal Cost*	*Increment of Total Costs*	*Total Tons Reduced*	*Total Cost*
Industrial stack cleaning	7,520	$ 12.94	$ 97,308	7,520	$ 97,308
500 ppm standard for new sulfuric acid plants	2,159	16.53	35,688	9,679	132,996
Stack cleaners for outlying utilities	11,250	24.88	279,900	20,929	412,896
Industrial conversion to natural gas	7,719	25.90	199,922	28,648	612,818
No outside burning of refuse	86	37.50	3,225	28,734	616,043
2% sulfur limit on industrial coal	10,760	46.50	500,340	39,494	1,116,383
2% sulfur limit on urbanized utilities	2,953	46.50	137,315	42,447	1,253,698
Stack cleaners for outlying utilities (with old precipitators)	11,250	49.70	559,125	53,697	1,812,823
500 ppm standard for existing sulfuric acid plants	5,288	54.94	290,470	58,985	2,103,293

2% sulfur limit on commercial and institutional coal	1,860	61.32	114,055	60,874	2,218,941
2% sulfur limit on residential coal	811	75.47	61,206	61,685	2,270,147
300 ppm standard for new sulfuric acid plants	178	93.24	16,597	61,863	2,286,744
300 ppm standard for existing sulfuric acid plants	425	93.24	39,627	62,288	2,326,371
2% sulfur content limit on fuel oil	490	99.40	48,706	62,778	2,375,077
.4% sulfur content limit on fuel oil	3,323	235.00	780,905	66,101	3,155,982
1½% sulfur content limit on industrial coal	4,401	262.50	1,155,263	70,502	4,311,245

It remains for a community presented with such a cost curve to select the degree of reduction desired. Generally, an air quality goal is attainable by restricting emissions to a certain level. If allowable emissions are 35,500 tons of sulfur dioxide in the St. Louis urban area, then 94,848 less 35,500 or approximately 59,000 tons of sulfur dioxide must be eliminated. According to the cost curve, this elimination can be achieved by carrying costs up to $55.00 per ton. Thus, all methods of reduction costing less than $55.00 per ton would be utilized. Some of these methods would be instituted by regulations, such as a 2 percent sulfur content limit on industrial coal. Other methods could be expected to be voluntarily adopted, such as conversion to natural gas or installation of stack cleaning devices. The voluntary methods would of course be stimulated by the required standards.[75]

The cost of control is the area under the curve, from zero to 59,000 tons. This can be read from the ninth line of Table 8 as $2,104,886 for a three month winter period in 1975 (in 1968 dollars).

Noticeably absent from the chart is a curve representing benefits from reducing sulfur dioxide pollution. If the air quality standard were chosen with complete knowledge of all the damage associated with

75. The least cost reduction tells us nothing about who should pay the cost of pollution control. In the case of a 2 percent sulfur restriction on coal, should coal users be reimbursed through subsidies or should they and their customers pay the incremental fuel costs? If every point on the cost curve represented required standards, the discussion of who pays would relate to problems of resource redistribution and air property rights. However, to the extent that a large range of the cost curve is voluntary, subsidies could avoid these possibilities. If coal users were subsidized in their purchases of low sulfur coal, there would be no inducement to substitue natural gas or stack cleaners, both of which would be highly desireable from a social point of view.

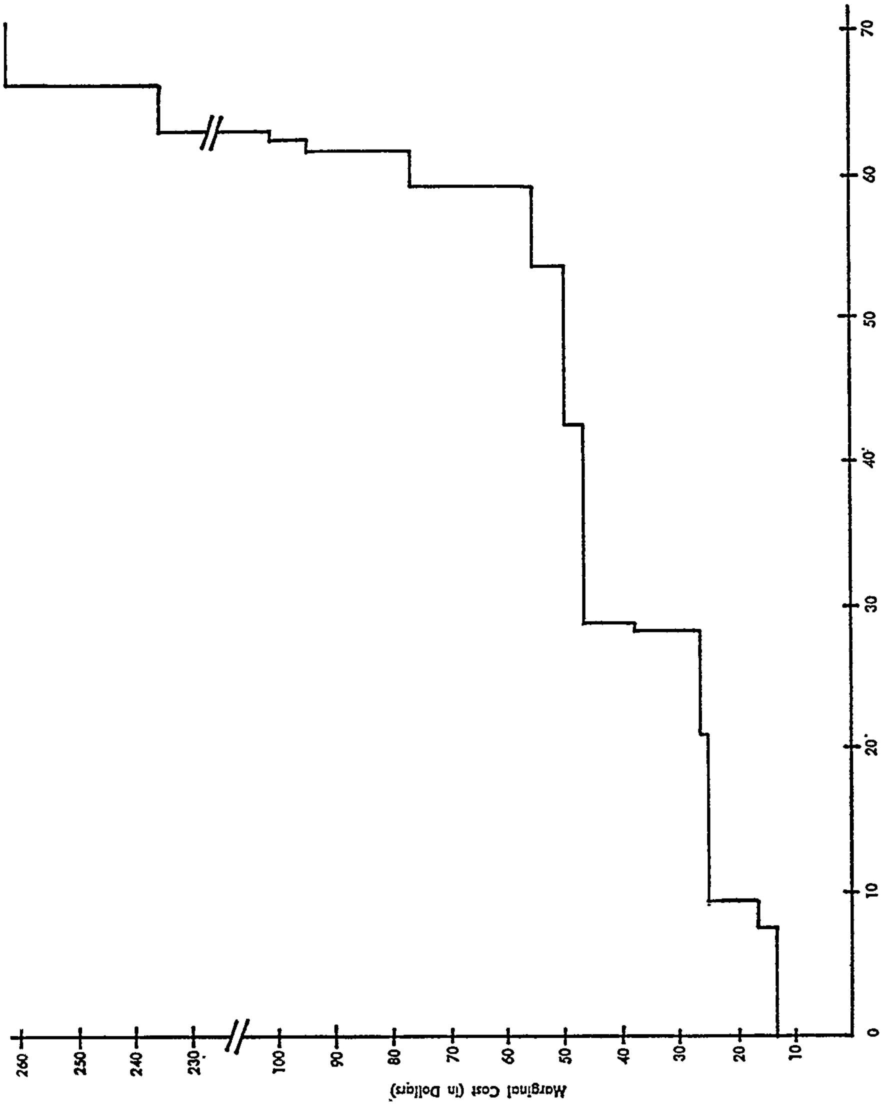

FIGURE XI

AGGREGATE MARGINAL COST CURVE OF SULFUR DIOXIDE REDUCTION sulfur dioxide, it might be expected that this curve would slope down from the left and intersect the aggregate cost function at $55.00 per ton. This would indicate that the marginal cost of eliminating sulfur dioxide was equal to the marginal benefit, and that the community was devoting the correct amount of resources to sulfur dioxide reduction. Knowledge of the damage function for a particular pollutant will never be much more than intuitive. However, a well developed cost schedule, as illustrated in this paper, can help a community achieve a desired air quality goal with the least expenditure of resources.