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Project Summary

Acid Rain Mitigation Study: Volume III. Industrial Boilers and Processes

J. G. Ball, C. A. Muela, and J. L. Meling

The U.S. EPA has initiated a multi-phased study of the acid rain problem. As part of Phase I, Radian Corporation investigated SO_2 emissions and controls in the industrial sector.

The scope of this 4-month study was limited to existing industrial sources of SO_2 emissions in the Acid Rain Mitigation Study (ARMS) region. This region includes all of the states east of the Mississippi River, as well as Minnesota, Iowa, Missouri, Arkansas, Louisiana, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas. The objectives of the study were to (1) identify and characterize existing industrial sources of SO_2 emissions, (2) identify the control techniques that can be used to reduce SO_2 emissions from these sources, and (3) estimate the SO_2 emission reduction potential and the associated costs in constant 1980 dollars based on application of these controls. Because of severe time limitations, only a portion of the SO_2 sources were investigated in detail. Simplifying assumptions were made about the balance of the SO_2 sources studied. Time contraints also prevented an evaluation of the availability of low sulfur control options (i.e., physically cleaned coal and low sulfur fuel oil). In addition, since site visits were not made, the remaining useful lives of the sources were not determined and "average" flue gas desulfurization unit retrofit factors were estimated. Each of these considerations significantly affects both the potential SO_2 emissions reduction and the associated costs.

The results of the investigations conducted to meet each study objective are presented in the report. Recommendations concerning the use of these results are also discussed.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

There is a growing concern about the acidity of precipitation in the northeastern United States and Canada. Many scientists think that acidic precipitation kills aquatic and plant life, damages crop-growing soil, and accelerates erosion and damage to buildings. Although the mechanisms producing acid rain are not clearly understood, sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) are thought to be the precursors of the chemicals that cause acid rain. Large quantities of SO_2 and NO_x are produced by various combustion and non-combustion processes in both the utility and industrial sectors. Reducing these SO_2 and NO_x emissions to the atmosphere should reduce the potential for acid rain.

Because of this growing concern, the U.S. EPA initiated a multi-phased study of the acid rain problem. As part of this study, Radian Corporation investigated SO_2 emissions and controls in the industrial sector; Teknekron, Inc. made a similar study of the utility sector. The study was to be completed in 4 months to provide direction for additional phases. These later phases were planned to investigate SO_2 emissions in more detail than Phase I, to investigate NO_x sources, and to model source/receptor relationships.

The scope of this study was limited to existing industrial sources of SO_2 emissions in the Acid Rain Mitigation Study (ARMS) region. This region includes all of the states east of the Mississippi River, as well as Minnesota, Iowa, Missouri, Arkansas, Louisiana, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas. The objectives of the study were to (1) identify and characterize existing industrial sources of SO_2 emissions, (2) identify the control techniques that can be used to reduce SO_2 emissions from these sources, and (3) estimate the SO_2 emission reduction potential and the associated costs* based on application of these controls. Because of severe time limitations, only a portion of the SO_2 sources were investigated in detail. Simplifying assumptions were made about the balance of the SO_2 sources studied.

It should also be noted that, due to time constraints, the availability of low sulfur control options (i.e., physically cleaned coal and low sulfur fuel oil) was not evaluated. In addition since site visits were not made, the remaining useful lives of the sources were not determined and "average" flue gas desulfurization unit retrofit factors were estimated. Each of these considerations significantly affects both the potential SO_2 emissions reduction and the associated costs.

Summary

The results of the investigations conducted to meet each study objective are summarized below. The assumptions made and recommendations concerning the use of these results are also discussed.

SO_2 Emissions Characterization

The Multistate Atmospheric Power Production Pollution Study (MAP3S) was used as a basis for a survey of industrial plants emitting SO_2 within the Acid Rain Mitigation Study (ARMS) region. This survey identified 257 major industrial emitters (an emitter may contain more than one point source) of SO_2 ranging in the magnitude of SO_2 emissions from 5,000 to 200,000 tons per year. These data show that utility and industrial plants emitting more than 5,000 tons per year of SO_2 account for 90 percent of the total SO_2 emissions. The total quantity of SO_2 emitted each year by these 257 industrial plants is 3.6 million tons. Because of time limitations in this initial phase, plants with 5,000 tons per year of SO_2 emissions were the smallest emitters evaluated in this study.

A total of 39 industrial plants, each emitting more than 20,000 tons of SO_2 per year, together account fo about 1.6 million tons of SO_2. Only these 39 plants were studied in detail. For these 39 plants, industrial boilers are responsible for 695,300 tons of SO_2 per year. Non-boiler processes in the metals industry emit about 543,200 tons of SO_2 pe year; and in other industries, includin chemicals, petroleum refining, an cement, non-boiler sources contribut some 350,000 tones of SO_2 per year These data are summarized in Table 1

Due to time and feasibility constraints SO_2 emissions from plants emittin between 5,000 and 20,000 tons pe year were not characterized individually They were evaluated by making a number of assumptions (1) the approximately 2 million tons of SO_2 per yea emitted by the 218 plants emittin between 5,000 and 20,000 per yea was assumed to result exclusively from coal-, oil-, and gas-fired boilers; (2) the distribution of these boilers was assume to be similar to the nationwide distribution of industrial watertube boilers; an (4) the percent sulfur in coal, oil, and gas was assumed to be the same as the fuel-weighted average sulfur content of the boilers in plants emitting more than 20,000 tons per year of SO_2. The results of these calculations are presented in Table 2.

Table 1. *Industrial SO_2 Emissions from 39 Largest SO_2 Emitters*

	Emissions (10^3 tons SO_2/year)*		
Process	*Per Process*	*Total*	*Percent of Total*
Boilers		*6.95.3*	*43.1*
Coal-fired (> 100 MW_t)	*(392.4)*		
Coal-fired (<100 MW_t)	*(86.9)*		
Oil-fired	*(172.6)*		
Gas-fired	*(43.4)*		
Metals Industry (excluding boilers)		*543.2*	*33.7*
Copper smelting	*(235.9)*		
Iron and steel	*(115.3)*		
Coke metallurgy	*(99.2)*		
Lead smelting	*(85.4)*		
Aluminum	*(3.1)*		
Other	*(4.3)*		
Other Industrial Processes (excluding boilers)		*350.0*	*21.7*
Cat crackers	*(71.3)*		
Process heaters	*(60.3)*		
Cement kilns	*(54.2)*		
Sulfuric acid	*(49.7)*		
Phosphate fertilizer	*(41.8)*		
Sulfur plants	*(33.9)*		
Alfalfa dehydration	*(21.6)*		
Flares	*(8.9)*		
Sulfite pulping	*(7.0)*		
Sludge conversion	*(1.3)*		
Unclassified		*25.5*	*1.5*
		1614.0	*100.0*

*Based on 1977 survey.

*All of the cost presented in this study are expressed in constant 1980 dollars.

Table 2. *Size Distribution of Boilers Needed to Account for 2 Million[a] Tons of SO_2 Emitted per Year from Plants Emitting Between 5,000 and 20,000 Tons/Year of SO_2*

	Coal			Oil			Gas			Total	
Average Boiler Size (MW_t)	10^3 tons SO_2/yr	10^3 tons SO_2/yr/Boiler	Approximate Number of Boilers[b]	10^3 tons SO_2/yr	10^3 tons SO_2/yr/Boiler	Approximate Number of Boilers[b]	10^3 tons SO_2/yr	10^3 tons SO_2/yr/Boiler	Approximate Number of Boilers[b]	Approximate Number of Boilers[b]	10^3 tons SO_2/yr
45	686	1.6	429	290	1.1	264	51	0.6	85	778	1027
96	371	3.4	109	135	2.3	59	22	1.3	17	185	528
220	172	7.8	22	56	5.4	10	17	2.9	6	38	245
700 (coal, oil)	149	24.9	6	15	17.1	1	—	—	—	7	164
1265 (gas)	—	—	—	—	—	—	36	16.9	2	2	36
Total	1378		566	496		334	126		110	1010	2000

[a] The actual total of 1996 x 10^3 tons per year was rounded to 2000 x 10^3 tons per year

[b] The number of boilers in each size category that would yield the annual SO_2 emissions derived in Table 3-8 (of the full report), given the fuel quality and average boiler size and capacity factor discussed in the text.

Applicable SO_2 Emission Control Technologies

Both pre- and post-combustion cleaning processes have been used to reduce SO_2 emissions from industrial combustors. The pre-combustion processes most commonly used for coal- and oil-fired combustors are physical coal cleaning and oil desulfurization, respectively. Another method of reducing SO_2 emissions from industrial boilers is to substitute naturally occurring low sulfur coal and oil for high sulfur fuels. The most commonly used post-combustion process is flue gass desulfurization (FGD). In the metals and process industries, SO_2 emissions from non-combustion sources have also been controlled by FGD processes. In addition, sulfuric acid plants are frequently used to recover the SO_2 if the flue gas is sufficiently concentrated to warrant economic recovery.

Estimated Costs of Applying SO_2 Control Techniques to Industrial Sources and the Potential SO_2 Emissions Reductions

Preliminary costs* for reducing SO_2 emissions from different industrial sources with the control alternatives identified above were developed. Because each control alternative cannot be effectively applied to all of the industrial sources, the control alternatives were applied only to those source categories that seem to be logical based on actual installations. Only one scenario was evaluated.

The use of physically cleaned coal to reduce SO_2 emissions was applied to boilers having capacities less than 75 MW_t (boiler heat input in thermal megawatts*), and firing coals with 2.0 percent or greater sulfur content. This control method was adopted for small coal-fired boilers because an FGD process would require very high capital investment/annual costs. The use of physically cleaned coal would reduce uncontrolled SO_2 emissions from these boilers by 219 x 10^3 tons per year, which represents about a 30 percent reduction. It was assumed that physically cleaned coal would be purchased from a major coal producer. As a result, each boiler operator would not incur the costs of constructing and operating a physical coal cleaning facility; instead, the operator would pay the producer a premium for cleaning the coal. The cost of physically cleaned coal was estimated to be $4.28 per ton (1980 dollars) for a total annual premium of approximately $46 x$10^6$ for the applicable industrial sources. This cost represents the cost of preparation and does not include the costs of raw coal, taxes, and transportation. The availability of physically cleaned coal to the SO_2 sources was not examined.

Low sulfur fuel oil was assumed to be used for reducing emissions from all oil-fired boilers. Uncontrolled SO_2 emissions from these boilers are approximately 669 x 10^3 tons per year. The use of low sulfur fuel oil (0.8 percent S) reduced the uncontrolled emissions by 51 percent assuming an average uncontrolled fuel oil sulfur content of 1.64 percent. It was assumed that low sulfur oil would be purchased from a major producer. The resulting incremental cost for the low sulfur oil was taken as $2.50/bbl (based on hydrode sulfurization costs) for a total annual premium of $314 x 10^6. This represents the incremental cost of the lower sulfur fuel compared to the fuel currently being used. The availability of low sulfur oil to the SO_2 emission source was not examined.

FGD systems were assumed to be used for reducing emissions from all of the larger coal-fired boilers (those having capacities greater than 75 MW_t). FGD would reduce SO_2 emissions from these boilers by approximately 940 x 10^3 tons per year. The capital investment cost for installing these FGD systems would be about $2,020 x 10^6.* The annual cost associated with these FGD systems would be approximately $565 x 10^6. The capital investment and annual costs for industrial FGD systems were derived by integrating cost studies for small industrial and large utility systems. This integration required putting the cost studies on the same equipment basis, using the same investment and cost algorithms, and using the same unit pricing of labor and raw materials.

FGD systems were also assumed to be used for most non-boiler sources in the metals and process industries for all processes emitting greater than 1000 tons per year of SO_2 from a single point source. Retrofitting an FGD process to the uncontrolled sources in the metals industry decreased SO_2 emissions from 543 x 10^3 to 62 x 10^3 tons per year. A

*The capital investment and annual costs are significant only to two figures, however, results are reported to the last whole significant figure to be consistent with other similar studies In this study, annual costs are first year costs and include O&M, overhead, utilities, etc., and capital-related charges equivalent to 0.13 times the total capital investment All of the costs presented in this report are expressed in constant 1980 dollars

*A boiler with a heat input capacity of 200 x 10^6 Btu/hr would have a capacity of 58.6 MW_t

*The capital investment for an FGD system retrofit was assumed to be 1.3 times the capital investment of an FGD system applied to a new boiler capital investment of \$420 x 10^6 and an annual cost of about \$128 x 10^6 would be required to achieve this reduction. In the process industry, the use of FGD systems on process heaters, sludge concentrators, sulfuric acid plants, catalytic crackers, and elemental sulfur plants reduced SO_2 emissions from 350 x 10^3 to 64 x 10^3 tons per year, an 82 percent reduction. The capital and annual costs required to achieve this reduction would be \$580 x 10^6 and \$178 x 10^6, respectively. Table 3 summarizes the assumed SO_2 control applications. Figures 1 and 2 show the costs used for FGD applications.

Overall, industrial-sector plants emitting greater than 5,000 tons per year of SO_2 (257 plants) generate approximately 3.6 x 10^6 tons of SO_2 per year. Implementation of the control options described above would reduce the uncontrolled SO_2 emissions by approximately 63 percent. To achieve this reduction, industry within the ARMS region would have to invest about \$3.0 billion for installing the control processes, as well as incur annual costs of about \$1.2 billion (see Table 4). Plants emitting more than 20,000 tons per year of SO_2 (39 plants) account for 1.6 x 10^6 tons per year of uncontrolled SO_2 emissions. Marginal cost and investment analysis shows that investment and cost per ton of SO_2 removed is lower for these plants than for plants emitting 5,000 to 20,000 tons per year of SO_2 (see Tables 4 and 5). The controls applied to the 39 plants could reduce uncontrolled SO_2 emissions by 75 percent and would require a \$1.5 billion capital investment and about \$0.6 billion in annual costs.

The cost effectiveness (in \$ ton/SO_2 removed) for the various control options are:

Application	Boiler Size MW_t	Fuel/ Wt. % Sulfur	SO_2 Control Technology	\$/ton SO_2 Removed for Plants Emitting More Than: 5000 tons/ yr SO_2	20,000 tons/ yr SO_2
Boilers	<75	Coal/3	Physical Coal Cleaning	210	210
Boilers	>75	Coal/2.4	FGD	601	536
Boilers	All	Fuel Oil/1.6	Low Sulfur Oil*	915	910
Nonboiler Sources/ Metals Industry	—	—	FGD	266	266
Nonboiler Sources/ Process Industry	—	—	FGD	622	622
Weighted Average				542	472

*Costs are based on hydrodesulfurization.

Table 3. Summary of SO_2 Control Applications

Control Applied	*Source Category*	*Type of Fuel Used*	*Average Sulfur Level in Fuel (%)*[a]	*Boiler Size (MW_t)*	*Number of Affected Boilers*
None[b]	*Boilers*	*Coal*	*1.3*	*All Sizes*	*31*[c]
Physically Cleaned Coal	*Boilers*	*Coal*	*3.0*	*<75*	*449*[c]
FGD (Limestone)	*Boilers*	*Coal*	*2.4*	*>75*	*193*
Oil Desulfurization (0.8% S Oil)	*Boilers*	*Oil*	*1.64*	*All Sizes*	*441*
None	*Boilers*	*Gas*	*0.8*	*All Sizes*	*160*
FGD[d]	*Non-boiler sources in metals industry*	*—*	*—*	*25-644*[e]	*—*
FGD	*Non-boiler sources in process industry*	*—*	*—*	*17-1000*[f]	*—*

[a]*Before controls are applied.*
[b]*Boilers in the top 39 SO_2-emitting plants currently firing 2.0% or lower sulfur coal do not require controls.*
[c]*Nine boilers were unclassified as to size and nine boilers were unclassified as to fuel type. Fourteen of these boilers were found to be at sites that used low S coal exclusively. Thus the number of low S coal burning boilers was increased from 17 to 31. The other four unclassified size/fuel boilers were arbitrarily assigned to physically cleaned coal.*
[d]*Sulfuric acid plants were used as controls on two smelting operations.*
[e]*The capacities of non-boiler sources in the metal industry are equivalent to boilers of this size range.*
[f]*The capacities of non-boiler sources in the process industry are equivalent to boilers of this size range.*

The average cost effectiveness for the controls evaluated range from about \$210/ton of SO_2 for physical coal cleaning to \$915/ton for oil hydrodesulfurization.

Recommended Use of Study Results

Preliminary estimates of the SO_2 reduction potential from existing industrial sources and the associated control costs are provided in this study and will be useful for planning future work in the acid rain area. Due to time and budget constraints, a number of key assumptions were made in order to obtain these results. Many of these assumptions were highlighted in this summary.

If control of existing industrial sources of SO_2 is considered to be a reasonable strategy for attacking the acid rain problem, then a more detailed evaluation of the industrial sector should be undertaken. The scope of work should include:

1. A more detailed characterization of the targeted point sources. Sites should be visited.
2. An evaluation of the availability and costs of low sulfur fuel oil, low sulfur coal, and physically cleaned coal to the various plants.
3. A characterization of source ages and remaining useful lives.
4. Engineering evaluations to assess the feasibility and cost of FGD retrofits.
5. An evaluation of other scenarios for controlling SO_2 emissions.

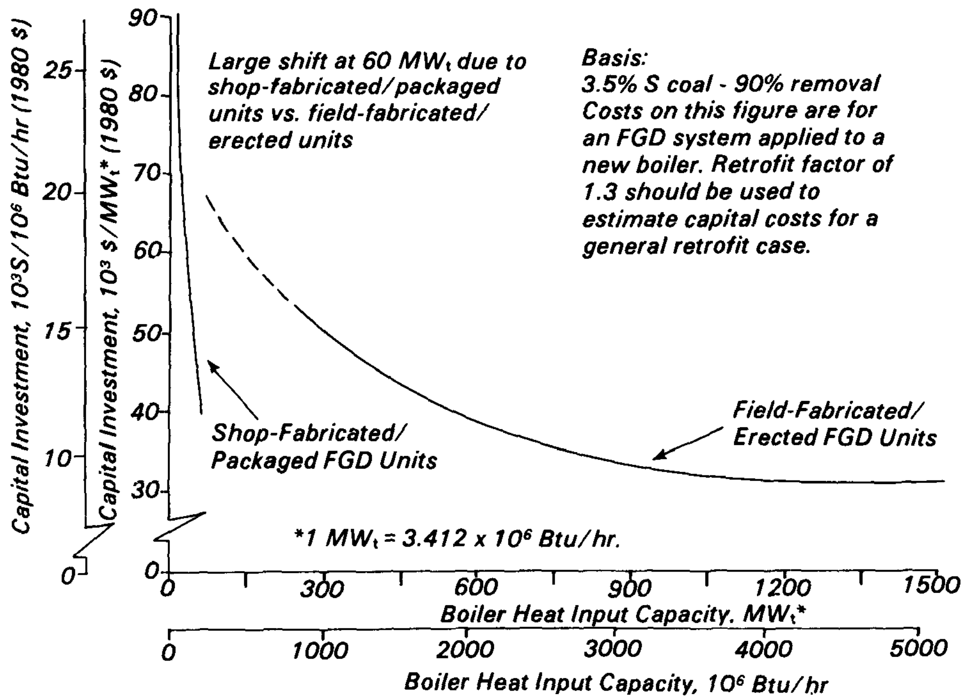

Figure 1. *Capital investment for a limestone FGD system (applied to new boiler).*

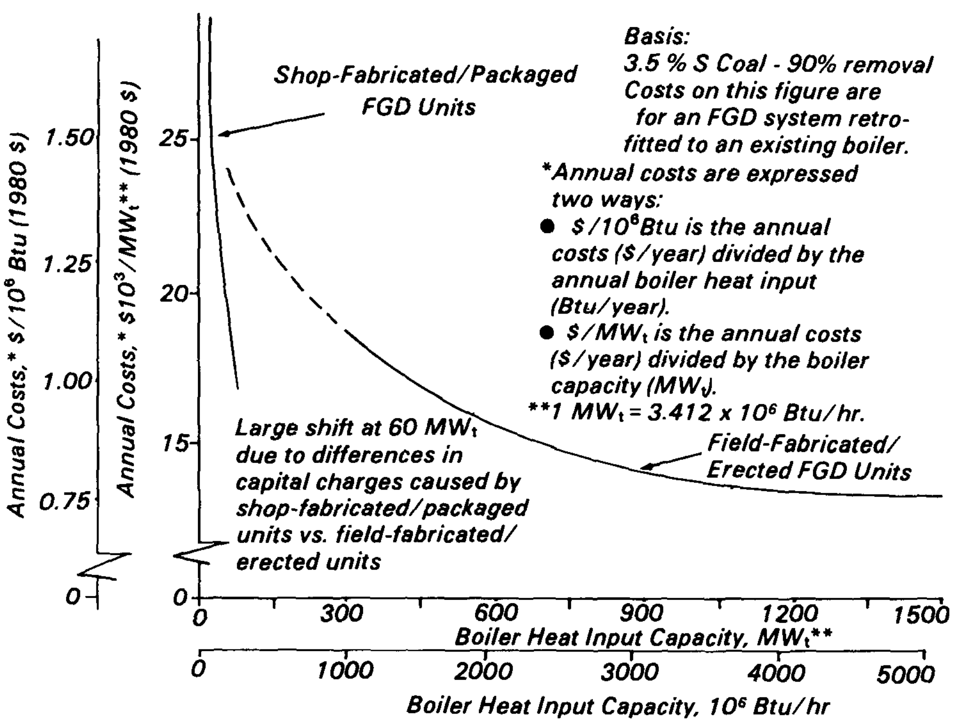

Figure 2. *Annual costs for a retrofitted limestone FGD system.*

Table 4. *Summary of Impact and Cost of Controls for Plants Emitting More Than 5,000 Tons/Year of SO_2*

	SO_2 Emission Sources[a]				SO_2 Control Processes					
Source Category	Fuel Type	Boiler Size (MWt)	Avg. Sulfur Level (%)	Uncontrolled SO_2 Emissions (10^3 ton/yr)	Control Applied	SO_2 Reduction Achieved (%)	Controlled SO_2 Emissions (10^3 ton/yr)	Capital Investment[g] ($\$10^6$)	Annual Cost ($\$10^6$)[b, c]	Cost Effectiveness[g] (\$/ton SO_2 Removed)
Boilers										
	Coal	—[d]	1.3	83	None	—	83	—	—	—
	Coal	<75	3.0	730	Physical Coal	30	511	—	46[e]	210
	Coal	>75	2.41	1044	FGD (Limestone)	90	104	2,020	565	601
	Fuel Oil	All	1 64	669	Low sulfur fuel oil	51[f]	326	—	314[e]	915
	Gas	All	0 8	169	None	—	169	—	—	—
Non-boiler Sources (Metals Industry)	—		—	543	FGD (Limestone)[g,h]	89	62	420	128	266
Non-boiler Sources (Process Industry)	—		—	350	FGD (Limestone)[h]	82	64	580	178	622
Totals				3,588		63[i]	1,319	3,020	1,231	542

[a] Uncontrolled emissions for 1977.
[b] In this report annual costs include annual O&M, overhead, utilities, etc., and annual capital-related charges equivalent to 0 13 times the total capital investment
[c] 1980 \$.
[d] Boilers in the top 30 SO_2 emitter that actually burn <2.0 percent sulfur coal
[e] The cost directly represents the premium paid by boiler operator for upgraded fuel.
[f] This reduction efficiency is set by assuming the use of 0.8 percent sulfur fuel oil down from an average level of 1 64 percent. The costs are based on resid hydrodesulfurization.
[g] Includes two sulfuric acid plants.
[h] FGD process applied to point sources emitting > 1000 tons per year SO_2.
[i] Weighted average.

Table 5. *Summary of Impact and Costs of Controls for Plants Emitting More Than 20,000 Tons/Year of SO_2*

	SO_2 Emissions Sources[a]				SO_2 Control Processes					
Source Category	Fuel Type	Boiler Size (MWt)	Avg. Sulfur Level (%)	Uncontrolled SO_2 Emissions (10^3 ton/yr)	Control Applied	SO_2 Reduction Achieved (%)	Controlled SO_2 Emissions (10^3 ton/yr)	Capital Investment[b] ($\$10^6$)	Annual Cost ($\$10^6$)[c, b]	Cost Effectiveness[b] (\$/ton SO_2 Removed)
Boilers										
	Coal	—[d]	1.3	83	None	—	83	—	—	—
	Coal	<75	3.0	44	Physical Coal Cleaning	30	31	—	3[e]	210
	Coal	>75	2.41	352	FGD (Limestone)	90	35	471	170	536
	Fuel Oil	All	1.64	173	Low sulfur oil	51[f]	84	—	81[e]	910
	Gas		0 8	43	None	—	43	—	—	—
Non-boiler Sources (Metals Industry)	—		—	543	FGD (Limestone)[g,h]	89	62	420	128	266
Non-boiler Sources (Process Industry)	—		—	350	FGD (Limestone)[h]	82	64	580	178	622
Total				1,588		75[i]	402	1,471	560	472[i]

[a] Uncontrolled emissions for 1977.
[b] 1980 \$.
[c] In this report annual costs include annual O&M, overhead, utilities, etc., and annual capital-related charges equivalent to 0 13 times the total capital investment
[d] Boilers in the top 39 SO_2 emitters that actually burn <2 0 percent sulfur coal.
[e] The cost directly represents the premium paid by boiler operator for upgraded fuel.
[f] This reduction efficiency is set by assuming the use of 0.8 percent sulfur fuel oil down from an average level of 1.64 percent. The costs are based on resid hydrodesulfurization
[g] Includes two sulfuric acid plants
[h] FGD process applied to point sources emitting >1000 tons per year SO_2
[i] Weighted average.

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J. G. Ball, C. A. Muela, and J. L. Meling are with Radian Corporation, Austin, TX 78759.
***William Baasel** is the EPA Project Officer (see below).*
The complete report, entitled "Acid Rain Mitigation Study: Volume III. Industrial Boilers and Processes," (Order No. PB 83-101 337; Cost: $11.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
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