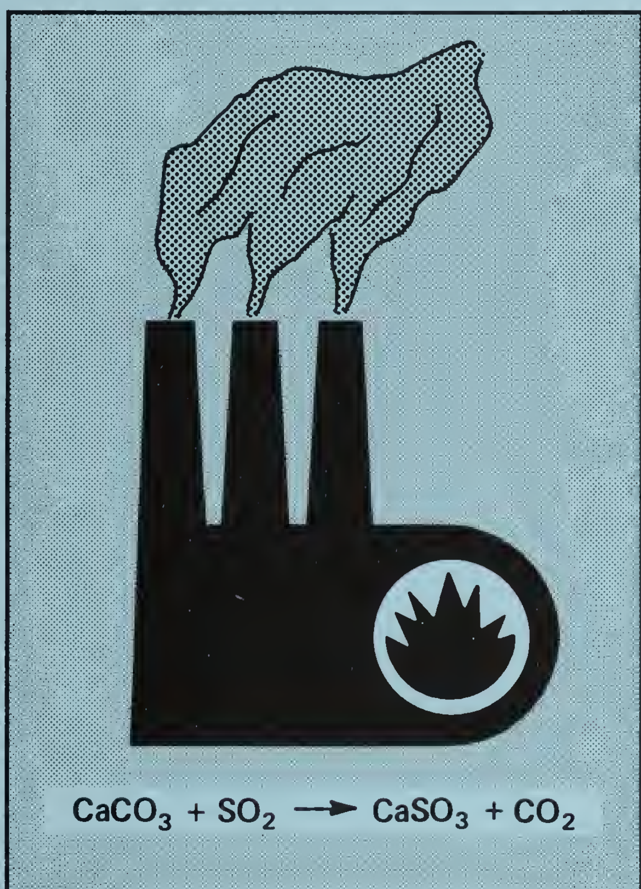
The lime and limestone market for sulfur removal: potential for 1992

Subhash B. Bhagwat



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Abstract

In the United States, the market for lime and limestone declined in the 1970s and early 1980s; however, following the passage of clean air regulations, a small niche in the market developed when lime and limestone became important components of processes used to reduce the sulfur dioxide emissions that result from burning coal. No demand for lime and limestone for sulfur removal existed in 1974, and tremendous growth was predicted. However, by 1983 sales of lime and limestone only achieved 8 percent of the predicted potential. The demand did not reach the projected level partly because of the availability of low-sulfur fuels, the differences in industrial growth rates from state to state, the flexibility in implementation of the Clean Air Act, and the demographics of the country.

Factors affecting future demand include the growth rates in electricity demand, the application of the revised 1979 clean air standards, and the prospect of enacting new acid rain legislation. The stoichiometry of chemical reactions and technological efficiencies in sulfur removal are the basis for future projections, but the implementation strategies chosen by the coal- and oil-burning utilities will greatly affect future demand. Two models yielded projections for lime and limestone demand for sulfur removal in 1992. Compared with the size of the limestone industry in the United States, the projected demand appears insignificant, but it should influence the sector of the limestone industry that produces high-quality limestone.

Introduction

The passage of the Clean Air Act in 1970 and the relatively small amount of low-sulfur coal produced in the United States at that time stimulated a search for low-sulfur coal deposits and methods to control the sulfur emissions that result from the burning of coal. This led to a dramatic increase in the production of low-sulfur coal and to the development of sulfur removal processes such as Flue Gas Desulfurization (FGD) and Fluidized Bed Combustion (FBC). If the FGD or FBC systems can be applied in an economical way, the market for medium- and high-sulfur coals from the Illinois Basin states and from other states will increase.

The FGD and FBC technologies remove sulfur after and during combustion, respectively, through a chemical reaction between sulfur and calcium. Because of the increase in electricity consumption anticipated in the 1970s, it was predicted that, along with the market for coal, the market for lime and limestone (as a source of calcium) would experience a strong surge. Malhotra and Major (1974) investigated the potential for the sales of lime, limestone, and other carbonate materials and reported that up to 32 million tons of limestone and carbonate materials or up to 14.4 million tons of lime could be required annually by 1980 for use in FGD systems in the United States.

Because virtually no demand for carbonate materials existed in 1974 for use in FGD systems, the estimated growth potential seemed staggering. However, by 1981 only about 908,000 tons of lime and 563,000 tons of crushed limestone were used for sulfur removal (Pressler, 1982). Thus, only about 8 percent of the projected demand was realized. The purpose of this report is to investigate the reasons for the difference between the potential and the actual demand, and to attempt a new projection for the year 1992 on the basis of a modified set of assumptions regarding future developments.

Coal in the electric utility industry

In the early 1970s obtaining sufficient supplies of low-sulfur coals to comply with the SO_2 emission regulations was thought to be difficult. Therefore, projections of demand for lime and limestone for sulfur removal were based on the assumption that most utilities would have to use one of the available lime or limestone sulfur-removal technologies. However, low-sulfur coal production was developed in the western United States in the 1970s. Most of the growth in coal production between 1970 and 1980 came from coal deposits west of the Mississippi; virtually no growth was observed in coal production east of the Mississippi (fig. 1). The east-west coal trade within the country had been nearly balanced and relatively small until 1973. In subsequent years, a shift in trade in favor of western coal occurred (fig. 2), although the magnitude of the imbalance was not significant in relation to total coal production in the United States.

Coal consumption for electricity generation in the high-sulfur coal areas of the eastern United States grew slightly between 1970 and 1982, from about 308 to 368 million tons. During the same period, coal consumption for electricity generation west of the Mississippi increased from 32 to 232 million tons. The most important reasons for this include the following:

- Total electricity generation west of the Mississippi increased at an average annual rate of 4.7 percent, compared with a 3 percent average annual increase east of the Mississippi between 1971 and 1981 (table 1).

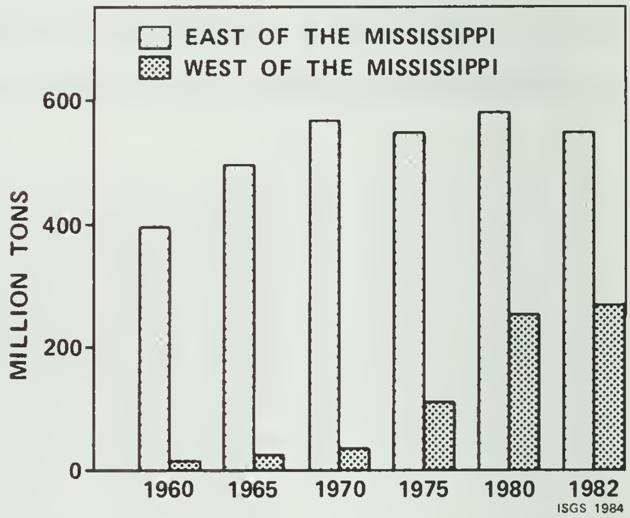

Figure 1. Eastern and western coal production, 1960–1982 (adapted from U.S. DOE [1982a] and previous publications of U.S. DOE and U.S. Bureau of Mines).

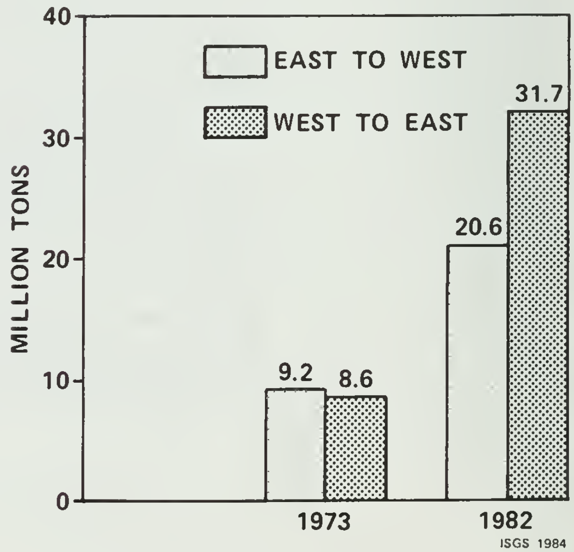

Figure 2. East-west coal trade, 1973 and 1982.

Table 1. Energy input for generation of electricity (trillion Btu).

Eastern states	1971	1981	Western states	1971	1981
Alabama	475.9	790.9	Arizona	150.7	425.0
Connecticut	262.0	256.0	Arkansas	125.3	267.3
Delaware	57.5	86.7	California	1,253.8	1,433.8
District of Columbia	30.1	5.4	Colorado	148.5	274.9
Florida	653.0	1,043.4	Idaho	78.3	98.8
Georgia	320.4	635.2	Iowa	177.1	254.9
Illinois	829.4	1,074.9	Kansas	192.2	291.0
Indiana	540.9	712.3	Louisiana	375.8	475.4
Kentucky	491.9	624.9	Minnesota	190.7	347.9
Maine	62.2	131.3	Missouri	332.4	511.9
Maryland	252.7	320.2	Montana	112.5	177.4
Massachusetts	313.0	336.5	Nebraska	87.5	174.3
Michigan	648.9	850.6	Nevada	90.0	172.8
Mississippi	125.9	175.5	New Mexico	173.7	252.5
New Hampshire	52.5	61.8	North Dakota	102.7	222.3
New Jersey	407.4	350.0	Oklahoma	263.1	450.6
New York	1,119.1	1,275.1	Oregon	359.8	425.3
North Carolina	527.7	712.0	South Dakota	91.1	87.2
Ohio	884.0	1,157.0	Texas	1,215.0	2,210.9
Pennsylvania	951.0	1,223.6	Utah	34.8	123.7
Rhode Island	19.0	10.5	Washington	779.2	1,161.1
South Carolina	223.2	433.3	Wyoming	70.2	296.3
Tennessee	428.0	591.1		6,404.4	10,135.3
Vermont	10.7	51.5		(37.5%)	(41.2%)
Virginia	300.2	405.4			(+ 58.3%)[1]
West Virginia	384.8	738.8			(+ 4.7% per year)[2]
Wisconsin	312.9	409.7			
	10,684.5	14,463.6			
	(62.5%)	(58.8%)			
		(+ 34.4%)[1]			
		(+ 3 % per year)[2]			

[1] Percentage increase, 1971-1981.
[2] Average annual increase.

- Nuclear electricity generation increased from 1.5 percent of the total in 1970 to about 12.6 percent in 1982. Almost 85 percent of nuclear electricity generation occurred east of the Mississippi.

- Population generally shifted from east to west. In 1970 about 67 percent of the population of the United States lived in the east; in 1980, about 63 percent. Population in the west increased by 17 million, compared with an increase of 7 million in the east.

- Per capita total energy consumption in the western states grew faster than in the eastern states. Between 1960 and 1981, the total per capita energy consumption in the west grew by 40 percent, compared with 28 percent in the eastern states.

Differences in regulations applicable to existing and newly constructed coal-burning utilities created considerable flexibility for compliance with Clean Air Regulations; consequently, coal production and consumption in the east showed little growth in the 1970-1982 period. The SO_2 emission standards set by the 1971 United States Environmental Protection Agency (U.S. EPA) regulations applied only to plants constructed or modified after August 17, 1971. Emissions from older plants were regulated by the states under State Implementation Plans (SIPs), which allowed higher emission levels than the Federal Clean Air regulations. The Clean Air Act was amended in 1977 and new emission regulations issued in 1979.

The SIPs have also been revised. However, the general procedure of permitting higher emissions from older plants under the SIPs has remained unaltered. Most coal-burning power plants east of the Mississippi benefitted from the SIPs permitting the use of higher-sulfur coals. This explains not only the stability, but also the lack of growth in coal use east of the Mississippi in the 1970-1980 period and consequently, the lagging of application of FGD systems behind expectations.

In the west, the growth of coal production and the electric utility industry in the 1970s did not result in extensive use of FGD systems because the low-sulfur contents of western coals enabled compliance with SO_2 emission limits set under the 1971 regulations.

The use of fuel oil in electricity generation fell rapidly in the 1970s, mainly due to the price increases of 1974 and 1979/80. In 1982 electric utilities consumed less than 45 percent as much oil as they did in 1972. About 90 percent of this consumption occurred in states east of the Mississippi. Total consumption of oil by electric utilities in the United States in 1982 was the equivalent of about 65 million tons of coal. The decline in use of oil was, however, not matched by a corresponding increase in use of coal in the eastern United States because of high costs and the problems that plagued the FGD operations. Instead, nuclear electricity generation increased.

Future of coal and oil markets

The 1979 revised performance standards, which require a percentage reduction in SO_2 emissions regardless of the sulfur content of coal, will result in greater use of lime- and limestone-based FGD systems in power plants constructed after September 18, 1979. The effects will be visible in the 1980s depending upon the rate of growth in the electric utility industry. A further increase in demand for lime- and limestone-based FGD systems could result from the proposed reductions in SO_2 emissions contained in the acid rain legislation. Such legislation could, however, result in declining demand for eastern coals, the use of which requires larger quantities of lime and limestone for sulfur removal than does the use of generally lower-sulfur western coals. The quantitative effects of any acid rain regulations in the 1980s will depend upon when they are passed and how they are implemented.

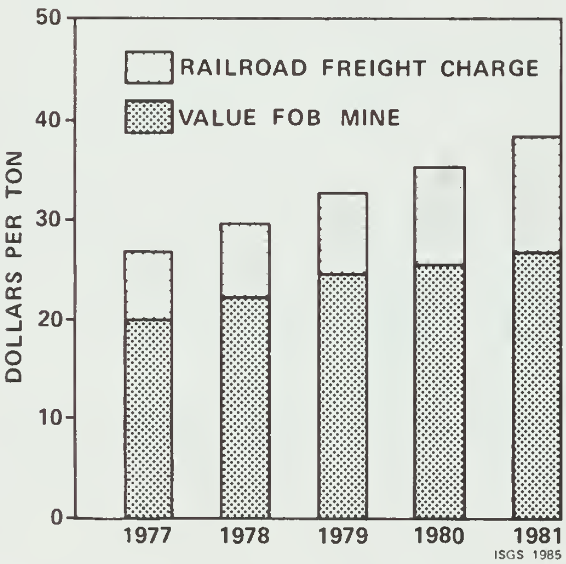

Figure 3. Average coal mine prices and railroad freight charges, 1977–1981. (Coal mine prices adapted from U.S. DOE [1982b]; railroad freight charges, from King, B. L. [1984].)

Other economic factors can also affect future demand for coal and limestone. Coal transportation, for example, is becoming increasingly expensive, especially since the deregulation of railroads in 1980 (fig. 3). Transportation costs amounted to about 30 percent of the delivered price of coal in 1981, as compared with about 27 percent in 1979; both are significantly higher than in 1969/70. The rising of coal prices in the mid-1970s represented an incentive for the railroads (which transport more than 60 percent of the tonnage in the U.S.) to raise freight rates. Efforts to introduce competition into the long-distance coal transportation business gathered momentum in the late 1970s when the policy of eminent domain was proposed for coal slurry pipelines. However, after initial success in various committees, the coal slurry pipeline bill was defeated by Congress by a large margin in September, 1983. Because of railroad deregulation and the lack of competition in long distance coal haulage, the rail freight rates could successfully capture a greater share of delivered coal prices in the 1980s and early 1990s.

The ultimate cost of coal consists of its mining, cleaning, and transportation as well as FGD systems and waste disposal. Eastern coal mines are closer to utility companies than western coal mines, and a somewhat smaller percentage of eastern coal is transported by railroads than western coal. However, most other cost factors favor the use of western coal. Eastern coal could also face increased competition from nuclear electricity generation. These developments would tend to reduce consumption of higher-sulfur eastern coals and therefore also slow the growth prospects for lime and limestone demand in the years up to 1992. However, technological developments such as coal/limestone pellets could open the industrial coal market and support the limestone market in the process.

Innovations and modifications in the conventional FGD systems may further influence the demand for lime and limestone. For example, some processes produce marketable gypsum during the removal of sulfur from the flue gases. This gypsum can reduce the cost of using high-sulfur coal and increase its use, thereby also promoting the sales of lime and limestone. However, if pre-combustion desulfurization of coal succeeds technically and economically, the demand for lime and limestone in sulfur removal may decline.

Oil price increases in 1974 and 1979/80 created a large differential between coal and oil as fuels for electricity generation. However, conversions from oil to coal have not been as widespread as expected because of environmental constraints. With the exception of California, the use of oil for electricity generation is concentrated in the eastern United States. In 1982, New York, Florida, Massachusetts, and Connecticut accounted for 70 percent of the oil consumed by electric utilities.

The average sulfur content of oil used by utilities in 1982 was 1.3 percent. In most states, however, the sulfur content of oil burned was low enough to satisfy the SO_2 emission limits of 0.8 lbs $SO_2/10^6$ Btu. About 88 percent of oil containing more than 1 percent sulfur was burned in three states (Massachusetts, New York, and Florida), and prices varied between $4.10 and $4.30 per million Btu (U.S. DOE, 1983). To comply with clean air standards, these utilities could either install scrubbers or switch to low-sulfur oil or coal. Low-sulfur oil of compliance quality presently costs about $0.50 to $1.00 per 10^6 Btu more than high-sulfur oil.

According to EPA regulations, switching to coal involves, among other costs, installation of scrubbers, thereby increasing the costs of conversion. No demand for lime and limestone can be expected if utilities decide to burn low-sulfur oil in place of high-sulfur coal. Given the availability of such oil, this seems to be the most likely development; however, concern about United States dependence on imported low-sulfur oil could prevent this. It is, therefore, reasonable to assume that if stricter SO_2 emission regulations to control acid rain are passed, electric utilities burning high-sulfur oil would use scrubbers.

Lime and limestone requirements for sulfur removal

The U.S. EPA (1981) conducted a survey of FGD systems installed, under construction, contracted, or planned in the United States; results indicated that approximately 18 different types of FGD systems are on the market, each using different materials or combinations of materials as absorbents. However, most of the processes are based on the use of lime or limestone. The two most commonly used materials for sulfur removal are limestone (52%) and lime (33%); other carbonate materials account for the remainder.

Two basic approaches are used in the FGD systems—wet and dry scrubbing. Wet processes use lime or limestone sludge as absorbents, and are generally more effective, especially for the fuels that have higher sulfur contents. Dry systems are cheaper to operate and more suitable for use with medium- and low-sulfur fuels. At present, the wet systems account for 92 percent of the FGD megawatt capacity. However, the importance of dry systems is increasing because the 1979 New Source Performance Standards (NSPS) require that all new coal-burning utilities remove 70–90 percent sulfur.

Because most coal produced in the western United States contains 1 percent or less sulfur and a large proportion of coal produced in the eastern United States contains a medium amount of sulfur (1-2%), the use of dry scrubbers is likely to increase in the future. For high-sulfur coal (more than 2% sulfur), such as that found in the Illinois Basin and in Ohio, wet scrubbers will have to be used in most cases. Within the time period under study in this report (up to 1992), planned and contracted FGD systems indicate a predominance of wet processes. Thus, for the purpose of projections it is assumed that lime and limestone-based wet processes will determine the requirements for sulfur removal from 1982 to 1992 (Kaplan and Princiotta, 1982).

The actual amount of lime or limestone used in the removal of sulfur from flue gases depends upon the theoretical needs determined by the chemical reaction between calcium oxide or calcium carbonate and sulfur dioxide (stoichiometric ratio) as well as the technological efficiency of the FGD system used. Theoretically, 1.75 tons of lime (CaO) or 3.13 tons of high purity limestone ($CaCo_3$) are required to absorb 2 tons of sulfur dioxide (1 ton of sulfur) (Malhotra and Major, 1974). However, technological efficiencies can be lower and require larger amounts of lime and limestone (Kaplan and Princiotta, 1982; EPA, 1979). Ratios of 1.0-1.2 for lime and 1.2-1.5 for limestone are considered practical and were, therefore, used in projecting demands for lime and limestone in this report (see appendix for details).

Compliance with clean air regulations

Clean air regulations have two broad goals: to reduce air pollution in areas where the limits set by the EPA are exceeded and to prevent deterioration of air quality in other areas in which pollution does not presently exceed ambient air quality standards. The strategy adopted by regulatory bodies includes 1) a specific maximum on permissible emission levels from new plants that are constructed after a certain date and are sources of pollution (NSPS) and 2) for existing plants, a planned gradual reduction in emissions (regulated by the SIPs) to ultimately meet the federal standards. The strategy is designed to attain the clean air objectives with as little economic disruption as possible. As existing plants are closed and emissions from the remaining ones are gradually reduced, the total emissions will decrease.

Since 1980 concern has been increasing about acid rain. Emissions of sulfur dioxides (SO_2) and nitrogen oxides (NO_X) from coal-burning utilities may react with water and cause increased acidity in rain and snow, possibly harming humans, animals, and plants. Legislative proposals concerning further mandatory reductions in SO_2 and NO_X emissions have been submitted to the United States House of Representatives and the Senate. Important questions remain unanswered, especially those concerning the geographic origin of emissions and their relationship to acid rain in remote geographic regions. However, all the proposals before Congress require reductions in SO_2 emissions by 8 to 12 million tons annually between 1991 and 1998.

The two main compliance strategies for achieving the emission reduction goals are switching to burning low-sulfur coal or retrofitting existing utilities with FGD systems. It is unlikely that either strategy would be exclusively applied. Several points must be considered before determining the precise combination of the two compliance strategies:

- Electric utilities burned about 600 million tons of coal in the United States in 1982; the average sulfur content of this coal was 1.5 percent. Utilities also burned 35.5 million tons of oil that averaged 1.3 percent sulfur. Therefore, the potential SO_2 emission in 1982 was about 18.9 million tons. On the basis of the SO_2 removal by existing FGD units and the fact that about 95 percent of potential emissions are released into the atmosphere, the actual SO_2 emissions from electric utilities in 1982 may have been about 17 million tons. A reduction by 8 to 12 million tons would lower the 1992 level of SO_2 emissions to a total of 5 to 9 million tons.

- Actual fuel use in 1992 is projected by NERC to be about 862 million tons of coal and 31.9 million tons of oil. Assuming that the average sulfur content of fuels will be about the same as in 1982, use of that amount of fuel would result in an SO_2 emission potential of about 22.3 million tons. Because proposed acid rain legislation would permit total emission levels of 5 to 9 million tons SO_2 in 1992, the SO_2 emission potential must be reduced by 13.3 to 17.3 million tons.

- Part of the needed reduction in potential SO_2 emissions in 1992 (13.3 to 17.3 million tons) would be accomplished by the present regulations that require new utilities to reduce potential emissions by 70 to 90 percent. Thus, new coal-burning facilities built between 1982 and 1992 would be fitted with FGD systems that remove 80 percent of the SO_2 from flue gases. This is, however, not likely to meet the SO_2 reduction requirements of the proposed acid rain legislation.

- Existing electric utilities in 1982, especially those burning high-sulfur eastern coals or high-sulfur oil, will be able to either switch to lower-sulfur coal and oil, respectively, or install FGD systems to comply with the further reduction in SO_2 emissions required by the proposed acid rain legislation. The demand for lime and limestone in 1992 would thus depend upon the compliance strategy chosen by the existing utilities.

The burden of complying with proposed acid rain legislation will mostly be borne by users of high-sulfur eastern coal and high-sulfur oil. The decision whether to switch to lower-sulfur fuels or to retrofit with FGD systems will be primarily influenced by the delivered prices of eastern and western coals at the utilities and the expected remaining economic life of existing utility plants.

Several factors indicate that switching to lower-sulfur fuels may not be attractive to a majority of utilities:

- The average delivered price ($\$/10^6$ Btu) of low-sulfur western coals in the eastern United States is now significantly higher than that of eastern medium- to high-sulfur coals.

- The Staggers Act enabled the railroads to increase coal freight rates. In 1973 freight rates accounted for about 30 percent of delivered coal prices. Despite the rising of coal prices in the mid-1970s, the railroads were unable to raise freight rates; their share of delivered coal prices fell to about 21 percent in 1975. It returned to 30 percent in 1981 and is expected to rise further in the future, making it more difficult for western coals to be competitive in the eastern United States.

- A survey of 24 electric utilities conducted by Edison Electric Institute (Baker, 1983) indicated that 80 percent of the utilities surveyed would use FGD systems rather than switch to lower-sulfur fuels.

However, retrofitting with FGD systems involves large investments that can only be justified if the remaining economic life of the utility plants permits recovery of these investments, if the price differential between high and low-sulfur fuels is large enough, and if the interest rates on borrowed capital are acceptable.

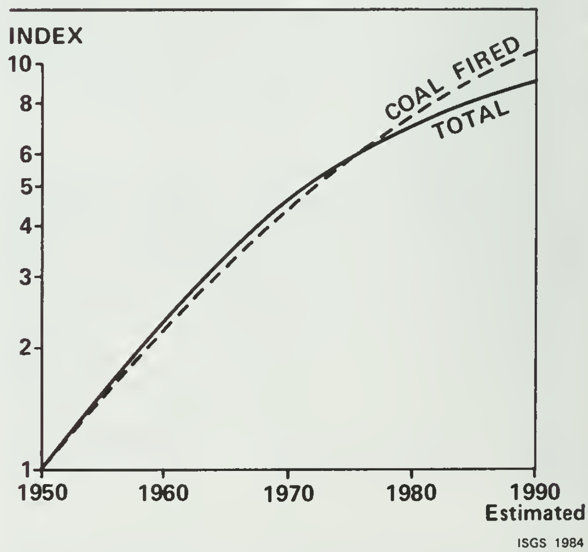

Figure 4. Index of energy consumption in electric power generation in the United States, 1950–1990.

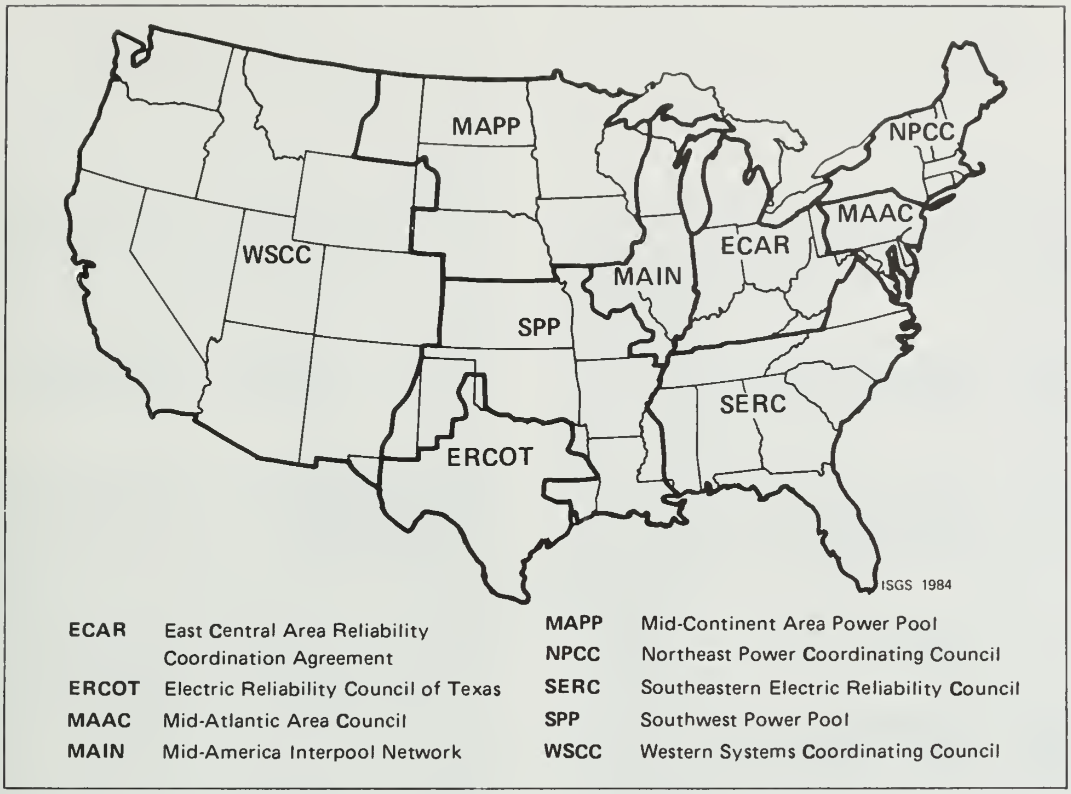

Figure 5. Regions of the North American Electric Reliability Council in the contiguous United States.

For the purpose of estimation, we begin with the assumption that investments in retrofitting with FGD systems will not be made if the remaining economic plant life is less than 15 years or about half of its entire expected life span. The energy consumption in electricity generation in the United States from 1950 to 1980 shows declining annual growth rates (fig. 4). However, because of an increasing base from which growth rates are calculated, the absolute new additions to generating capacity have been high. Thus, only about one-third of all existing plants can be assumed to be older than 15 years; by the year 1992, over half are expected to be. Therefore, between 1982 and 1992 about 60 percent of existing utilities can be expected to retrofit with FGD systems, thereby affecting future demand for lime and limestone. It is assumed that all the high-sulfur oil ($>$1% sulfur) burned by utilities will be subject to scrubbing.

Other considerations affecting compliance strategies stem from practical problems encountered in implementing environmental regulations. Utilities for which retrofitting with FGD systems is not an economically viable option may be permitted to follow an extended time schedule for compliance. This would allow them to continue burning eastern coal in their own economic interest as well as that of the eastern coal-producing states. The impact on demand for western coal as well as for lime and limestone may be negligible in the next ten years.

Projected 1992 SO_2 removal requirements

For the 1982-1992 period, estimates predict that the demand for eastern coal used in electricity generation in the United States will increase from 359 to 440 million tons; the demand for western coal will increase from 249 to 418 million tons (tables 2 and 3). The demand for oil by electric utilities in 1982 totaled about 35.5 million tons (table 2); estimates indicate that this will decline to 31.9 million tons by 1992 (U.S. DOE, 1980; Keystone, 1982). In 1982 most oil, except that of the NPCC and SERC census regions of the North American Electric Reliability Council (NERC) (fig. 5), complied with SO_2 emission regulations. The SO_2 emission limit for oil-fired electric utilities is 0.8 lbs $SO_2/10^6$ Btu, and is satisfied by oil containing $<$0.77 percent sulfur, assuming that the heating value of oil is 5.8 by 10^6 Btu/bbl.

On the basis of the average sulfur content of fuel burned in NERC census regions in 1982 and the assumption that about 95 percent of the sulfur reaches the atmosphere as SO_2 after burning, it is estimated that total emissions of SO_2 from electric utilities would have been about 17.95 million tons (table 2). However, about 47 million tons of eastern coal and 23 million tons of western coal were subject to FGD in 1982 (Kaplan and Princiotta, 1982) and about 1.08 million tons or an average of 50 percent of contained SO_2 was removed. As a result, actual 1982 SO_2 emissions amounted to about 16.87 million tons.

Table 2. Estimated 1982 emissions from coal- and oil-burning electric utilities in the United States.

NERC census region	Eastern coal: Consumption (10^6 tons)	Eastern coal: Average sulfur[1] (%)	Eastern coal: Total SO_2 content (10^6 tons)	Western coal: Consumption (10^6 tons)	Western coal: Average sulfur (%)	Western coal: Total SO_2 content (10^6 tons)	Oil: Consumption (10^6 tons)	Oil: Average sulfur (%)	Oil: Total SO_2 content (10^6 tons)	Overall total SO_2 content (10^6 tons)	SO_2 emissions (95% of overall total) (10^6 tons)
ECAR	149	2.1	6.258	11	0.7	0.154	0.638	0.7	0.0090	6.4209	6.0999
ERCOT	–	–	–	57	0.6	0.798	0.237	0.6	0.0028	0.8008	0.7608
MAAC	53	2.1	2.226	–	–	–	4.842	0.73	0.0707	2.2967	2.1819
MAIN	41	3.0	2.460	28	0.7	0.392	1.237	0.75	0.0186	2.8706	2.7271
MAPP	3	2.0	0.120	44	0.6	0.528	0.106	0.6	0.0013	0.6493	0.6168
NPCC	10	1.5	0.300	–	–	–	16.660	1.5	0.4998	0.7998	0.7598
SERC	102	1.6	3.264	2	0.6	0.024	8.904	1.6	0.2849	3.5729	3.3943
SPP	0.5	2.0	0.020	31	0.6	0.372	0.449	0.6	0.0054	0.3974	0.3775
WCC	–	–	–	76	0.7	1.064	2.454	0.35	0.0172	1.0812	1.0271
Total	359		14.648	249		3.332	35.527		0.9096	18.8896	17.9451[2]

[1] Sulfur content averages estimated from NERC and DOE data. NERC census regions do not exactly match state boundaries; DOE data are reported by states. Averages are estimated by including complete states into NERC regions if major portions of the state are included in the region.

[2] About 47 million tons of eastern coal and 23 million tons of western coal are being subjected to FGD. Estimated SO_2 removal in 1982 amounted to 1.08 million tons. Actual 1982 SO_2 emissions are estimated to be about 16.87 million tons.

Table 3. Projected 1992 reduction of SO_2 emissions under NSPS, as applicable at present.

NERC census region	Eastern coal: Consumption[1] (10^6 tons)	Eastern coal: Potential SO_2 emissions[2] (10^6 tons)	Eastern coal: Tonnage scrubbed in new plants (10^6 tons)	Eastern coal: SO_2 removed[3] (10^6 tons)	Western coal: Consumption (10^6 tons)	Western coal: Potential SO_2 emissions (10^6 tons)	Western coal: Tonnage scrubbed in new plants (10^6 tons)	Western coal: SO_2 removed (10^6 tons)	Total SO_2 removed (10^6 tons)
ECAR	171	6.823	22	0.702	13	0.173	2	0.021	0.723
ERCOT	–	–	–	–	100	1.140	43	0.392	0.392
MAAC	39	1.556	–	–	–	–	–	–	
MAIN	38	2.166	–	–	26	0.346	–	–	–
MAPP	5	0.190	2	0.061	69	0.787	25	0.228	0.289
NPCC	28	0.798	18	0.410	–	–	–	–	0.410
SERC	158	4.803	56	1.362	3	0.034	1	0.010	1.372
SPP	1	0.038	0.5	0.015	96	1.094	65	0.593	0.608
WCC	–	–	–	–	115	1.530	39	0.415	0.415
Total	440	16.374	98.5	2.550	422	5.104	175	1.659	4.209

[1] Assuming ratio of consumption of eastern and western coals unchanged from 1982.
[2] Assuming 1982 average sulfur contents of coal and 95% emission potential.
[3] Assuming 80% of emission potential removed by scrubbing.

For 1992 two models must be considered: 1) The 1979 New Source Performance Standards (NSPS), under which all new plants must reduce potential pollution by 70 to 90 percent regardless of the sulfur content of the fuel burned, could continue to be applied. This requires mandatory installation of FGD systems in new plants and assumes continued use of higher-sulfur fuels in existing plants in accordance with SIPs. 2) A proposed acid rain bill might be passed and implemented, thus requiring a reduction of SO_2 emissions by 8 to 12 million tons from present annual levels between 1992 and 1998. In this report, only those existing plants that are likely to retrofit with scrubbers (FGD) are of interest.

Table 3 contains projections for the first model about consumption of eastern and western coals by NERC regions, the expected growth from 1982 that will be subject to FGD, and the amount of SO_2 expected to be removed. For these estimates, it is assumed that the growth in coal consumption will result from new power plants that must be equipped with FGD systems as required by 1979 NSPS. Because overall oil consumption in 1992 is projected to be less than the 1982 levels, no oil-fired plants will use FGD in 1992. The total SO_2 removal using FGD in new plants in 1992 will be about 4.21 million tons. Thus, if present clean air regulations continue to be applied in 1992, a total of 4.21 + 1.08 = 5.29 million tons of SO_2 will be removed by FGD using lime or limestone. Actual SO_2 emissions from coal burning will be about 16.2 million tons. SO_2 emissions from oil-burning electric utilities (31.9 million tons of oil with 1.3% sulfur) are expected to be about 0.82 million tons. Total SO_2 emissions from coal- and oil-burning plants in 1992 will be about 17 million tons, nearly the same as in 1982.

Table 4 contains information about the second model for 1992. As explained earlier, this model is based on the assumption that about 60 percent of the existing utilities burning high-sulfur eastern coal would use FGD in the next decade. In addition, the SO_2 removal by FGD from newly constructed coal-fired plants is also considered. Use of high-sulfur oil is mostly concentrated in the NPCC and SERC regions; therefore, only those regions appear in table 4. Total SO_2 removal by FGD in 1992 is estimated at about 11.35 million tons. This includes 1.08 million tons of SO_2 that were removed by FGD in 1982; additional FGD applications will remove 10.27 million tons of SO_2 annually by 1992. Actual SO_2 emissions from all utility plants in 1992 are estimated to be 22.3 - 11.35 = 10.95 million tons (about 5 million tons less than in 1982).

Not all acid rain proposals define required compliance strategies. It must be assumed that SO_2 reductions beyond the 5 million tons attained by FGD applications will be reached by switching to lower-sulfur fuels, especially to low-sulfur coals. Coal would have to have <0.65 percent sulfur; this would affect the demand for approximately 154 million tons of eastern coals. This makes possible another model for future coal production that is beyond the scope of this investigation.

Table 4. Projected 1992 reduction of SO_2 emissions by FGD systems under proposed acid rain legislation.

	Eastern coal			Oil		
NERC census region	Tonnage subject to FGD in plants existing in 1982[1] (10^6 tons)	SO_2 removed in 1992 from plants existing in 1982[2] (10^6 tons)	SO_2 removed from new plants[3]	Consumption of oil with $\leq$1% SO_2 content[4] (10^6 tons)	SO_2 removed in 1992[2] (10^6 tons)	Total SO_2 removed by FGD in 1992[5] (10^6 tons)
ECAR	89.4	2.853	0.723	–	–	3.576
ERCOT	–	–	0.392	–	–	0.392
MAAC	23.4	0.747	–	–	–	0.747
MAIN	22.8	1.041	–	–	–	1.041
MAPP	1.8	0.548	0.289	–	–	0.837
NPCC	6.0	0.137	0.410	4.56	0.152	0.699
SERC	61.2	1.490	1.372	4.85	0.158	3.020
SPP	0.3	0.009	0.608	–	–	0.617
WCC	–	–	0.415	–	–	0.415
Total	204.9	6.825	4.209	9.41	0.310	11.344

[1] Assuming 60% of coal burning utilities existing in 1982 will use FGD systems by 1992.
[2] Assuming average sulfur contents same as in 1982, 95% potential emissions, and 80% SO_2 removal rate.
[3] From last column of table 3.
[4] 1 ton of oil = 6.667 bbl; average sulfur content NPCC = 2.2% and SERC = 2.15%.
[5] Sum of columns 2, 3, and 5.

Projected 1992 lime and limestone demand for SO_2 removal

Table 5 summarizes the projected demand of lime and limestone for removal of SO_2 from flue gases of electric utilities in 1992 by NERC census region. If application of the 1979 NSPS (model 1) is continued, and if either material is used exclusively, about 3.7 to 4.4 million additional tons of lime (CaO) or about 7.9 to 9.85 million tons of limestone ($CaCO_3$) would be required in 1992 for SO_2 removal. The lower demand figures are more probable because actual needs more nearly approach stoichiometric ratios. Actual demand will be lower for both materials because some plants will use lime and others, limestone. In 1981, utility companies used about 0.9 million tons of lime and about 0.56 million tons of limestone. Because of the higher reaction efficiency of lime and its ability to reduce waste disposal costs, use of lime has been more widespread. However, lime is about 12 to 13 times more expensive than limestone, and fine-grinding of limestone is making limestone scrubbers highly efficient. Marketability of by-products such as gypsum could also influence the actual use of either material.

Model 2 in table 5 shows the effects of proposed acid rain legislation, in which the estimated 1992 demand for lime would be about 9.9 to 11.9 million tons; for limestone, about 21.3 to 26.6 million tons. A much greater degree of uncertainty must be attached to projections in model 2. First, it is uncertain when acid rain legislation will be passed. Even if the legislation were implemented immediately, effects on demand for lime or limestone would not be apparent for several years. Second, the regional economic impacts of acid rain legislation will be different from region to region. The states in the ECAR and SERC regions will be most severely affected (table 5). The possibility of fuel switching expected to result from the acid rain legislation would affect some coal-producing regions so severely that resistance from individual states would be strong. The SIPs would then have to be modified, thus delaying the effects on demand for lime and limestone. Projections for 1992 using model 2 must therefore be looked upon as highly optimistic from the point of view of the lime and limestone industry.

Consequences for the lime, limestone, and gypsum industries

In 1983 about 14.4 million tons of lime were produced and 14.7 million tons of lime were used in the United States (U.S. Bureau of Mines, 1983). Between 1978 and 1983, lime production and consumption declined by 31.4 percent. In the same period, the value of lime increased 37.6 percent from \$36.7 to \$50.5 per ton. The projected increase in demand for lime for SO_2 removal would mean a substantial improvement in lime sales during the next 10 years. Potentially, between 3.7 million tons (model 1) and 9.9 million tons (model 2) of additional lime could be used in 1992. Although part of this potential will probably not be realized because of use of limestone for SO_2 removal, the actual production of lime in 1992 could be 20 to 40 percent higher than in 1983.

Table 5. Projected 1992 lime and limestone demand for SO_2 removal, by NERC regions.

NERC census region	Model 1				Model 2			
	10^6 tons of lime		10^6 tons of limestone		10^6 tons of lime		10^6 tons of limestone	
	1.0[1]	1.2[2]	1.2[1]	1.5[2]	1.0	1.2	1.2	1.5
ECAR	0.6326	0.7591	1.3556	1.6945	3.129	3.7548	6.7050	8.3813
ERCOT	0.3430	0.4116	0.7347	0.9184	0.343	0.4116	0.7347	0.9184
MAAC	–	–	–	–	0.654	0.7848	1.4006	1.7508
MAIN	–	–	–	–	0.911	1.0932	1.9519	2.4399
MAPP	0.2529	0.3035	0.5419	0.6774	0.732	0.8784	1.5694	1.9617
NPCC	0.3588	0.4306	0.7687	0.9609	0.612	0.7344	1.3106	1.6383
SERC	1.2005	1.4406	2.5726	3.2157	2.643	3.1716	5.6626	7.0783
SPP	0.5320	0.6384	1.1400	1.4250	0.540	0.6479	1.1569	1.4461
WCC	0.3631	0.4357	0.7781	0.9726	0.363	0.4356	0.7781	0.9726
Additional demand in 1992	3.6829	4.4194	7.8916	9.8645	9.926	11.9112	21.2698	26.5873
1982 demand	0.908		0.560		Included in above totals			

[1] Stoichiometric ratio

[2] Required excess ratio

Limestone production in the United States has also declined, from about 1,050 million tons in 1978 to about 874 million tons in 1983. Its value increased from about $2.65 per ton in 1978 to about $3.75 per ton in 1983. Even if demand increases by 7.9 million tons (model 1) to 20.8 million tons (model 2) by 1992, it would not greatly affect the limestone mining industry.

Production of "desulfogypsum," i.e., gypsum produced in the process of flue gas desulfurization, is expected to increase in the future as a remedy to waste-disposal problems. The required technology already exists and is applied commercially in Japan and Western Europe. This technology is likely to improve rapidly because some European countries require that FGD systems produce commercial grade gypsum. The potential for production of desulfogypsum in the United States ranges from about 9 million tons per year (model 1) to about 24 million tons per year (model 2) in 1992.

Production of gypsum in the United States declined 29 percent, and consumption, by 23 percent between 1978 and 1982 (fig. 6). However, production and consumption are estimated to have increased substantially in 1983 because of increased construction activity (Industrial Minerals, 1983). Imports of crude gypsum, which declined 19 percent in 1982 from the 1978 level of 8.3 million tons, are estimated to have returned to the 1978 level in 1983. The FOB mine prices of crude gypsum increased from $6.25 per ton in 1978 to an estimated $9.00 per ton in 1983. In model 1, desulfogypsum could significantly affect the gypsum market. Because desulfogypsum is a by-product, its use could reduce gypsum imports, and allow recovery of about 40% of the costs incurred in flue gas desulfurization (based on 1983 lime and gypsum prices).

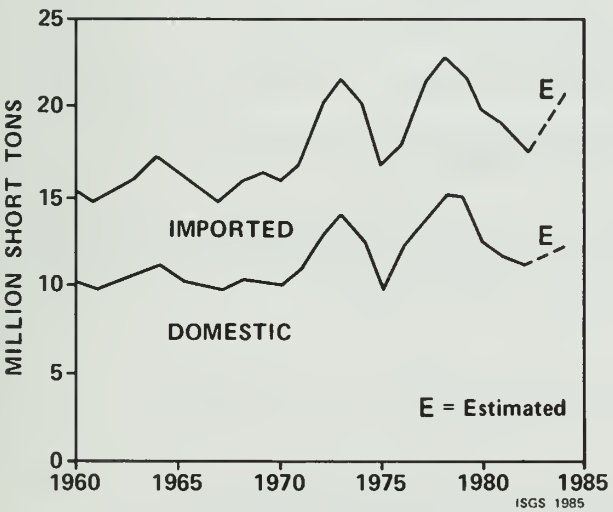

Figure 6. Sources of the United States supply of crude gypsum, 1960–1984.

Summary

Demand for lime and limestone in flue gas desulfurization (FGD) has not been as great as anticipated in the 1970s. This is partly due to increased nuclear power generation, increased production of low-sulfur coal, and a slower growth rate in electricity demand than expected in the high-sulfur coal areas of the eastern United States. Much of the increase in coal production and consumption during the 1970s occurred west of the Mississippi River.

Future markets for lime and limestone in FGD must be studied by using two clean air models that take into account the requirements of 1) the New Source Performance Standards of 1979, and of 2) proposed acid rain legislation.

In the first model, only the new power plants starting construction after September, 1979, would be equipped with FGD systems; most existing plants would operate as before, without FGD. In the second model, additional SO_2 emission reductions would require some or all existing plants to contribute to the clean-up effort. Data from 1950 to 1980 suggest that rates of increase in energy consumption for generating electricity have successively declined. However, because the total generating capacity has been increasing, younger electricity generating units (less than 15 years old) are presently estimated to constitute about two-thirds of all the generating capacity. Because only relatively new plants would possess the economic incentive to invest in the FGD systems, it is estimated that only about 60 percent of existing plants using high-sulfur coal would begin using FGD systems.

In model 1, it is estimated that about 3.7 million tons of lime (or about 7.9 million tons of limestone) would be required additionally in 1992. About 0.9 million tons of lime and 0.56 million tons of limestone were used in 1982. However, if acid rain legislation is passed and effectively implemented soon (model 2), the additional demand in 1992 could be about 9.0 million tons for lime, or about 20.8 million tons for limestone. The use of FGD alone will probably not achieve the required lowering in SO_2 emissions. Possible alternative methods include mandatory scrubbing requirements, financial subsidies in the form of tax breaks for utilities using FGD systems, and outright financial aid through increased electricity prices and/or taxes.

Thus, although the projected demand for lime and limestone in FGD in 1992 is estimated to be much lower than the previously estimated potential even for 1980, the increase in demand could be significant to the faltering lime and limestone industries, and possibly also to the gypsum industry. About half of this increase in demand is estimated to take place in the ECAR and SERC census regions of eastern United States. In the acid rain model, a number of midwestern and eastern states in the MAIN, MAPP, MAAC, and NPCC areas will also be affected.

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Appendix

A. Theoretical requirements of lime (CaO) and limestone ($CaCO_3$) for SO_2 removal

CaO and $CaCO_3$ requirements are based on the ratio of molecular weights of CaO and $CaCO_3$ to that of SO_2. The chemical reactions involved are approximately as in the following equations:

Lime	Limestone
$CaO + H_2O \rightarrow Ca(OH)_2$	$H_2O + SO_2 \rightarrow H_2SO_3$
$H_2O + SO_2 \rightarrow H_2SO_3$	$CaCO_3 + H_2SO_3 \rightarrow CaSO_3 + H_2CO_3$
$Ca(OH)_2 + H_2SO_3 \rightarrow CaSO_3 + 2H_2O$	$H_2CO_3 \rightarrow H_2O + CO_2$

The $CaSO_3$ thus generated partially oxidizes to $CaSO_4$ because of oxygen present in the solution. In some processes oxygen is introduced to the process in order to stabilize $CaSO_3$ as $CaSO_4$.

The molecular weights of Ca = 40, C = 12, O = 16, and S = 32 result in the following weight ratios:

$$CaCO_3 : SO_2 = 100 : 64 = 1.5625 \quad \textit{and} \quad CaO : SO_2 = 56 : 64 = 0.875$$

$$\textit{or} \quad CaCO_3 : S = 100 : 32 = 3.125 \quad \textit{or} \quad CaO : S = 56 : 32 = 1.75$$

Thus, theoretically 3.125 tons of $CaCO_3$ or 1.75 tons of CaO are required to remove 1 ton of sulfur; 1.5625 tons of $CaCO_3$ or 0.875 tons of CaO are required to remove 1 ton of SO_2.

Theoretical calculations assume that all CaO or $CaCO_3$ molecules react with SO_2, i.e., that the reaction stoichiometry is 1:1. Because of the short residence time and slow reaction rates between SO_2 and large CaO and/or $CaCO_3$ particles, the theoretical combination of SO_2:$CaCO_3$ will not be achieved.

B. Actual requirements of lime (CaO) and limestone ($CaCO_3$) for SO_2 removal

The most commonly cited requirements are 100 to 120 percent for lime and 120 to 150 percent for limestone; i.e., the actual CaO and $CaCO_3$ needs are expected to be up to 1.2 and 1.5 times the stoichiometric needs. Not all the sulfur in the fuel is emitted into the atmosphere; some of it is retained as inorganic sulfides in the ashes. About 95 percent of the sulfur in the fuel can be assumed released into the atmosphere in the form of oxides. The following calculations of actual requirements of CaO and $CaCO_3$ are based on these assumptions:

let X = pounds of SO_2 to be removed per ton of fuel burned

Y = Btu content of fuel per pound

Z = permissible SO_2 emission in lbs $SO_2 / 10^6$ Btu

S = sulfur content of fuel, in percent

Therefore:

$$X = 2 * 0.95 * \frac{2.000 * S}{100} - Z * \frac{2.000 * Y}{1.000.000}$$

Amount of lime or limestone required to remove enough SO_2 to meet the permissible SO_2 emission level Z is:

L = requirement for lime = (required multiple of ratio) * 0.875 * X

LS = requirement for limestone = (required multiple of ratio) * 1.5625

Values of L and LS could vary depending upon the required multiple of ratio used.

C. Example of calculating lime and limestone requirements

Fuel characteristics = coal with 11,000 Btu/lb and 3 percent sulfur, i.e., Y = 11,000 and S = 3

Permissible SO_2 emissions = 1.2 lbs $SO_2 / 10^6$ Btu heat input, i.e., Z = 1.2

$$X = SO_2 \text{ to be removed} = 2 * 0.95 * \frac{2,000 * 3}{100} - 1.2 * \frac{2.000 * 11.000}{1.000.000}$$

= 87.6 (lbs SO_2 /tons of coal burned)

L = lime requirements = (required multiple of ratio) * 0.875 * X

= 1.2 * 0.875 * 87.6

= 91.98 (lbs CaO/t coal burned)

LS = limestone requirements = (required multiple of ratio) * 1.5625 * X

= 1.5 * 1.5625 * 87.6

= 205.3125 (lbs $CaCO_3$ /t coal burned)

NOTE: Because of improving procedures, the required multiples may soon approach a ratio of 1 : 1 for lime and 1 : 1.2 for limestone. Values used above are for illustrative purposes only.