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ELECTRIC UTILITY PLANT FLUE-GAS DESULFURIZATION:

A Potential New Market for Lime, Limestone, and Other Carbonate Materials

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INTRODUCTION

Difficulties in obtaining sufficient quantities of low-sulfur fuels to meet current and proposed air-quality emission standards of the Federal Environmental Protection Agency for steam-electric power plants have created a strong impetus to develop processes capable of removing sulfur oxides from flue gases of plants burning high-sulfur fuels, including the coal found in most Eastern and Midwestern coal deposits. Because the technology for removing the sulfur from the coal itself by gasification, liquefaction, or solvent refining has not yet been perfected, one of the most promising methods for significantly reducing sulfur oxide emissions at the present time is a process of wet "scrubbing" the flue gas. In the scrubbing process flue gases react with chemically active materials to form a sulfur compound that can be recovered, disposed of, or possibly used for some beneficial purpose.

Among the many processes under consideration, wet scrubbers that use lime, limestone, and other carbonate materials as the reactant appear to be the most advanced and to offer a potential temporary solution. A recent report by the Sulfur Oxide Control Technology Assessment Panel (SOCTAP, 1973) assessed the future of wet scrubbers as follows:

In the United States during the 1973-1980 period, electric utilities will probably continue the current pattern in selecting wet scrubbers systems, with the majority of orders probably for wet lime/limestone scrubbers producing a throwaway sludge. There probably will be a limited number of orders for regenerative processes using reagent liquors based on magnesium, sodium, and other compounds.

Despite unresolved waste disposal problems, scrubber systems are being installed at a number of utility plants. Two of the most advanced of these projects are at Duquesne Light Company's F. Phillips station in Pittsburgh, Pennsylvania, and at Louisville Gas & Electric Company's Paddy's Run Station in Louisville, Kentucky. Duquesne Light has installed a 400-megawatt capacity SO_2 scrubber system designed by Chemico (Hesketh, 1974). Louisville Gas & Electric is using Combustion Engineering Company's lime scrubbing system retrofitted to its Paddy's Run Plant, and the utility has indicated that it intends to install nine more scrubber systems by 1980 at its other units, *provided* that the tests on the No. 6 unit at the Paddy's Run Plant are successful (Hesketh, 1974).

This report (a) estimates the approximate size and location of potential new markets for lime, limestone, and other carbonate materials that could develop from the widespread installation and use of wet scrubber systems on steam-electric power plants, and (b) evaluates the potential impact of these installations on the lime and limestone industries.

SULFUR EMISSIONS

According to the U.S. Bureau of Mines, 367 million tons of coal (1973c, p. 66, 71), 436 million barrels of residual oils, 68 million barrels of distillate oils (U.S. Bur. Mines, 1973d, p. 11), and 3.98 trillion cubic feet of natural gas (U.S. Bur. Mines, 1973b, p. 8) were burned at utility plants in the United States during 1972. The natural gas burned was essentially sulfur-free and therefore caused no air-pollution problems. Most of the distillate oil burned was sufficiently low in sulfur to meet air-quality standards as expressed in emissions per million Btu of heat input.

The amount of sulfur emitted from the burning of coal has been calculated on a state-by-state basis (table 1) by using the average sulfur content of coal burned by utilities in each state and by assuming that all of the contained sulfur was actually emitted. Detailed data on the sulfur content of residual fuel oil burned by utilities on a state-by-state basis was not available. For the purpose of this report, the amounts of sulfur emitted in each state from utility plants using such fuels in 1972 has been estimated (table 1) from U.S. Bureau of Mines data (1973d, p. 11) on sales of residual oil to utilities in each state and from Federal Power Commission data (1973a, 1973b) on sulfur content of fuels burned by electric utilities during the last two quarters of 1972. According to our estimates, in 1972 the burning of high-sulfur fuels at utility plants in the United States resulted in flue gases that contained approximately 10.6 million tons of sulfur.

As none of the states' air-quality standards for utility plants require zero discharge of sulfur oxide in flue gases, the amount of sulfur to be removed by scrubber treatment will not be equal to the amount emitted. On the basis of the most stringent air-quality regulations to go into effect in 1975, Padgett (1972, p. 26, 28) has grouped the states according to the maximum sulfur that can be burned by utility plants in these states. The sulfur limits in effect in the various categories (table 1) are as follows:

Category	Percent sulfur
I	< 0.8
II	0.8-1.6
III	1.6-2.5
IV	> 2.5

To determine the amount of sulfur that must be removed by scrubber treatment to meet 1975 EPA standards, the following sulfur levels were used as the basis for calculation:

Category	Percent sulfur
I	0.8
II	1.6
III	2.5
IV	3.0

On the basis of these assumptions, 81 percent of the coal (296 million tons averaging 3.0 percent sulfur) and 42 percent of the residual oil (182 million barrels averaging 1.8 percent sulfur) burned in 1972 would have required scrubber treatment, and 56.1 percent of the total sulfur emitted (10.6 million tons) would have had to be removed to comply with 1975 standards.

In Mississippi, Arkansas, Louisiana, Montana, Nevada, Oregon, and Washington, only a very limited amount of the fuels burned in 1972 would have required scrubber treatment, but in Ohio, Indiana, Kentucky, Pennsylvania, and Illinois most of the utility fuels burned in 1972 would have required scrubber treatment. On the average, 70 percent of the emitted sulfur in flue gases in these states would have had to be removed to meet the 1975 EPA air-quality standards.

RAW MATERIAL REQUIREMENTS

The amount of lime (CaO), limestone ($CaCO_3$) or carbonate materials such as marl, shell, or chalk that would be required in a wet scrubber system to clean up flue gases would largely be determined by the quantity of sulfur that must be removed and on the effective reactivity of the reagent used. Based on chemical reactions involved in the wet scrubbing systems, at 100 percent stoichiometry 1.75 tons of lime (100 percent CaO) are required to remove one ton of sulfur (2 tons of sulfur dioxide) from flue gases. Although it is theoretically possible to get 100 percent removal efficiency with 100 percent stoichiometry, such high levels of efficiency are not achieved in actual operation, and therefore a higher stoichiometry is used to obtain the required level of cleaning. At 120 percent stoichiometry the requirement increases to 2.10 tons of lime per ton of sulfur removed.

If limestone (100 percent $CaCO_3$) or other carbonate materials are used in place of lime, the amount of reactant required to remove one ton of sulfur from flue gases increases considerably, for example, at 100 percent stoichiometry

TABLE 1—POTENTIAL NEW MARKETS FOR LIME, LIMESTONE,

District and state	Fossil fuels burned in 1972 and amounts of sulfur emitted: COAL		OIL		Air-quality regulations and amount of sulfur to be removed: 1975 Air-quality regulations for existing plants†			
	Total coal burned (1000 tons)	Amount of sulfur emitted (tons)	Total oil burned (1000 bbl)	Amount of sulfur emitted (tons)	Coal-fired	Oil-fired	Total sulfur emitted (tons)	Amount of sulfur to be removed to meet 1975 air-quality standards‡ (tons)
NEW ENGLAND								
Massachusetts	26	456	46,284	105,882	I	I	106,338	43,362
Connecticut	54	1,134	27,963	54,776	I	I	55,910	17,173
Maine, New Hampshire, Rhode Island, Vermont	1,229	40,557	10,429	41,429	II	II	81,986	56,607
MIDDLE ATLANTIC								
New York	5,790	173,694	79,855	187,195	I	I	360,889	204,982
New Jersey	1,259	33,541	41,193	59,885	I	I	93,426	28,161
Pennsylvania	35,480	837,075	20,055	28,570	I	I	865,645	559,148
EAST NORTH CENTRAL								
Ohio	42,238	1,281,354	825	2,392	I	II	1,283,746	939,806
Indiana	26,090	1,038,213	397	1,087	I	II	1,039,300	836,709
Illinois	32,294	983,206	7,139	20,330	II	II	1,003,536	510,328
Michigan	21,424	669,293	5,862	16,332	I	I	685,625	506,815
Wisconsin	10,885	392,509	610	1,672	II	II	394,181	221,649
WEST NORTH CENTRAL								
Minnesota	6,674	133,913	751	3,215	I	II	137,128	86,096
Iowa	5,429	158,912	78	334	IV	II	159,246	214
Missouri	13,714	537,182	341	985	II	III	538,167	183,709
North Dakota, South Dakota	5,295	36,011	246	743	III	IV	36,754	285
Nebraska, Kansas	2,303	70,420	459	1,293	III	II	71,713	31,232
SOUTH ATLANTIC								
Delaware, Maryland	5,408	143,844	4,162	11,980	I	I	155,824	106,363
District of Columbia	146	1,848	4,673	12,803	I	I	14,651	7,084
Virginia	4,894	50,316	24,171	103,472	III	III	153,788	33,111
West Virginia	22,752	531,978	643	1,762	II	II	533,740	212,636
North Carolina	19,696	216,462	4,048	17,329	I	I	233,791	68,984
South Carolina	5,480	60,280	1,385	4,265	I	I	64,545	18,591
Georgia	10,870 }‡	482,072	3,572	14,250	II	II	701,414	8,808
Florida	6,124 }	—	64,050	205,092	—	II	—	27,790
EAST SOUTH CENTRAL								
Kentucky	23,460	754,105	333	912	I	I	755,017	568,116
Tennessee	18,894	171,155	—	—	II	II	171,155	271,177
Alabama	18,807‡	658,245‡	—	—	I	II	658,245	405,216
Mississippi	581‡	20,335	1,244	3,407	IV	IV	23,742	—
WEST SOUTH CENTRAL								
Arkansas	—	—	2,081	10,311	III	III	10,311	—
Louisiana, Oklahoma	—	—	959	1,314	III	III	1,314	—
Texas	—	—	506	2,075	III	III	2,075	602
MOUNTAIN								
Arizona	—	—	936	2,305	I	I	2,305	1,189
Colorado	3,655	21,930	484	1,326	I	I	23,256	663
Utah	592	4,144	1,272	3,433	II	II	7,577	—
Montana	753	6,777	16	43	II	II	6,820	—
Nevada	—	—	75	205	I	I	205	137
New Mexico	6,844	41,064	396	705	I	I	41,769	163
Wyoming	4,903	29,418	111	304	IV	IV	29,722	—
PACIFIC								
Oregon	—	—	17	23	—	—	23	—
Washington	2,597	38,955	60	164	II	II	39,119	—
California	—	—	47,340	63,748	I	I	63,748	1,297
ALASKA AND OTHERS	386	2,702	30,327	—	—	—	2,702	—
TOTAL	367,026	9,623,179	435,348	987,348			10,610,527	5,958,203

* 5.84 barrels = 1 ton of residual fuel oil.

† Category I - less than 0.8 percent sulfur; II - 0.8-1.6 percent sulfur; III 1.6-2.5 percent sulfur; and IV - over 2.5 percent sulfur (Padgett, 1972).

‡ Estimated. Sources: U.S. Bureau of Mines, 1973c; U.S. Bureau of Mines, 1973d; Federal Power Commission, 1973a.

AND OTHER CARBONATE MATERIALS BY DISTRICT AND STATE

Quantity of lime and limestone or other carbonate materials required to desulfurize flue gases, 1972					
Limestone or carbonate materials			Lime		
1.0 Stoichiometry	1.2 Stoichiometry	1.5 Stoichiometry	1.0 Stoichiometry	1.2 Stoichiometry	District and
3.1 ton/ton of S	3.75 ton/ton of S	4.7 ton/ton of S	1.75 ton/ton of S	2.10 ton/ton of S	state
					NEW ENGLAND
135,723	162,607	203,801	75,883	91,060	Massachusetts
53,751	64,398	80,713	30,052	36,063	Connecticut
177,179	212,276	266,052	99,062	118,874	Maine, New Hampshire, Rhode Island, Vermont
					MIDDLE ATLANTIC
641,593	768,682	963,415	358,718	430,462	New York
88,144	105,603	132,356	49,281	59,138	New Jersey
1,750,133	2,096,805	2,627,995	978,509	1,174,210	Pennsylvania
					EAST NORTH CENTRAL
2,941,592	3,524,272	4,417,088	1,644,660	1,973,592	Ohio
2,618,899	3,137,658	3,932,532	1,464,240	1,757,088	Indiana
1,597,326	1,913,730	2,398,541	893,074	1,071,688	Illinois
1,586,330	1,900,556	2,382,030	886,926	1,064,311	Michigan
693,761	831,183	1,041,750	387,885	465,462	Wisconsin
					WEST NORTH CENTRAL
269,480	322,860	404,651	150,660	180,801	Minnesota
670	802	1,006	374	450	Iowa
575,009	688,908	863,432	321,490	385,788	Missouri
892	1,068	1,339	499	598	North Dakota, South Dakota
97,756	117,120	146,790	54,656	65,587	Nebraska, Kansas
					SOUTH ATLANTIC
332,916	398,861	449,906	186,135	223,362	Delaware, Maryland
22,172	26,565	33,294	12,397	14,876	District of Columbia
103,637	124,166	155,621	57,944	69,533	Virginia
665,550	797,385	999,389	372,113	446,535	West Virginia
215,920	258,690	324,225	120,722	144,866	North Carolina
58,189	69,716	87,377	32,534	39,041	South Carolina
27,569	33,030	41,397	15,414	18,497	Georgia
86,983	104,212	130,613	48,632	58,359	Florida
					EAST SOUTH CENTRAL
1,778,203	2,130,435	2,670,145	994,203	1,193,043	Kentucky
848,784	1,016,913	1,274,531	474,559	569,472	Tennessee
1,268,326	1,519,560	1,904,515	709,128	850,953	Alabama
—	—	—	—	—	Mississippi
					WEST SOUTH CENTRAL
—	—	—	—	—	Arkansas
—	—	—	—	—	Louisiana, Oklahoma
1,884	2,257	2,829	1,053	1,264	Texas
					MOUNTAIN
3,721	4,458	5,588	2,080	2,496	Arizona
2,075	2,486	3,116	1,160	1,392	Colorado
—	—	—	—	—	Utah
—	—	—	—	—	Montana
429	513	644	240	288	Nevada
510	611	766	285	342	New Mexico
—	—	—	—	—	Wyoming
					PACIFIC
—	—	—	—	—	Oregon
—	—	—	—	—	Washington
4,059	4,863	6,096	2,269	2,723	California
—	—	—	—	—	ALASKA AND OTHERS
18,648,495	22,342,449	27,953,542	10,426,845	12,512,182	TOTAL

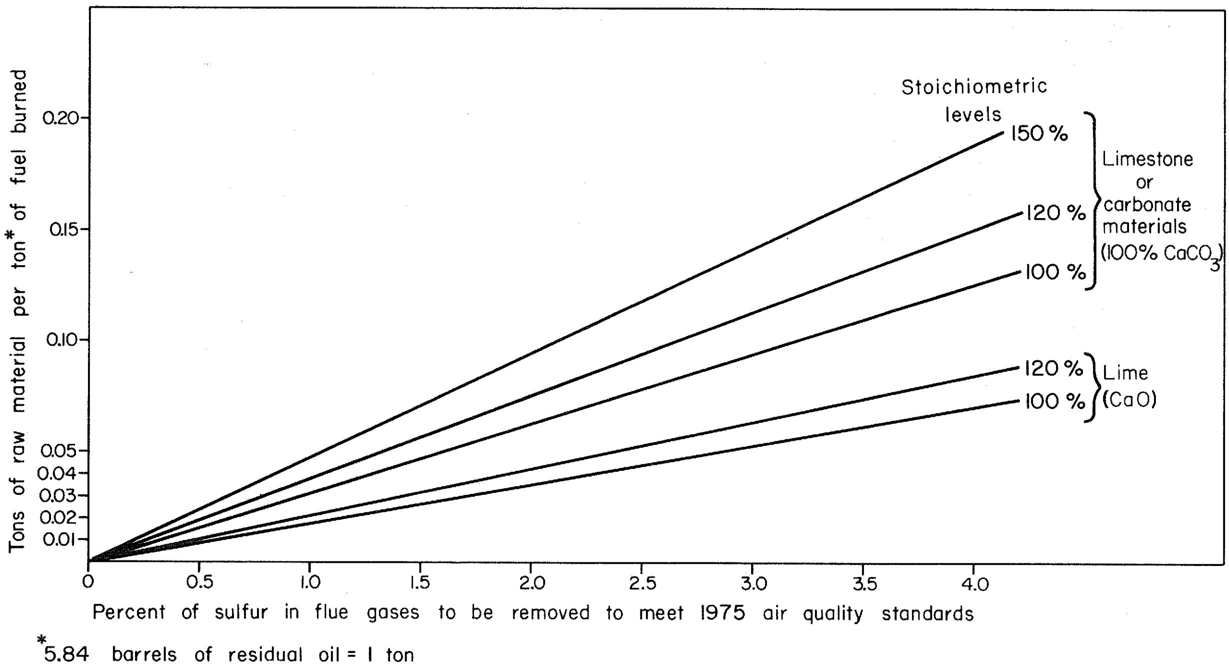


Fig. 1 - Amount of limestone or other carbonate materials or lime required to desulfurize electric utility plant fuel at various stoichiometric levels.

3.13 tons of limestone is needed to remove 1 ton of sulfur. The weight required increases to 3.75 tons of limestone, if higher stoichiometry of 120 percent is needed to achieve the desired level of cleaning. In most cases it has been found that a stoichiometric level as high as 150 percent, or 4.70 tons of limestone, was needed to meet the desired level of efficiency.

The relation between the percentage of sulfur to be removed from flue gases, the stoichiometry used, and the amount of lime, limestone, and other carbonate materials required are shown in figure 1. From these nomographs, the amount of lime, limestone, or any other carbonate materials required at various levels of stoichiometry to desulfurize 1 ton of fuel containing X amount of sulfur above the level allowed can be approximated. For example, if a utility plant is burning a fuel containing 4 percent sulfur and if air-quality standards allow emissions the equivalent of only 1 percent sulfur, three-fourths of the sulfur emitted in the flue gases will have to be removed. The amount of lime, limestone, or other carbonate materials the plant would require (fig. 1) would be 0.14 tons of limestone or other carbonate material (at 150 percent stoichiometry) or 0.065 tons of lime (at 120 percent stoichiometry) per ton of fuel burned.

For most of the systems now under consideration, definite specifications for reactant material are not available. At the plants where the Babcock and Wilcox limestone scrubbing system is being tested, it is reported that a finely ground limestone (< 325 mesh), which is high in calcium carbonate (> 95 percent $CaCO_3$) and low in magnesium carbonate (< 1 percent $MgCO_3$), is being used. Low magnesium carbonate content minimizes the formation of soluble magnesium sulfate and potential water pollution problems associated with its runoff from disposal sites (Gifford, 1972, p. 247). In the Chemico lime scrubber system, the use of commercial-grade slaked lime preferably containing over 95 percent CaO is recommended (J. F. Kane, Chemico, personal communication, 1974). For the Chemico lime system, which has been installed at the Duquesne Light Company's F. Phillips plants, a special type of lime, Thiosorbic Lime, prepared by the Dravo Corporation is being tested for scrubbing purposes (D. C. Slack, Dravo Corp., personal communication, 1974). Detailed information about this special lime has not yet been announced. The Combustion Engineering Company's scrubber system, which has been installed at the Paddy's Run Station of Louisville Gas and Electric Company, utilizes waste lime generated in the manufacture of carbide (Campbell and Ireland, 1972, p. 83).

As the amount of reactant needed varies with the stoichiometric level required in a given scrubber system, the chemical and physical properties of limes, limestones, and other carbonate rocks and their effects on the reactivity in scrubber systems are being studied at several institutions. It has been found that for a few particular limestones, the reactivity increases with decreasing particle size. Therefore, to achieve a high level of reactivity, a limestone should be ground to a particle size of < 325 mesh. The minor differences in chemical composition of relatively pure limestones have not been found to affect strongly a limestone's reactivity in a system. However, it has been observed that in the limestones tested mineral impurities such as dolomite, clays, feldspar, and quartz essentially remained chemically inert during the scrubbing process and did not contribute to the SO_2 removal reaction (Drehmel and Harvey, in press).

In carbonate materials, physical features, including grain size (crystallite size), pore volume, pore size, surface area, and sodium oxide trace content have been found to correlate with the materials' rate of dissolution. On the basis of these findings, Harvey, Frost, and Thomas (1973; 1974) have suggested that lake marl, chalk, shells, and carbonate-rich waste sludge could also be used for flue-gas desulfurization. Advantages of using these other carbonate materials instead of limestone are their ease of production and much lower grinding costs. Little information has been published about differences in reactivity of various types of lime in scrubber systems, but it is generally known that different types of quicklime have different reactivities.

POTENTIAL NEW DEMAND

The quantity of lime, limestone, or other carbonate material required for flue-gas desulfurization for a particular plant would, as discussed earlier, largely depend on the amount and the sulfur content of the fuel burned, the type of scrubber system utilized, and, most important of all, the level of sulfur oxides emissions permitted in a given air-quality region under 1975 EPA standards. By assuming 100 percent stoichiometry and using pertinent 1975 air-quality emission standards, we estimate that if *all* utilities that burned high-sulfur fuels in 1972 had been equipped with lime scrubbers, at least 10.4 million tons of lime would have been required to remove 6.0 million tons of sulfur to bring the plants into compliance with the 1975 standards. Even with these conservative estimates, the market for lime used for scrubbing purposes would have been equal to the *combined* current sales of the three largest markets for lime—the steel industry, the chemical industry (for alkalis), and water purification.

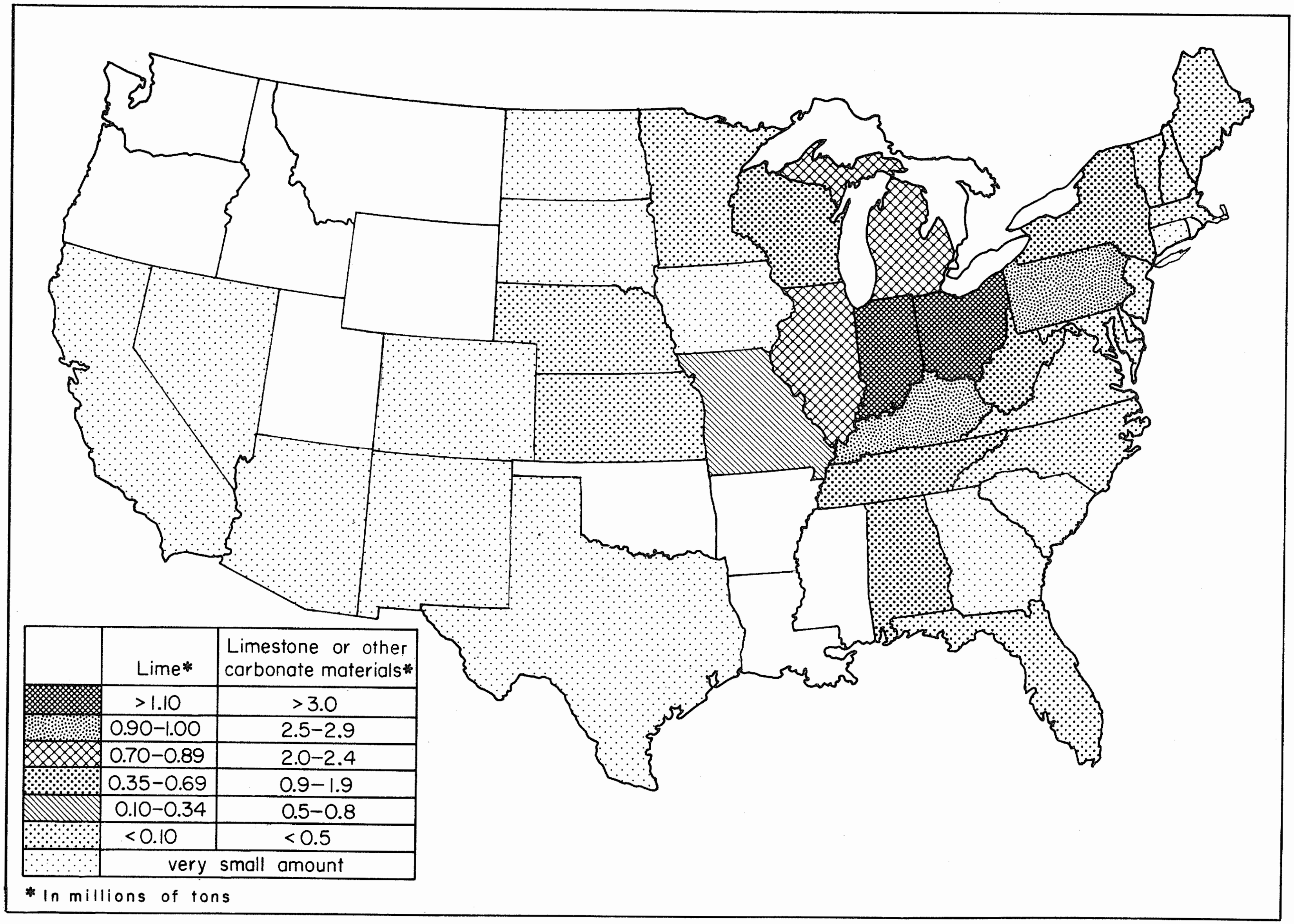


Fig. 2 - Potential market for lime, limestone, or other carbonate materials for scrubbing purposes, at 1.0 stoichiometry for lime and 1.5 stoichiometry for limestone and other carbonate materials.

On the other hand, if *all* utility plants that burned high-sulfur fuels in 1972 had been equipped with limestone scrubbers (with high-calcium limestone or other carbonate materials as the reactant), the reactant requirements would have been 18.7 million tons (equivalent to about 10 percent of the total high-calcium limestone and carbonate materials* produced in the United States in 1972). Since a higher stoichiometric level will be required in actual operations to bring many plants into compliance with 1975 standards, the amount of sulfur to be removed would be larger than the amount assumed in these calculations. Hence, it is possible that the demand for these reactants would be considerably higher than our estimates.

The estimated potential demand in 1972 for lime, limestone, or other carbonate materials for scrubber purposes, on a state by state basis, is shown in table 1 and figure 2. The states where the main potential demand for these reactants would have concentrated (fig. 2) are as follows:

	Market demand (percent)
Ohio	15.8
Indiana	14.0
Kentucky	9.5
Pennsylvania	9.4
Illinois	8.6
Michigan	8.5
Alabama	6.8
Tennessee	4:6
Sub-total	77.2
Other states (less than 4% per state)	22.8
TOTAL MARKET............	100.0

Because fossil fuel requirements for electric power generation have been projected (Jimeson, 1972, p. 345) to grow to 425 million tons of coal and 565 million barrels of oil by 1975 and to 500 million tons of coal and 640 million barrels of oil by 1980, the amount of sulfur emitted from the burning of these fuels is also expected to increase. On the basis of the 1972 ratio of fuel burned to sulfur emitted, we estimated that the amount of sulfur emitted from the burning of these fuels could amount to 10.8 million tons in 1975 and 12.7 million tons in 1980. As mentioned earlier, only 63 percent of the total sulfur emitted in power plant flue gases during 1972 would have required removal to meet 1975 EPA air-quality regulations. In 1980, if the same proportion of sulfur must be removed, the amount of sulfur requiring elimination will range between 7 and 8 million tons.

* Includes calcareous marls and shells.

An increase in the market demand for lime, limestone, and other carbonate materials that will actually develop between now and 1980 will largely be determined by (a) the number of wet scrubbers installed, (b) the type of reactant material selected for use in the installed systems, and (c) the amount of low-sulfur coal and low-sulfur oil available for utility use to replace or blend with high-sulfur fuels.

In the SOCTAP report (1973, p. 77-85), a forecast of the amount of electric generating capacity that will be outfitted with sulfur oxides (SO_x) control equipment during each of the years between 1975 and 1980 was estimated. According to the panel's more realistic ("one year delay scenario") forecast (fig. 3), the electric generating capacity so outfitted in 1975 would be 10,000 megawatts and would increase to 161,000 megawatts in 1980. In order to estimate the potential demand for lime, limestone, or other carbonate materials that could develop if this forecast proves true, we have converted this estimated capacity into coal equivalents (250,000 tons = 100,000 megawatts) and have made the following assumptions:

(a) that all of the sulfur oxides control equipment installed at utility plants will be of the wet scrubber type using lime, limestone, or other carbonate materials as the reactant;

(b) that the average sulfur content of the fuels burned will be 2.7 percent;

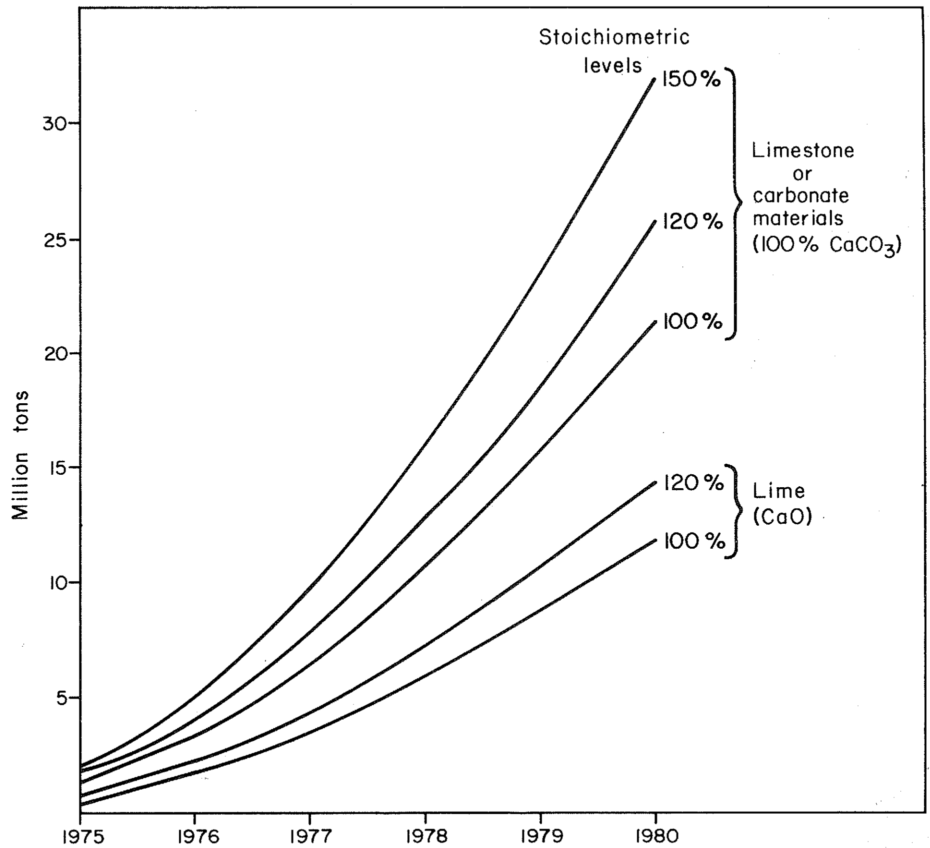
(c) that at least 63 percent of the total emitted sulfur will have to be removed to meet the EPA 1975 air-quality regulations.

The potential growth in the market for lime, limestone, or other carbonate materials that could develop between 1975 and 1980, if these assumptions prove correct, is shown in figure 3. According to figure 3, if all scrubbers installed by 1980 use limestone or other carbonate materials as the reactant, the demand for these materials could amount to 32.1 million tons. If, instead, wet scrubbers using lime are installed exclusively, then the potential demand for lime by 1980 could amount to 14.4 million tons.

In view of the energy crisis, the relatively slow progress in demonstrating successful systems, the waste disposal problems, the large capital requirements, and the time lag involved in the manufacture and installation of scrubber systems, it is very likely that the growth in potential market indicated in figure 3 for the period 1975-1980 may develop somewhat more slowly than the figures show.

POTENTIAL IMPACT ON INDUSTRY

Widespread installation of wet scrubbing systems at utility plants would have a definite impact on the lime and limestone industries. One way to evaluate this impact is to assume that the potential demand for lime, lime-



	1975	1976	1977	1978	1979	1980
Cumulative capacity (megawatts) of power plants equipped with SO_2 removal systems*	10,000	24,000	48,000	80,000	117,000	161,000
Coal equivalent (million tons)	25	60	120	200	293	402
Sulfur emitted† (thousand tons)	675	1,620	3,240	5,400	7,911	10,854
Sulfur to be removed‡ (thousand tons)	425	1,026	2,041	3,402	4,893	6,838
Percentage of total capacity of power plants equipped with SO_2 removal systems*	6		25			75

* Source: Sulfur Oxide Control Technology Assessment Panel (SOCTAP) Report, 1973.

† Assuming an average sulfur content of 2.7% in all fuels burned.

‡ Assuming that 63% of sulfur emitted must be removed in order to bring plants into compliance with 1975 air-quality standards.

Fig. 3 - Estimated growth in market for lime, limestone, and other carbonate materials for flue-gas scrubbing purposes between 1975 and 1980, based on the SOCTAP forecast of installation of sulfur oxides removal systems.

stone, and other carbonate materials for scrubbing purposes will not be considerably higher in 1980 than the demand shown in the estimates for 1972 (table 1).

If all utilities were to install limestone scrubbers using high-calcium limestone or other carbonate materials, the increase in demand for such materials (depending on the stoichiometric level achieved) would be between 18.7 and 28.0 million tons, or about 10 to 15 percent above the 1972 level of output of these materials. To meet this increase in demand would require the opening of the equivalent of 50 new high-calcium limestone quarries and/or other carbonate materials operations, each with an average capacity of 500,000 tons per year. The development of high-calcium limestone quarries and other carbonate materials operations would be determined largely by the availability of resources.

The location of electric power plants vis-a-vis counties in which limestone and/or dolomite has been produced in recent years is shown in figure 4.

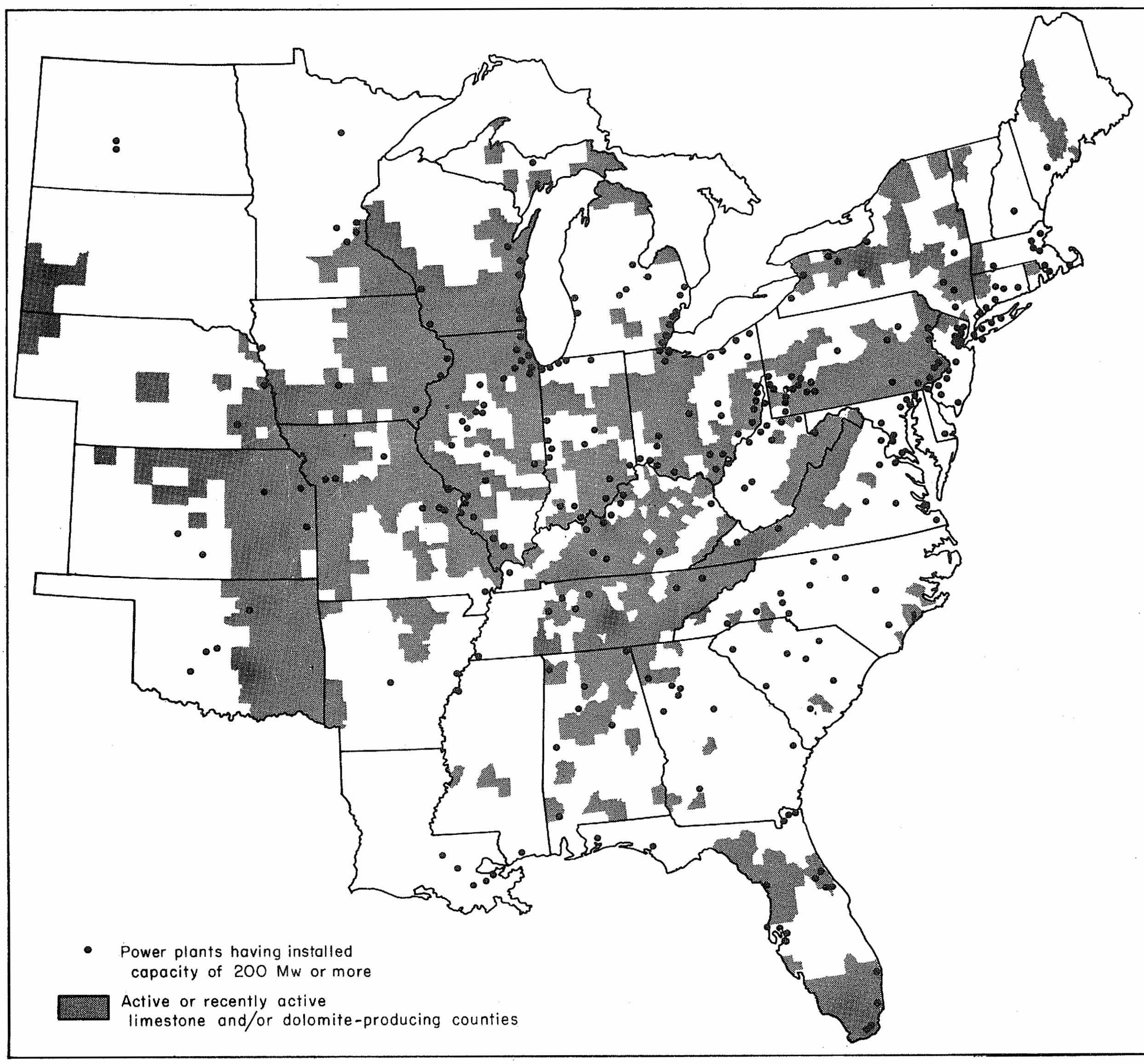


Fig. 4 - Location of power plants in relation to limestone and/or dolomite-producing counties.

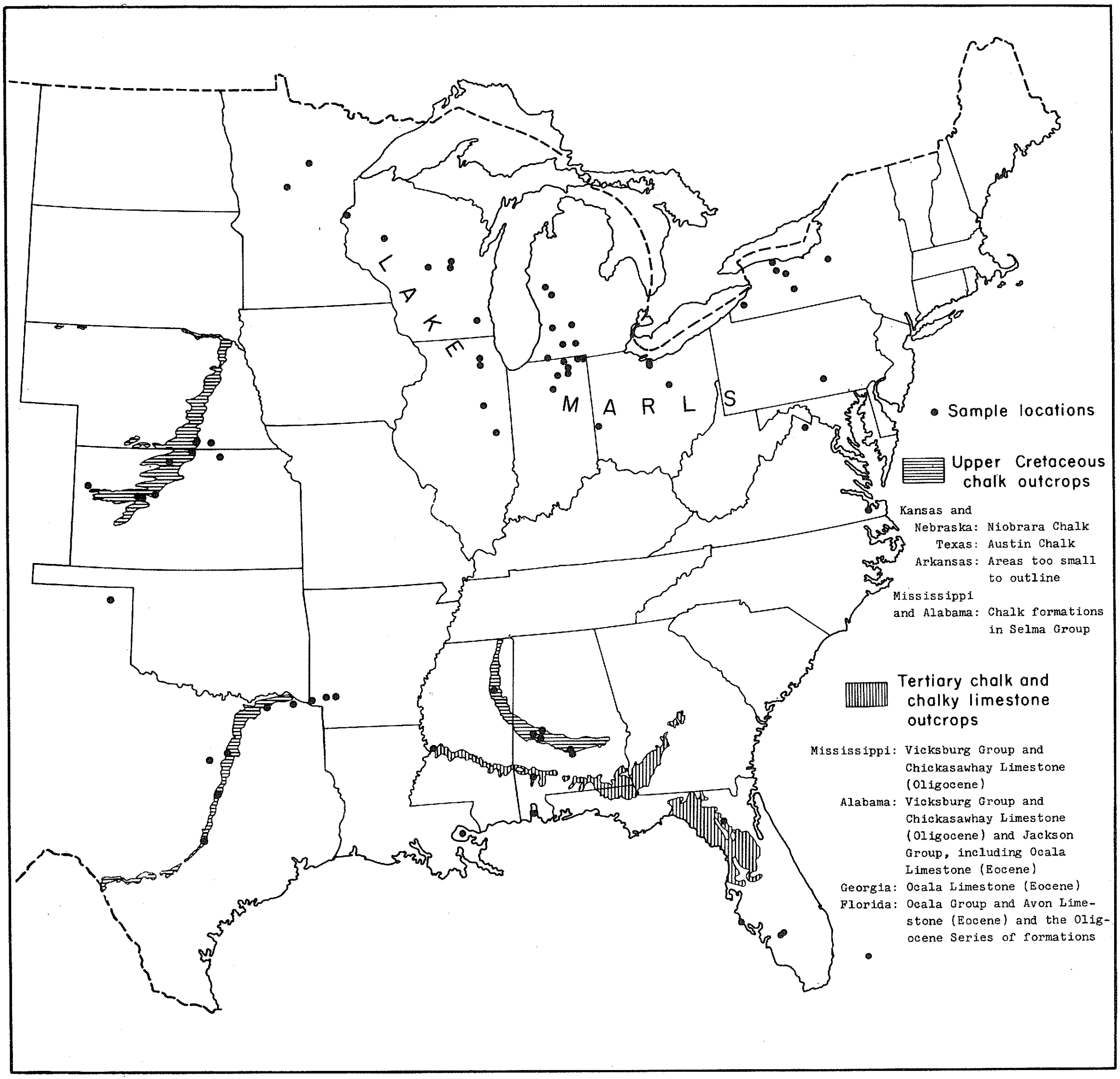


Fig. 5 - Location of samples of chalk, chalky linestone, and lake marls tested as potential sources of scrubbing material. (Modified from Harvey, Frost, and Thomas, 1973.)

Although most electric power plants are located near available limestone resources, some plants would depend on reactant materials from more distant sources. In those areas where high-calcium limestone deposits are not available, it may be possible to use other carbonate materials (fig. 5). Where both high-calcium limestone and other carbonate materials are available, the marls, chalks, and chalky limestones may be the more economical to use because they cost less to grind. In localities such as New England, where limestone or other carbonate rocks are unavailable in sufficient quantities, carbonate waste sludge from paper mills and other types of industrial plants could be used as the reactant in scrubbing systems. In spite of all these options, some power plants may need to bring in reactant materials from distant sources and pay the resulting high transportation costs. In these cases, it may prove more economical to use a regenerative (noncarbonate) sulfur oxide removal system when they have been proved feasible.

Although the tonnages of high-calcium limestone and other carbonate materials required to meet this potential market demand are quite large, their impact on the over-all stone industry is likely to be relatively small, because it already is operating at the level of 800 to 900 million tons per year. As a result, the scrubber market would add only 3 to 4 percent to the total demand.

If, on the other hand, because of economic and operating advantages (Burchard, 1972, p. 91-128; Slack, 1973) it is decided to choose lime as the reactant in *all* the wet scrubbers that are installed, the impact on the lime industry could be very significant. To meet this new demand for lime—a minimum of 10.4 million tons—the lime capacity in the United States would need to be significantly increased. This increase in capacity could require the construction of the equivalent of 50 new lime plants, each with an average capacity of 200,000 tons per year. To produce raw material (20 to 30 million tons of high-calcium limestone or other carbonate materials) needed for these plants, the equivalent of 50 quarries, each with an average capacity of 500,000 tons a year, would have to be developed. In other words, the potential increase in demand for limestone or other carbonate material would remain approximately the same even if lime scrubbers are chosen instead of limestone scrubbers.

The location of existing lime plants in relation to large utility plants with an installed capacity of 200 megawatts or more is shown in figure 6. In a number of cases the capacities at the existing lime plants (fig. 6) might be expanded to meet nearby utility plant needs. However, to serve the demand at numerous utility plants that are located at some distance from existing lime plants, it may be feasible to construct new lime facilities to meet new markets in those deficient areas. Several problems could influence how quickly the lime industry could respond to an upsurge in demand for lime for use in flue-gas scrubber systems. Currently, the industry is thought to be operating near capacity, and, therefore, construction of new plants would be necessary to meet the increased demand. The history of low return on investment may make it difficult to attract new capital to the industry. Moreover, the lime industry is energy-intensive. The current fuel shortages and rising fuel prices may put a special burden on any attempt by the industry to increase its capacity rapidly. Even if we assume that only 25 percent of this potential market for lime scrubbers actually develops within the next 7 years, the United States' demand for lime in 1980 would be increased by approximately 12 to 18 percent over the demand that existed in 1972. This could make flue-gas scrubbing the second largest single market for lime in 1980, exceeded only by the amount of lime used in basic oxygen steel furnaces.

Potential impact of flue-gas scrubber installations on the lime and limestone industry in various states is shown in table 2. It is evident that in several states the widespread installation of wet scrubbers, using lime, limestone, or other carbonate materials, will considerably increase the existing demand for these materials, and, as a result, some utilities in these states may have difficulties in securing sufficient raw materials for proposed scrubber systems.

TABLE 2—POTENTIAL IMPACT OF SCRUBBER INSTALLATIONS ON LIME/LIMESTONE INDUSTRY, BY STATES

State*	Lime sold or used in 1974† (short tons)	Potential scrubber lime market‡ (short tons)	Increase (%)	High-calcium limestone and other carbonate materials used or sold in 1972⁑ (short tons)	Potential scrubber limestone and other carbonate materials market‡ (short tons)	Increase (%)
Ohio	3,654,756	1,644,660	45.0	14,549,000	4,417,088	30.4
Indiana	1,533,904	1,464,240	95.5	5,502,000	3,932,532	71.5
Kentucky	485,458	994,203	204.8	6,170,000	2,670,145	43.3
Pennsylvania	2,261,634	978,509	43.3	22,211,000	2,627,995	11.9
Illinois	1,023,017	893,074	87.3	10,126,000	2,398,541	23.7
Michigan	1,654,096	886,926	53.6	30,610,000	2,382,030	7.8
Alabama	385,452	709,128	184.0	8,503,000	1,904,575	22.4
Tennessee	135,980	474,559	349.0	5,751,000	1,274,531	22.1
Wisconsin	152,399	387,885	254.5	1,357,000	1,041,750	76.8
West Virginia	343,517	372,113	108.3	5,591,000	999,389	17.9
New York	998,545	358,718	35.9	11,144,000	963,415	8.7
Missouri	208,275	321,490	154.3	16,989,000	863,432	5.1
Delaware and Maryland#	436,880	198,532	45.4	2,941,000	483,200	16.4
Minnesota	139,293	150,668	108.2	1,439,000	404,651	28.1
North Carolina	125,922	120,722	95.9	W	324,225	N.A.
New Hampshire and Vermont	W	99,062	N.A.	W	266,052	N.A.
Massachusetts	68,843	75,883	110.2	799,000	203,801	25.5
Virginia	149,694	57,944	38.7	9,597,000	155,621	1.62
Nebraska and Kansas	131,356	54,656	41.6	4,073,000	146,790	3.60
Other states	6,442,914	183,873	2.85	26,970,000	493,779	1.83
United States total	20,331,935	10,426,845	51.3	184,322,000	27,953,542	15.2

* Includes states where over 30,000 tons of sulfur may have to be treated by wet scrubbers to meet required emission standards.

† Source: U.S. Bureau of Mines, 1973a.

‡ Based on 1.0 stoichiometry for lime (CaO) and 1.5 stoichiometry for limestone ($CaCO_3$).

⁑ Estimated from U.S. Bureau of Mines Data (H. J. Drake, personal communication, 1974). Includes use of stone for such purposes as cement manufacture, lime manufacture, flux stone, chemicals, or glass.

Includes District of Columbia.

W - Data withheld to avoid disclosing individual company information; included with other states' total.

N.A. - Data not available.

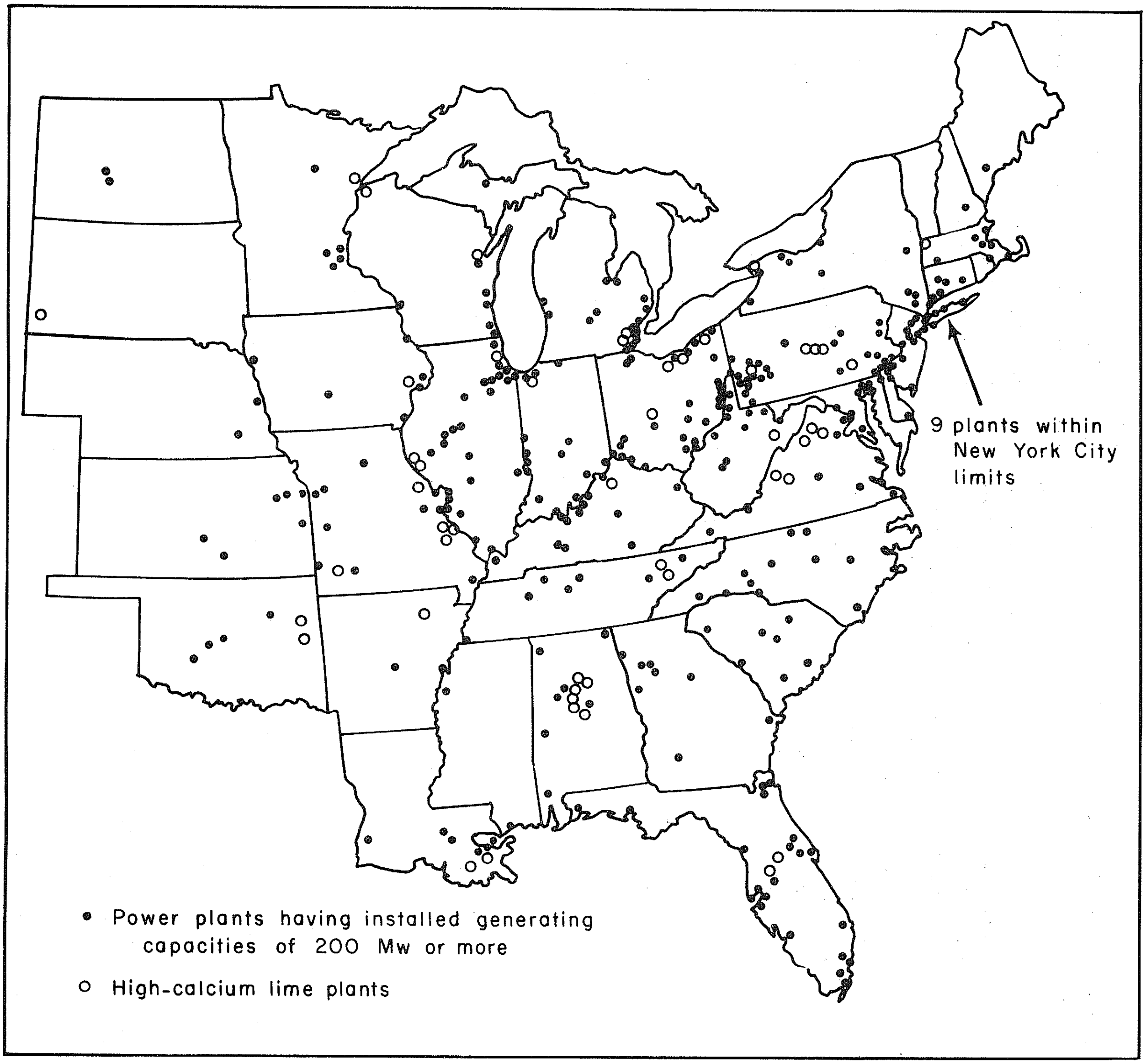


Fig. 6 - Location of high-calcium lime plants in relation to power plants. (Sources: K. A. Gutchick, Natl. Lime Assoc., personal communication, 1974; M. W. Kellogg Company, 1972.)

CONCLUSIONS

(1) The widespread installation of wet scrubber systems on steam-electric power plants would create a large market for lime, limestone, and other carbonate materials.

(2) Over 75 percent of this potential demand, if it is assumed that the quality of fuel burned at the electric utility plants does not considerably change by 1980, would be concentrated in the following eight states: Ohio (15.8 percent), Indiana (14.0 percent), Kentucky (9.5 percent), Pennsylvania (9.4 percent), Illinois (8.6 percent), Michigan (8.5 percent), Alabama (6.8 percent), and Tennessee (4.6 percent).

(3) If, as the SOCTAP report predicts, 161,000 megawatts of electrical capacity can be equipped with flue-gas scrubber systems by 1980, and if all utilities select wet scrubbers using limestone or carbonate materials as the reactant, then the new demand for these raw materials could amount to 32.1 million tons. If all of the utilities that install scrubber systems by 1980 select lime wet scrubbers, 14.4 million tons of lime would be needed.

(4) The impact of wet scrubber installations on the lime and limestone industry would be substantial. It is estimated that even at 1972 levels the installation of limestone scrubbers could have required up to 28.0 million tons of high-calcium limestone or other carbonate materials—equivalent to about 15 percent of the total high-calcium limestone and other carbonate materials produced in the United States in 1972. If, on the other hand, lime scrubbers were installed, the potential demand would have amounted to at least 10.4 million tons of lime—51.3 percent more than the amount produced in the United States during 1972.

(5) It is more likely that both lime and limestone scrubbers will be installed. The widespread use of lime scrubbers would not significantly change the quantity of limestone and other carbonate materials required because 2 tons of limestone or other carbonate materials would be required to produce 1 ton of lime. However, the widespread use of limestone scrubbers would reduce the demand for lime.

(6) The development of lime scrubber installations to any significant size would require additional lime capacity because there is little current excess capacity in the lime industry. Expansion of existing plants and/or construction of new plants may be affected by a number of problems, including low return on invested capital, rising fuel prices, time lags involved in the construction of new capacity (which may be as long as 2 to 3 years), and local shortages of high-calcium limestone or other carbonate material deposits that can be recovered economically. In light of these problems, some utility companies may have difficulties in securing sufficient raw materials for proposed scrubber systems.

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