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EPA-600/7-80-131
July 1980

Tennessee Valley
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Energy Demonstrations
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TVA EDT-115

Projection of 1985 Market Potential for FGD Byproduct Sulfur and Sulfuric Acid in the U.S.

Interagency Energy/Environment R&D Program Report

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EPA-600/7-80-131
TVA EDT-115
July 1980

Projection of 1985 Market Potential for FGD Byproduct Sulfur and Sulfuric Acid in the U.S.

by

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EPA Interagency Agreement No. D9-E721-BI
Program Element No. INE624A

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

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ABSTRACT

The 1985 U.S. FGD byproduct sulfur and sulfuric acid markets (sales to U.S. sulfuric acid plants) are projected to be 165,000 tons of sulfur from 11 power plants and 554,000 tons of acid from 6 power plants, with a combined benefit to the affected industries of $20 million. Improvements in FGD technology and increases in costs, particularly for fuel oil, enhanced the FGD sulfur market potential and decreased the FGD sulfuric acid potential, relative to previous projections. The 1979 revised NSPS, as well as the requirement, in many cases, for FGD waste treatment, improved the potential for both products. The revised NSPS, which restrict the use of low-sulfur coal as an option, greatly increase the FGD market potential for plants coming on-line after the mid-1980's. Fuel oil cost escalation is an important factor in reducing FGD sulfuric acid market potential, as are process modifications for chloride control. Limestone scrubbing with waste sludge ponding remains the economically predominant option. The limestone scrubbing advantage is decreased, however, when extensive waste treatment and landfill are required.

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EXECUTIVE SUMMARY

INTRODUCTION

Emission of sulfur oxides (SO_x) from coal-fired utility power plants, and wastes resulting from their control, have been subjected to increasingly stringent regulations during the past decade. The new-source performance standards (NSPS) promulgated by the U.S. Environmental Protection Agency (EPA) in 1971, the revised 1979 NSPS, and State implementation plans (SIP's) place restrictions of varying severity on SO_x emissions. In addition, the Resources Conservation and Recovery Act (RCRA) of 1976 has placed restrictions on disposal of wastes from processes used to meet the emission regulations.

The use of a clean (low-sulfur) fuel and flue gas desulfurization (FGD) are the strategies commonly used to meet SO_x emission regulations. FGD is for some time likely to be the method used to meet the 1979 revised NSPS, which require SO_x emission reduction regardless of the fuel sulfur content. Among the several FGD processes and their numerous variations, scrubbing with a slurry of ground limestone or lime is the most widely used. The large volume and intractable nature of the waste sludge have led increasingly to additional treatment. Dewatering and chemical treatment (fixation) to form a landfill material is becoming a common practice. Recovery processes in which the scrubber effluent is processed to recover the absorbent and produce a sulfur byproduct can also be used. They are usually more expensive than waste-producing processes, but the sale of the byproduct can partially alleviate the additional cost of the FGD process. Among several of the more promising recovery processes are the magnesia process and the Rockwell International aqueous carbonate process (ACP). In the magnesia process the SO_2 produced by regeneration of the MgO absorbent is converted to sulfuric acid. The ACP is unique among recovery processes in that it uses spray dryer technology. The spent absorbent is collected as a dry material. Residual fly ash is also removed in the process, eliminating the need of a separate high-efficiency fly ash removal system. The salts are reduced using coal as the reductant and further processed to regenerated absorbent and sulfur.

Utilities selecting an SO_x emission control strategy are faced with a variety of complex decisions in which the economics of the possible strategies are important factors. The relative economics of clean fuel, waste-producing FGD, and recovery FGD strategies are seldom clearly evident. FGD costs vary widely depending on power plant and fuel conditions. The economics of recovery processes are affected by the marketability and price of the byproduct. In addition, the comparisons must be based on conditions that will exist several years in the future. This byproduct marketing projection is an attempt to integrate the many factors affecting SOx emission control strategies into a coherent computer model that projects the future potential for marketing FGD byproducts as an economical strategy.

The byproduct marketing system consists of various programs, models, and data bases used to make cost comparisons of SO_x emission control strategies. A power plant data base contains boiler, fuel, and emission regulation data on existing and planned U.S. utility power plants. For recovery processes transportation and sulfur-sulfuric acid industry data bases are used to determine the marketability and price of the FGD byproduct. The system determines FGD costs of a recovery process and a waste-producing process for each power plant. As an alternative strategy, the use of clean fuel at specified price premiums (alternative clean fuel levels--ACFL's) is also included. The cost difference between the recovery process and the lowest cost alternative strategy (the incremental cost) is used to determine the byproduct revenue required to make the two strategies economically equivalent. Marketability is determined in a linear programming model that determines transportation costs and selling prices at the U.S. sulfuric acid plants. The model integrates the results to maximize the combined savings to the utility and sulfuric acid industries. The power plants for which markets are established become projected FGD byproduct marketing candidates.

This 1985 projection contains several revisions representing economic, technical, and regulatory conditions that promise to have important effects on the economics of SO_x emission control. The design of the FGD processes has been revised to include recent technology, including chloride removal in a separate step for process and corrosion control in the magnesia process and sludge fixation and landfill as a disposal option in the limestone scrubbing process. The use of the ACP for sulfur production has also altered FGD cost relationships. In addition, inclusion of the 1979 revised NSPS and projected 1985 costs for fuels have had important effects.

RESULTS

Power Plants

For 1985, 124 eligible boilers at 83 power plants are included in the projection; 74 scheduled to be on stream by 1979 and 50 scheduled for startup in 1980-1985. The number of eligible boilers is lower than the number in previous projections because of a trend toward earlier strategy selection (boilers for which a strategy precluding byproduct production has been announced are excluded). Of the 50 eligible boilers (out of a total of 170 boilers) scheduled for 1980-1985 startup, 21 are scheduled for 1985. The increase in 1985 is the result of the arbitrary assignment of the 1979 revised NSPS to boilers starting up in 1985, thus excluding clean fuel alone as an SO_x emission control strategy. The 124 boilers are projected to represent a maximum potential production of 2.5 million tons of sulfur or 7.6 million tons of sulfuric acid.

Computer Model Runs for 1985

ACFL values of $0.70, $1.00, and $1.25/MBtu were used for the clean fuel premium. The FGD byproduct alternatives used were sulfur production and sulfuric acid production with and without chloride removal included in the magnesia process. These were compared with limestone scrubbing with ponding and limestone scrubbing with fixation and landfill.

Sulfuric Acid Plants and Smelters

In 1985, 87 sulfur-burning acid plants consuming 10 million tons of sulfur and producing 30.5 million tons of sulfuric acid are projected to be in operation, 75 of which are in the Eastern United States. Smelter sulfuric acid production is projected to be about 1 million tons in 1985. The eastern acid plants represent the market for FGD byproducts. Smelter sulfuric acid represents competition for FGD byproducts.

FGD Byproduct Sulfur

For the comparison using limestone scrubbing with ponding, there are four potential candidates for FGD sulfur production. All four are 1985 plants subject to the 1979 NSPS and excluded in this study from the clean fuel option, which would have been more economical at the $0.70/MBtu ACFL. Their potential production is about 63,000 tons/year. When limestone scrubbing with fixation and landfill is the waste-producing alternative, the number of potential candidates for sulfur production increases to 12, 8 of which are 1985 plants subject to the 1979 NSPS. Their potential production is 215,000 tons/year.

For the comparison using limestone scrubbing with ponding, markets for the entire production of the four potential candidates for FGD sulfur production are projected. For the comparison using limestone scrubbing with fixation and landfill, markets for 11 of the 12 candidates are projected. The remaining plant does not have markets for which the incremental cost plus transportation costs do not exceed the acid plant's sulfur cost from other suppliers. Under the most favorable conditions the potential market is 165,000 tons, representing about 1.6% of the total sulfur market.

FGD Sulfuric Acid

For the comparisons using the magnesia process with chloride removal, there were no power plants selected as potential candidates for sulfuric acid production. There are four potential candidates using the magnesia process without chloride removal in comparison with limestone scrubbing with ponding. Two of the four potential candidates for sulfuric acid production would have been selected for clean fuel at the $0.70/MBtu ACFL but are subject to the 1979 revised NSPS. The four plants have a combined potential production of 300,000 tons/year. For the comparison using the fixation and landfill disposal option, 13 plants with a combined production of 2 million tons/year are projected as potential candidates for sulfuric acid production at the $0.70/MBtu ACFL. Of these, six plants are subject to the 1979 revised NSPS. At the higher ACFL's of $1.00 and $1.25 there are 15 additional plants, making a total of 28 plants with a combined potential production of 4 million tons/year.

For the comparison using limestone scrubbing with ponding, markets are projected for two of the four plants. For the comparison using fixation and landfill, markets are projected for 4 of the 13 plants at the $0.70/MBtu ACFL and for 8 of the 28 plants at the higher ACFL's. Under the most favorable conditions, the potential market is 868,000 tons, or about 3% of the total sulfuric market.

Integrated Sulfur-Sulfuric Acid Results

When the sulfur and sulfuric acid projections were combined (Table S-1) several conflicts were resolved by choice of the most economical option for power plants projected for both sulfur and sulfuric acid production. There was little difficulty in assigning alternative markets for sulfur but few alternative sulfuric acid markets were found. The FGD sulfur market is projected at about 165,000 tons/year from 11 power plants. The FGD sulfuric acid market is projected at about 554,000 tons/year from six power plants. The combined potential market is about 2% of the total sulfuric acid market and 1.6% of the total sulfur market. The combined benefits for the electric utility and acid industries are about $10 million each for sulfur and sulfuric acid, for a total benefit of about $20 million in 1985.

DISCUSSION OF RESULTS

About four-fifths of the power plants projected for sulfur marketing are scheduled for startup in 1985 and are therefore defined in this study as new plants subject to the 1979 revised NSPS. The preponderance of plants scheduled for startup in 1985 projected for sulfur marketing is partly the effect of the ACP design, which includes provision for final fly ash removal. Separate fly ash electrostatic precipitators (ESP's) are not needed and the capital and operating costs are applied as a cost credit, whereas in pre-1985 plants they are assumed to be in existence and only operating costs are credited. Another factor favoring plants scheduled for 1985 startup is the 1979 revised NSPS, which restrict the use of clean fuel as a compliance strategy.

The total sulfur removed also has an effect on strategy selection. In comparisons with limestone scrubbing and with acid production, sulfur production is favored at lower sulfur removal levels.

FGD sulfur marketing potential increased dramatically in this projection, whereas FGD sulfuric acid marketing potential declined in

TABLE S-1. PRODUCTION AND DISTRIBUTION FGD

SULFUR AND FGD SULFURIC ACID

Power plant location	Tons	Consumer location	Tons
Sulfur			
Staten Island County, NY	7,000	Newark, NJ	7,000
Martin County, FL	28,000	Pierce, FL	28,000
Washington County, FL	20,000	Dothan, AL	7,000
		White Springs, FL	13,000
Sherburne County, MN	8,000	Dubuque, IA	8,000
Westmoreland County, PA	24,000	North Bend, OH	8,000
		Copley, OH	16,000
Montgomery County, MD	10,000	Baltimore, MD	10,000
Shelby County, AL	12,000	Tuscaloosa, AL	12,000
Williamson County, IL	11,000	East St. Louis, IL	11,000
Rusk County, TX	9,000	Fort Worth, TX	9,000
Henderson County, TX	7,000	Fort Worth, TX	7,000
Armstrong County, PA	29,000	Cleveland, OH	29,000
	165,000[a]		165,000[a]
Sulfuric Acid			
Person County, NC	103,000	Richmond, VA	36,000
		Wilmington, NC	26,000
		Norfolk, VA	41,000
Jasper County, IL	122,000	Tuscola, IL	122,000
Pike County, IN	51,000	Indianapolis, IN	51,000
Northhampton County, PA	182,000	Deepwater, NJ	95,000
		Edison, NJ	74,000
		Gibbstown, NJ	13,000
Delaware County, PA	53,000	Gibbstown, NJ	53,000
Titus County, TX	43,000	Shreveport, LA	43,000
	554,000[b]		554,000[b]

a. The potential revenue/savings to both industries combined is projected to be as much as $10,000,000 for an approximate average of $60/short ton of sulfur.

b. The potential revenue/savings to both industries combined is projected to be as much as $10,500,000 for an approximate average of $19/short ton of sulfuric acid.

comparison with previous projections. These changes are partially the result of the process design changes already discussed. Another very important factor, however, is the price escalation for fuel oil. This is a severe disadvantage to the magnesia process in competition with the limestone scrubbing process, which uses little fuel, and the ACP, which uses coal. In addition, sulfuric acid plants converting to purchase of FGD sulfuric acid are likely to revert to oil-fired boilers for steam production, a further disproportionate deterioration of the avoidable production costs. Transportation costs are also more important to the relatively high-volume sulfuric acid than to sulfur. The combined effects result in the reduced competitiveness of FGD sulfuric acid production vis-a-vis other compliance strategies.

The increased attractiveness of FGD sulfur production as a compliance strategy can be attributed in part to the use of the ACP. Arguably, it is an unproven process, subject to the same technological cost increases seen in this projection in the magnesia process and in FGD processes in general. Other relative cost advantages of the ACP over FGD byproduct processes using wet scrubbing, such as reduced or eliminated flue gas reheating and simultaneous fly ash and sulfur salt collection, are unlikely to be greatly affected.

The inclusion of fixation and landfill as a disposal option for the limestone scrubbing process improved the competitiveness of FGD byproduct processes. Limestone scrubbing remains the most economical FGD strategy in the majority of cases, however.

CONCLUSIONS

The potential for FGD sulfur marketing is increased over previous projections whereas the FGD sulfuric acid marketing is decreased. Technological and economic revisions to the byproduct marketing system both contribute to these trends. Application of the 1979 revised NSPS and more costly waste disposal methods for limestone scrubbing enhance the potential for both FGD sulfur and FGD sulfuric acid.

The addition of chloride scrubbing to the magnesia process, coupled with cost escalations (especially fuel oil), eliminated the FGD sulfuric acid market shown in previous projections. Processes that can use coal as the FGD byproduct energy source will have increasing economic advantages over those which use fuel oil or natural gas.

In the ACP, simultaneous removal of SO_x and the remaining fly ash in the same ESP presents an advantage for new (1985) plants when compared with alternative FGD processes which require separate high-efficiency fly ash removal.

The number of power plant candidates for FGD byproduct marketing will increase with the application of the revised NSPS. It is estimated that this will affect boilers with startup dates in and after 1985. The majority of boilers coming on stream before 1985 have selected a clean fuel compliance strategy that will not generally be an option for future plants covered by the revised NSPS.

The potential for FGD sulfur and sulfuric acid byproduct marketing is extremely limited when limestone scrubbing with slurry ponding is a feasible alternative. Potential for production and marketing of FGD byproducts increases when fixation and landfill are required.

Escalation of transportation costs will affect the marketing range of byproduct sulfur and, especially, byproduct sulfuric acid. Rail rate increases will also affect the marketing range of competitive sources of sulfur and sulfuric acid, however.

Nonvoluntary sulfur production is becoming a more important factor in the marketing economics of FGD byproduct sulfur. The effect of nonvoluntary sources on price stability in the sulfur market is difficult to project.

RECOMMENDATIONS

An FGD sulfur and sulfuric production and marketing forecast should be projected for 1990 or beyond. This projection to 1985 reflects only the beginning of the effects of the 1979 revised NSPS. Also, the lead time required to analyze and implement FGD strategies necessitates a more extended time frame.

Technical and economic developments in spray dryer FGD recovery processes should be followed closely. Also, developments allowing the use of coal for FGD byproduct processes should be incorporated into future studies.

Future studies should include projections of fertilizer industry requirements to expand the demand system beyond existing and announced sulfuric acid plants.

Projected demand for sulfur for new uses, such as partial or full replacement of asphalt in paving, should be included.

The supply of refinery recovered sulfur should be projected because of the potential increase in use of high-sulfur crude oil.

A specific byproduct marketing study should be made for the approximately 100 power units designated by the Department of Energy for conversion from oil to coal. Many of these plants are in high-population areas where disposal of wastes, if FGD were required, would be difficult.

PROJECTION OF 1985 MARKET POTENTIAL FOR FGD BYPRODUCT SULFUR AND SULFURIC ACID IN THE UNITED STATES

INTRODUCTION

Sulfur oxides (SO_x) are the major gaseous pollutants currently subject to environmental regulations in the flue gas of fossil-fuel-fired boilers. Coals, which may contain up to several percent sulfur, are the predominate contributors to these emissions, and the electric utility industry with its many coal-fired plants is an important source. Increasing electrical use and increasing emphasis on coal as the preferred fossil fuel for utility use are expected to increase the quantity of coal consumed in electricity generation for many years (Griffith and Clarke, 1979). The use of coal, however, is particularly sensitive to the increasingly strict environmental regulations governing the emission of SO_x to the atmosphere and disposal of wastes produced by control of SO_x emissions. In addition to a proliferation of State and local regulations, the new-source performance standards (NSPS) promulgated by the U.S. Environmental Protection Agency (EPA) in 1971 (Federal Register, 1971), the revised NSPS promulgated in 1979 (Federal Register, 1979a), and solid-waste regulations stemming from the Resources Conservation and Recovery Act (RCRA) of 1977 (Federal Register, 1979b) are particularly important to electric utilities. The NSPS restrict plants upon which construction began after 1971 but before September 1979 to a maximum emission of 1.2 lb of SO_x per million Btu of fuel. The revised NSPS, applying to plants upon which construction began, or begins, after September 1978, retain the same maximum and, in addition, require a reduction of 70% to 90% in sulfur emissions regardless of the sulfur in the untreated fuel. RCRA, though not fully defined by promulgated regulations, will restrict and possibly eliminate some methods of waste disposal.

Numerous strategies, existing and potential, can be applied to the control of fossil-fuel power plant SO_x emissions. Some are applicable to all emission regulations, some are applicable to only the less stringent regulations, and some may be circumscribed by RCRA regulations. The most widely used SO_x control strategy is flue gas desulfurization (FGD) using wet or dry scrubbing techniques. In the past 10 years a flourishing FGD industry has developed, offering a proliferating variety of FGD processes. Another strategy is the use of a clean (low-sulfur) fuel. There is, however, a limited supply of low-sulfur coal, and this strategy will be restricted by the requirements of the 1979 revised

NSPS. Other approaches such as coal gasification and fluidized-bed combustion are not advanced to the level of technology likely to make them a widely used SO_x control strategy in the next 5 years. Within the time span of this marketing projection, the use of clean fuel to meet some non-Federal and 1971 NSPS regulations and FGD to meet any applicable regulation are likely to be the overwhelmingly predominate SO_x control strategies of the electric utility industry.

The most widely used FGD processes employ wet scrubbing using an alkali solution or slurry to produce a waste slurry of calcium-sulfur salts. Finely ground limestone and hydrated lime have been the most widely used absorbents, a use projected to continue well into the 1980's (Smith et al., 1979). In the simplest method of disposal, the waste is pumped to a diked pond where it settles to a semisolid sludge. The large volume of unstable waste presents a number of practical and environmental disposal problems, however, particularly in view of RCRA regulations (Duvel et al., 1979).

Increasingly, utilities using limestone scrubbing are turning to dewatering, stabilization, and fixation of the waste. In the more extreme of these treatments, the FGD waste is transformed to a solid suitable for landfill disposal. This usually involves mechanical dewatering of the FGD sludge, blending it with dry fly ash (stabilization), and adding a chemical additive to promote cementlike reactions (fixation). The degree to which waste treatments between untreated ponding and full chemical fixation will be widely employed is problematical, although some form of waste treatment is increasingly used and several utilities use full fixation and landfill processes (Santhanam et al., 1979).

As an alternative to waste-producing FGD processes, recovery processes in which the scrubber reaction products are processed to regenerate the absorbent and produce a commercially useful sulfur byproduct have also proven attractive. Although sharing a contemporaneous development with waste-producing processes, the more complex, and usually more expensive, recovery processes have not been as widely used by electric utilities. Recovery processes are, however, in commercial use or under construction and several are in advanced stages of development. The products most widely produced or envisioned for these processes are elemental sulfur and sulfuric acid, both extensively used basic industrial chemicals.

Utilities faced with the selection of an SO_x emission control strategy thus have a variety of complex decisions. In the most general sense, the choice evolves to the use of a clean fuel or to the use of one of several types of FGD processes and is governed, within the constrictions of the applicable regulations, by economic considerations. The most economical choice is seldom clearly evident, however. FGD costs vary widely, even for the same process, depending on many power plant and fuel conditions. The selection of a recovery process also depends in important measure on the marketability of the byproduct whose revenue reduces the operating cost of the process. The selection is dependent not only on conditions at the particular power plant, but upon selections at other power plants as well as conditions within other supportive or competing industries. An economically sound decision to use a recovery process based on a certain market could be invalidated by the same decision elsewhere. Marketing decisions are also influenced by the costs of transportation and competition from other producers.

Further complicating these decisions is the necessity of projecting to anticipated conditions several years in the future. The necessity of securing regulatory agency approval and extended construction periods combine to extend the effects of current decisions into a more distant and less certain future.

This byproduct marketing projection is an attempt to correlate these many and diverse factors into a coherent model, a decision-making tool which defines the future potential for marketing of FGD byproducts as an economical option for compliance with SO_x emission regulations. Perhaps equally important, it also identifies trends and the factors responsible, through which future and correlative analyses may be more efficiently applied.

For the past decade, the Tennessee Valley Authority (TVA), in conjunction with EPA and others, has conducted design and economic evaluations of FGD systems to develop a systematic analysis of FGD costs applicable to both general and specific conditions in the electric utility industry. The byproduct marketing analysis system has been an important part of these studies. From a limited computerized production-transportation-marketing program (Waitzman et al., 1973), the methodology was expanded and extended to other products (Corrigan, 1974; Bucy et al., 1976), and finally to a comprehensive analysis of potential sulfuric acid production and marketing by U.S. electric utilities (Bucy et al., 1978). The byproduct marketing system used in the 1978 projection was made available for general use, in whole or in part, through publication of a users manual (Anders, 1979).

In recognition of the rapidly changing FGD technology and the need to extend such projections as far as possible into the future, the byproduct marketing system has been continually modified to represent current projections of technological and economic conditions. An update extending the 1978 projection to 1983 and incorporating byproduct sulfur in addition to sulfuric acid was published in 1979 (O'Brien and Anders).

In addition to extending the project to 1985, this study incorporates the effects of several technological and legislative developments and recent economic trends. The limestone scrubbing FGD process used for the waste-producing option has been expanded to include both untreated ponding and fixation and landfill as waste disposal options. The magnesia process used for the sulfuric acid production option has been modified to include recent technical developments. In particular, provisions for prescrubbing to remove chlorides from the flue gas before SO_2 absorption have been added. Operating experience with closed FGD systems, in which the absorber liquid is recycled, has revealed that the chloride content of flue gases produced by many coals is sufficient to cause intolerable accumulations of chlorides in the recycled liquid. High levels of dissolved chlorides cause severe corrosion and interfere with the SO_2 absorption and absorbent regeneration reactions. For the sulfur production option, the Rockwell International aqueous carbonate process (ACP) is used in recognition of rapidly developing FGD spray dryer technology. Spray dryer FGD processes include final fly ash collection as an intrinsic part of the process. Final fly ash removal can be included in this function, eliminating the need for separate high-efficiency fly ash collection facilities. The effects of the revised NSPS, which restrict clean fuel as a compliance option for boilers coming on-line at the end of the projection period, have also been incorporated into the system. More recent cost data, particularly those representing recent projections of fuel costs, have also been included.

A full description of the processes used in the byproduct marketing system (except for the ACP) and the design and economic premises upon which they are based have been published in recent TVA and EPA studies (Anderson et al., 1980). A description of the byproduct marketing computer system and a brief description of the FGD processes are given in Appendix A. [A more detailed description of the computer system is contained in the users manual (Anders, 1979).] A description of computer system revisions and additions specific to the 1985 projection is given in Appendix B.

RESULTS

The results from the 1985 projection show that changing economic, technological, and regulatory conditions have had significant effects on the feasibility of producing and marketing FGD sulfur and sulfuric acid. Previous model results, projected for 1978 and 1983, were based only on the following regulatory compliance alternatives:

- Use of clean fuel
- Limestone scrubbing with sludge ponding
- Magnesia scrubbing (under the existing technology without chloride removal) with byproduct sulfuric acid production

For the 1985 projection these alternatives are no longer adequate. First, the revised NSPS will restrict the use of clean fuel as a compliance method for boilers coming on stream as early as 1985. This factor alone could double the potential candidates for FGD byproduct marketing. Less than half of the boilers scheduled for 1980 through 1984 are committed to FGD--the majority have selected clean fuel.

In addition to the more stringent SO_x removal standards, the revised NSPS call for a much more rigorous fly ash emission standard. The 1985 results show that the most attractive compliance strategy may be one that combines both SO_x and final fly ash removal in one step as is common in dry scrubbing. The advantage of simultaneous removal is seen primarily in new boilers (1985) wherein the capital investment for an electrostatic precipitator (ESP) solely for the high-efficiency fly ash removal requirements can be avoided.

Another significant factor observed in the preparation of the 1985 projection is the increased use of sludge fixation and landfill rather than direct sludge ponding. Although the 1985 projection shows very little potential for byproduct marketing when sludge ponding is feasible, the marketing opportunities are increased when sludge fixation and landfill are required for the limestone process.

Finally, escalation of capital and operating costs (particularly No. 6 fuel oil) and the addition of chloride removal provisions (i.e., a prescrubber) in the magnesia process virtually eliminated the production and marketing of sulfuric acid under conditions projected for 1985. Only when the chloride removal requirements were eliminated from the magnesia scrubbing process did production and marketing of byproduct sulfuric acid reemerge as a feasible power plant alternative.

POTENTIAL 1985 SUPPLY AND DEMAND

Power Plants

For 1985, 124 boilers at 83 power plant sites are projected to be potential FGD byproduct marketing candidates. Of these 124 boilers, 74 were scheduled to be on stream by the end of 1979 and 50 are scheduled for 1980 through 1985. The number of boilers projected to be marketing candidates in 1985 is much smaller than in previous model runs for 1978 and 1983. Not only have more existing boilers selected a complying strategy that precludes byproduct marketing, the compliance strategy for new boilers is being selected and implemented concurrently with boiler construction, thereby precluding the possibility of byproduct marketing much earlier than in the past. As an example of strategy selection for new boilers, 170 boilers are scheduled for startup in 1980-1985. Of these 170, 69 have selected a complying fuel, 21 have selected scrubbing, 50 have not committed to a specific strategy to the extent that byproduct marketing is necessarily precluded, 6 are less than the minimum size considered feasible for byproduct marketing (less than 100 MW), and there were not enough data available on 24 boilers to project byproduct marketing economics. Of the 50 new boilers that are potential byproduct marketing candidates, 2 are scheduled for 1980, 2 for 1981, 9 for 1982, 6 for 1983, 10 for 1984, and 21 for 1985. The increased number of new boilers in 1985 projected to be potential marketing candidates results from the assumption that they must meet the revised NSPS and cannot use a complying fuel alone (i.e., they must use FGD).

Based on the compliance analysis results, SO_2 emissions at the 83 plant sites will have to be reduced by a maximum of about 5,000,000 tons to meet regulatory levels. This represents a maximum power plant FGD production potential of about 2,500,000 tons of sulfur or about 7,600,000 tons of sulfuric acid.

Sulfuric Acid Plants

In 1985, 87 sulfur-burning acid plants are projected to be in operation. These plants are projected to require about 10,000,000 tons of sulfur and produce about 30,500,000 tons of sulfuric acid. They represent the maximum 1985 demand projected for FGD byproduct sulfur and sulfuric acid. Of these plants, 75 are in the 37 Eastern States. They represent about 93% of the demand and are projected to require 9,400,000 tons of sulfur to produce 28,500,000 tons of acid. The remaining 12 plants are in the 11 Western States. They represent about 7% of the demand and are projected to require 600,000 tons of sulfur to produce about 2,000,000 tons of acid. Appendix B contains details on sulfur sources and costs and sulfuric acid avoidable production costs.

Sulfuric acid plants using smelter off-gas are acid producers of necessity and represent market competition for power plant acid. Although the current market is assumed to be generally balanced between supply and demand any production increases by smelters could reduce the potential market for FGD sulfur and sulfuric acid. This possibility was provided for with a projected 10% increase by 1985 in smelter sulfuric acid production as follows: Eastern U.S. smelters, 275,000 tons; Canadian smelters, 200,000 tons; and Western U.S. smelters, 450,000 tons. These projected quantities represent not only direct competition for FGD sulfuric acid, but also indirect competition for the equivalent FGD sulfur because sulfur is not required for the smelter acid production.

Model Runs for the 1985 Projection

Model changes for 1985 resulted in a much more complex analysis than those of the previous projections. The changes were the addition of limestone scrubbing with waste fixation and landfill as an additional compliance alternative, inclusion of the revised NSPS that were assumed to eliminate the use of a complying fuel for new plants, the provision for chloride removal in the magnesia process, the inclusion of power plant FGD sulfur producers in the model for the first time, and the inclusion of Canadian recovered sulfur as direct competition with Port Sulphur Frasch sulfur and power plant FGD sulfur. Three different cost premiums for complying fuels (alternative clean fuel level--ACFL) were used, but this option does not apply to plants required to meet the revised NSPS; their only alternative is one of the FGD options. Of the 83 plants considered as potential marketing candidates in 1985, 20 are projected to come under the revised NSPS and therefore were assumed to require an FGD option. The remaining 63 plants are projected to have the option of a complying fuel and therefore the ACFL would affect the compliance strategy selection at these plants.

The ACFL's used for 1985 were $0.70, $1.00, and $1.25/MBtu. The various scrubbing alternatives that were compared at each of these levels are:

- Sulfur production versus limestone scrubbing with sludge ponding
- Sulfur production versus limestone scrubbing with sludge fixation and landfill
- Sulfuric acid production with chloride removal versus limestone scrubbing with sludge ponding
- Sulfuric acid production with chloride removal versus limestone scrubbing with sludge fixation and landfill
- Sulfuric acid production without chloride removal versus limestone scrubbing with sludge ponding
- Sulfuric acid production without chloride removal versus limestone scrubbing with sludge fixation and landfill

FGD BYPRODUCT SULFUR

Previous projections for 1978 and 1983 FGD sulfur production were based on the Wellman-Lord/Allied Chemical natural-gas reduction process. The ACP is used in the 1985 projection for byproduct sulfur production (see Appendix B). The ACP as used for this projection is illustrative of two important FGD process advantages. First, coal is used as the energy source instead of oil or natural gas, and second, both SO_x and final fly ash removal are combined. Combining the removal of SO_x and final fly ash eliminates the costs of a separate ESP solely for fly ash removal in new installations. In this study 85%-efficient cyclones are used for initial fly ash removal.

Two constraints were placed on the selection of potential power plant sulfur marketing candidates. The first constraint was a minimum production capacity of 5000 tons of sulfur per year. The second constraint was that no plant with an incremental sulfur production cost greater than $100 was considered. These values are considered to represent the limits of economically feasible marketing potential, and they allow the costs of using the computerized model to be significantly reduced.

Sulfur Production Versus Limestone Scrubbing with Sludge Ponding

Candidates at the $0.70, $1.00, and $1.25 ACFL--

The model results, in terms of the number of power plants using a compliance strategy based on a comparison of sulfur production and limestone scrubbing with sludge ponding at each of the three ACFL's, in $/MBtu premium for complying fuel, are:

Compliance strategy	Number of plants		
	$0.70 ACFL	$1.00 ACFL	$1.25 ACFL
Complying fuel	26	2	2
Limestone scrubbing with sludge ponding	53	77	77
Possible sulfur production	4	4	4

Only four plants projected to select a scrubbing strategy at the $0.70 ACFL have a projected sulfur production capacity of at least 5000 tons/year and an incremental cost of less than $100/ton. All four of these plants would have selected a complying fuel at the $0.70 ACFL, but they are projected to have to comply with revised NSPS and therefore do not have the option of using a complying fuel alone. Even though the number of plants projected to select an FGD strategy increases significantly at the higher ACFL's, there are no additional sulfur production candidates. The four marketing candidates have a combined sulfur production potential of about 63,000 tons/year.

Projected market potential--

The model results indicate potential markets for the total production of the four marketing candidates. The projected distribution for these plants is shown in Table 1. The final results from the comparison of sulfur production with sludge ponding at each of the ACFL's are:

Compliance strategy	Number of plants		
	$0.70 ACFL	$1.00 ACFL	$1.25 ACFL
Complying fuel	26	2	2
Limestone scrubbing with sludge ponding	53	77	77
Sulfur production	4	4	4

TABLE 1. SULFUR PRODUCTION VERSUS LIMESTONE

SCRUBBING WITH SLUDGE PONDING

($0.70, $1.00, and $1.25 ACFL, in $/MBtu premium for complying fuel; all plants shown are scheduled for 1985)

Power plant location	Tons of sulfur	Consumer location	Tons of sulfur
Washington County, FL	20,000	Dothan, AL	7,000
		White Springs, FL	13,000
Westmoreland County, PA	24,000	North Bend, OH	8,000
		Copley, OH	16,000
Montgomery County, MD	10,000	Baltimore, MD	10,000
Rusk County, TX	9,000	Fort Worth, TX	9,000
	63,000		63,000

Sulfur Production Versus Limestone Scrubbing with Sludge Fixation and Landfill

Candidates at the $0.70, $1.00, and $1.25 ACFL--

The comparison of sulfur production and limestone scrubbing with sludge fixation and landfill instead of sludge ponding shows distinctly improved prospects for marketing. The results at each of the three ACFL's, in $/MBtu premium for complying fuel, are:

Compliance strategy	Number of plants		
	$0.70 ACFL	$1.00 ACFL	$1.25 ACFL
Complying fuel	51	9	2
Limestone scrubbing with sludge fixation and landfill	20	62	69
Possible sulfur production	12	12	12

Twelve plants projected to select an FGD strategy at the $0.70 ACFL have a projected sulfur production capacity of at least 5000 tons/year and an incremental cost of less than $100/ton. All of the plants that were candidates based on the comparison with sludge ponding described earlier are also candidates when compared with sludge fixation and landfill. Four of the 12 plants have projected scrubbing costs less than the $0.70 ACFL and 8 plants are projected to have to comply with revised NSPS and have no complying fuel option under the assumptions of this study. As in the comparison with sludge ponding, the number of plants selecting an FGD strategy increases significantly at the $1.00 and $1.25 ACFL but there are no additional candidates for sulfur production. The 12 marketing candidates have a combined sulfur production potential of about 215,000 tons/year.

Projected market potential--

The model results show potential markets for 11 of the 12 candidates. The single excluded plant was considered because FGD was the only option, but the incremental cost plus shipping cost to potential consumers is projected to exceed the consumers cost from other suppliers. The projected market distribution for the 11 plants is shown in Table 2. All of the plants with marketing potential based on the comparison with sludge ponding described earlier also have marketing potential based on the comparison with sludge fixation and landfill, and the projected distribution for these four plants is unaffected by the competition from the seven additional plants. The final results from the comparison of sulfur production and limestone scrubbing with sludge fixation and landfill at each of the ACFL's, in $/MBtu premium for complying fuel, are:

Compliance strategy	Number of plants		
	$0.70 ACFL	$1.00 ACFL	$1.25 ACFL
Complying fuel	51	9	2
Limestone scrubbing with sludge fixation and landfill	21	63	70
Sulfur production	11	11	11

FGD BYPRODUCT SULFURIC ACID

Two variations of the magnesia process were used for FGD sulfuric acid production in the 1985 projection. Separate process variations were used because of questions related to chloride control requirements for various coal characteristics and operating conditions (see Appendix B).

As in the case of the sulfur models, two constraints were placed on the selection of potential power plant sulfuric acid marketing candidates. The first constraint was a minimum production capacity of 40,000 tons of sulfuric acid per year. The second constraint was that no plant was considered if the incremental sulfuric acid production cost exceeded $40/ton. These values were selected because FGD acid production installa-

TABLE 2. SULFUR PRODUCTION VERSUS LIMESTONE SCRUBBING WITH SLUDGE FIXATION AND LANDFILL ($0.70, $1.00, and $1.25 ACFL)

Power plant location	Tons of sulfur	Consumer location	Tons of sulfur
Staten Island County, NY	7,000	Newark, NJ	7,000
Martin County, FL[a]	28,000	Pierce, FL	28,000
Washington County, FL[a]	20,000	Dothan, AL	7,000
		White Springs, FL	13,000
Sherburne County, MN	8,000	Indianapolis, IN[b]	8,000
Westmoreland County, PA[a]	24,000	North Bend, OH[c]	8,000
		Copley, OH[c]	16,000
Montgomery County, MD[a]	10,000	Baltimore, MD	10,000
Shelby County, AL	12,000	Tuscaloosa, AL	12,000
Williamson County, IL[a,d]	11,000	East St. Louis, IL	5,000
		Indianapolis, IN[b]	6,000
Rusk County, TX[a]	9,000	Fort Worth, TX	9,000
Henderson County, TX	7,000	Fort Worth, TX	7,000
Armstrong County, PA[a,e]	29,000	Cleveland, OH[c]	29,000
	165,000		165,000

a. Scrubbing costs were greater than $0.70 ACFL, but 1985 boilers cannot comply by using clean fuel alone.
b. Also a potential purchaser of power plant acid, which is projected to result in greater savings.
c. Also a potential purchaser of power plant acid, but purchasing sulfur is projected to result in greater savings.
d. Scrubbing costs were greater than $1.00 ACFL, but 1985 boilers cannot comply by using clean fuel alone.
e. Also a potential producer and marketer of acid, but sulfur production is projected to result in greater revenues.

tions of less than 40,000 tons/year are not projected to be economically feasible and there are no markets projected for sulfuric acid at prices above $40/ton regardless of location.

Effects of No. 6 Fuel Oil Price Escalation

Of particular significance to the magnesia process are the effects of fuel oil price escalation. Table 3 illustrates the effects of various annual percentage price escalation rates for No. 6 fuel oil and the equivalent unit price increases in No. 6 fuel oil, natural gas, and coal. Based on a late 1979 wholesale price of $0.60/gallon for No. 6 fuel oil, even a 5% per year escalation amounts to an increase of over $0.20/gallon by late 1985. The energy-equivalent increase for natural gas is $1.37/kft^3 and for coal is over $30.00/ton. At a 15% per year No. 6 fuel oil price escalation rate (the approximate rate projected through 1985), the price of coal would have to increase by over $116/ton (over three times the current price) to equal the No. 6 fuel oil price escalation on an energy-equivalent basis.

TABLE 3. NO. 6 FUEL OIL ESCALATION COMPARED WITH ENERGY EQUIVALENT INCREASES IN NATURAL GAS AND COAL

No. 6 fuel oil annual price escalation rate, %	Equivalent price increase, 1979-1985		
	No. 6 fuel oil, $/gal (149,000 Btu/gal)	Natural gas, $/kft^3 (1,000 Btu/ft^3)	Coal, $/ton (11,000 Btu/lb)
5	0.20	1.37	30.13
10	0.46	3.11	68.35
15	0.79	5.29	116.32
20	1.19	8.00	175.94
25	1.69	11.33	249.36

The magnesia FGD byproduct sulfuric acid process, which uses No. 6 fuel oil for drying and calcining the magnesium sulfite, is particularly sensitive to the projected escalation. An increase of $0.01/gallon increases the FGD sulfuric acid production cost by $0.55/ton. This relationship in terms of percentage annual price escalation from late 1979 through 1985 is shown in Figure 1. At the projected 15% annual price escalation, the No. 6 fuel oil price increase equals a sulfuric acid production cost increase of over $43/ton. The net effect on incremental sulfuric acid costs is reduced somewhat by escalation of costs for limestone scrubbing with fixation and landfill, but their projected escalation rate is not nearly as high as that for No. 6 fuel oil. Obviously, the economics of this process would be improved substantially by substitution of coal for the fuel oil.

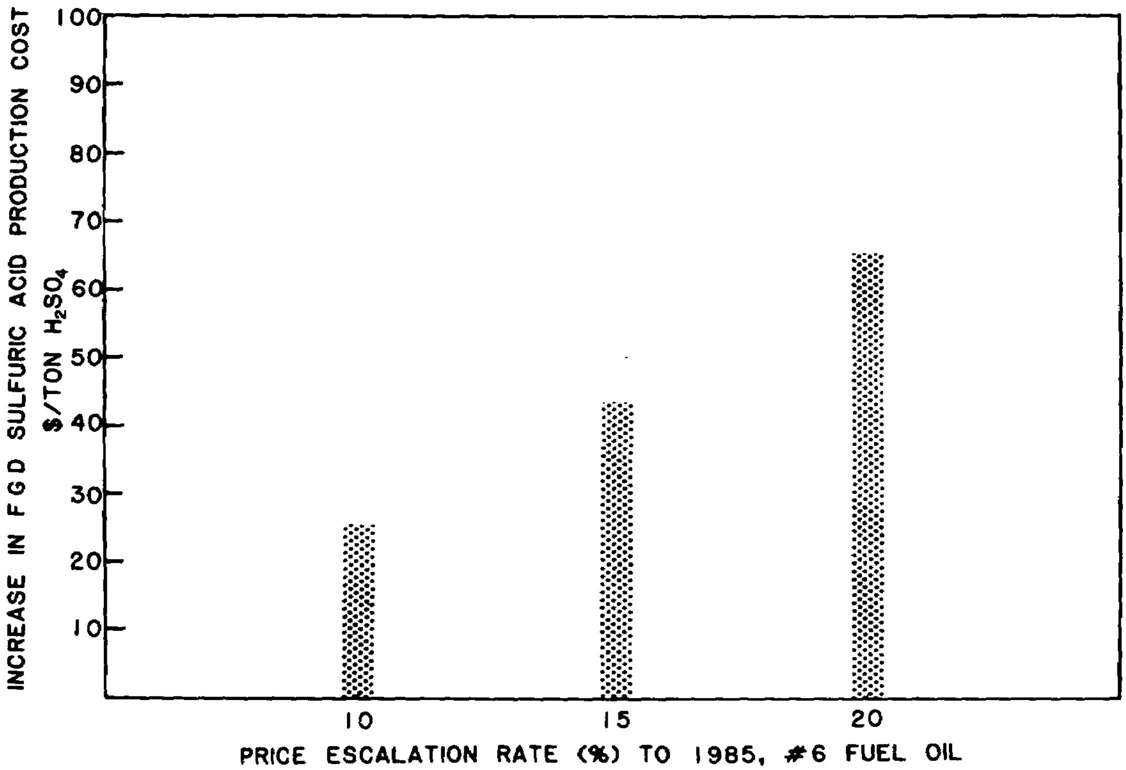

Figure 1. Increase in FGD sulfuric acid production cost with No. 6 fuel oil annual price escalation.

The avoidable production costs for the existing sulfuric acid producers who represent the potential market for FGD byproduct sulfuric acid are also affected by increases in fuel oil costs. In order to shut down their sulfur-burning plants and purchase FGD sulfuric acid they must replace the byproduct steam generated in their sulfuric acid production process. This involves installing a fossil-fuel-fired boiler. Frequently the overall capital and operating costs for coal-fired boilers (including coal receiving and handling, ash disposal, etc.) are prohibitive for this type of chemical plant operation, which often has limited industrial land available. Also, natural gas may not be available. These plants would likely select an oil-fired boiler. The value of the steam credit from acid production therefore increases with fuel oil price escalation. This relationship between the steam credit and No. 6 fuel oil price escalation is shown in Figure 2. At the 15% annual price increase rate used for fuel oil in this study, the avoidable production cost decreases, through the increase in steam credit, by over $11/ton of sulfuric acid. At the 10% annual price increase the steam credit decreases the avoidable production cost by almost $7/ton of sulfuric acid. The 20% escalation rate would result in an avoidable product cost decrease of more than $17/ton of sulfuric acid.

Both the increase in FGD byproduct production cost and decrease in avoidable production cost for the existing producers reduce the potential

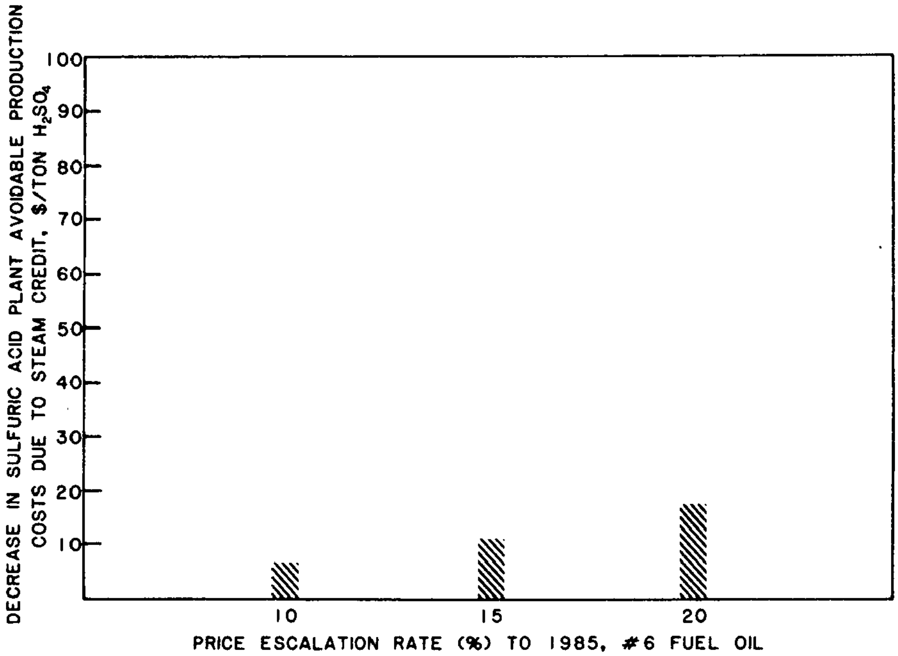

Figure 2. Decrease in sulfuric acid plant avoidable production cost due to steam credit with No. 6 fuel oil annual price escalation.

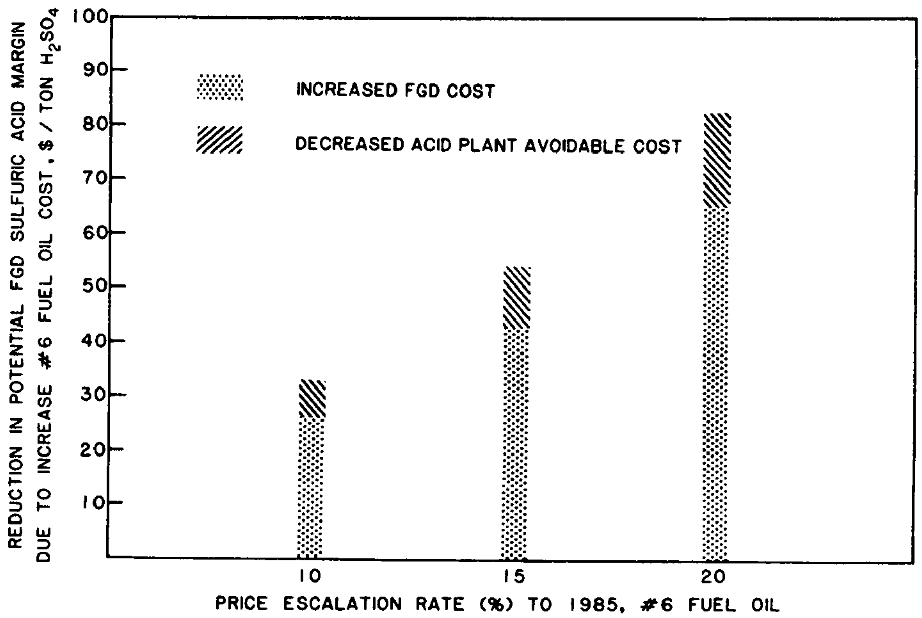

Figure 3. Reduction in potential FGD sulfuric acid margin with No. 6 fuel oil annual price escalation.

margin for sales of FGD sulfuric acid. Their additive effect on potential FGD sulfuric acid sales margin is shown in Figure 3. At the projected 15% escalation rate for No. 6 fuel oil, the combined effect of increased FGD production costs and decreased existing acid producer avoidable production costs results in a reduction of the potential FGD sulfuric acid sales margin of about $54/ton.

Chloride Removal Required

There are no potential candidates for sulfuric acid marketing based on the magnesia process variation with provisions for chloride scrubbing. The provision for chloride scrubbing increases acid production costs to the point that, in comparison with limestone scrubbing with sludge ponding, there are no plants with a projected incremental production cost of less than $90/ton. In comparison with limestone scrubbing with sludge fixation and landfill there is some improvement, but even then there are no plants with a projected incremental cost of less than $60/ton.

Chloride Removal Not Required

When provisions for chloride removal are not included in the magnesia process (as in previous projections for 1978 and 1983), potential candidates for sulfuric acid marketing reappear as in the earlier projections. However, as in the case of sulfur production, the projected potential for marketing in comparison with limestone scrubbing with sludge ponding is much less than when the comparison is made with limestone scrubbing with sludge fixation and landfill.

Sulfuric Acid Production Versus Limestone Scrubbing with Sludge Ponding

Candidates at $0.70, $1.00, and $1.25 ACFL--

The model results from the comparison of sulfuric acid production with limestone scrubbing with sludge ponding at each of the ACFL's, in $/MBtu premium for complying fuel, are:

Compliance strategy	Number of plants		
	$0.70 ACFL	$1.00 ACFL	$1.25 ACFL
Complying fuel	26	2	2
Limestone scrubbing with sludge ponding	53	77	77
Possible acid production	4	4	4

Only four plants projected to select an FGD strategy at the $0.70 ACFL have a projected sulfuric acid production capacity of at least 40,000 tons/year and an incremental cost of less than $40/ton. Two of these plants would select a complying fuel at the $0.70 ACFL, but they are projected to have to comply with revised NSPS and, therefore, do not have the option of a complying fuel alone. As in the other comparisons, the number of plants projected to select an FGD strategy increases at the higher ACFL values, but there are no additional acid production candidates. The four marketing candidates have a combined sulfuric acid production potential of about 300,000 tons/year.

Projected market potential--

The model results show potential markets for only two of the four candidates. Both of the excluded plants were considered because FGD was their only option, but delivered costs to potential customers are projected to be greater than the customers' own avoidable production cost. The projected market distribution is shown in Table 4. The final results from the comparison of sulfuric acid production and limestone scrubbing with sludge ponding at each of the ACFL's, in $/MBtu premium for complying fuel, are:

Compliance strategy	Number of plants		
	$0.70 ACFL	$1.00 ACFL	$1.25 ACFL
Complying fuel	26	2	2
Limestone scrubbing with sludge ponding	55	79	79
Acid production	2	2	2

TABLE 4. ACID PRODUCTION (NO CHLORIDE SCRUBBING) VERSUS

LIMESTONE SCRUBBING WITH SLUDGE PONDING

($0.70, $1.00, and $1.25 ACFL)

Power plant location	Tons of acid	Consumer location	Tons of acid
Person County, NC	103,000	Richmond, VA	36,000
		Wilmington, NC	26,000
		Norfolk, VA	41,000
Titus County, TX	43,000	Shreveport, LA	43,000
	146,000		146,000

Acid Production Versus Limestone Scrubbing with Sludge Fixation and Landfill

Candidates at the $0.70, $1.00, and $1.25 ACFL--

The model results from the comparison of sulfuric acid production and limestone scrubbing with sludge fixation and landfill at each of the ACFL's, in $/MBtu premium for complying fuel, are:

Compliance strategy	Number of plants		
	$0.70 ACFL	$1.00 ACFL	$1.25 ACFL
Complying fuel	48	9	2
Limestone scrubbing with sludge fixation and landfill	22	46	53
Possible sulfuric acid production	13	28	28

Thirteen plants projected to select a possible sulfuric acid production strategy at the $0.70 ACFL have a projected production capacity of at least 40,000 tons/year and an incremental cost of less than $40/ton. These 13 plants include all of the plants that are marketing candidates in the comparison with limestone scrubbing with sludge ponding. Seven of the 13 plants have projected scrubbing costs less than the $0.70 ACFL and 6 plants are projected to have to comply with the revised NSPS and, therefore, have no option for a complying fuel alone. Unlike the comparisons described previously, in this case there is a significant increase in the number of potential marketing candidates at the $1.00 and $1.25 ACFL. There is no change between the $1.00 and $1.25 ACFL, but at these levels there are 15 additional candidates (over the $0.70 ACFL) for a total of 28. Because all candidates required to comply with the revised NSPS were selected at the $0.70 ACFL, the additional candidates are projected to select an FGD strategy only at the higher ACFL's. The candidates at the $0.70 ACFL have a combined sulfuric acid production potential of about 2,000,000 tons/year, and at the $1.00 and $1.25 ACFL the projected production potential increases to almost 4,000,000 tons/year of sulfuric acid.

Projected market potential--

The model results show potential markets for 4 of the 13 candidates at the $0.70 ACFL and for 8 of the 28 candidates at the $1.00 and $1.25 ACFL. The projected market distribution is shown in Tables 5 and 6. The two plants with marketing potential based on the comparison with limestone scrubbing with sludge ponding also have marketing potential in comparison with limestone scrubbing with sludge fixation and landfill. The projected distribution for these two plants is not affected by the competition from the additional plants. The final results from the comparison of sulfuric acid production with sludge fixation and landfill at each of the ACFL's, in $/MBtu premium for complying fuel, are:

Compliance strategy	Number of plants		
	$0.70 ACFL	$1.00 ACFL	$1.25 ACFL
Complying fuel	48	9	2
Sludge stabilization and landfill	31	66	73
Acid production	4	8	8

TABLE 6. ACID PRODUCTION (NO CHLORIDE SCRUBBING) VERSUS LIMESTONE SCRUBBING WITH SLUDGE FIXATION AND LANDFILL ($1.00 and $1.25 ACFL)

Power plant location	Tons of acid	Consumer location	Tons of acid
Person County, NC	103,000	Richmond, VA	36,000
		Wilmington, NC	26,000
		Norfolk, VA	41,000
Jasper County, IL	122,000	Tuscola, IL	122,000
Pike County, IN	51,000	Indianapolis, IN[a]	51,000
Jefferson County, OH	228,000	North Bend, OH[b]	90,000
		Cleveland, OH[b]	91,000
		Copley, OH[b]	47,000
Northhampton County, PA	182,000	Deepwater, NJ	95,000
		Edison, NJ	74,000
		Gibbstown, NJ	13,000
Delaware County, PA	53,000	Gibbstown, NJ	53,000
Titus County, TX	43,000	Shreveport, LA	43,000
Armstrong County, PA[c]	86,000	Cleveland, OH	86,000
	868,000		868,000

a. Also a potential purchaser of power plant sulfur, but purchasing acid is projected to result in greater savings.
b. Also a potential purchaser of power plant sulfur, which is projected to result in greater savings.
c. Also a potential producer and marketer of sulfur, which is projected to result in greater revenues.

TABLE 5. ACID PRODUCTION (NO CHLORIDE SCRUBBING) VERSUS

LIMESTONE SCRUBBING WITH SLUDGE FIXATION AND LANDFILL

($0.70 ACFL)

Power plant location	Tons of acid	Consumer location	Tons of acid
Person County, NC	103,000	Richmond, VA	36,000
		Wilmington, NC	26,000
		Norfolk, VA	41,000
Northhampton County, PA	182,000	Deepwater, NJ	90,000
		Edison, NJ	26,000
		Gibbstown, NJ	66,000
Titus County, TX	43,000	Shreveport, LA	43,000
Armstrong County, PA[a,b]	86,000	Cleveland, OH[c]	86,000
	414,000		414,000

a. Scrubbing costs were greater than $0.70 ACFL, but 1985 boilers cannot comply by using clean fuel alone.

b. Also a potential producer and marketer of sulfur, which is projected to result in greater revenues.

c. Also a potential purchaser of power plant sulfur, which is projected to result in greater savings.

INTEGRATED ANALYSIS

The computerized model results just described were developed independently for each ACFL and scrubbing process (waste disposal versus marketable byproducts). Although the higher ACFL values carry the implication of increased market competition from other power plants, this is not directly addressed by the model and the competitive marketing aspects of FGD sulfur in comparison with FGD sulfuric acid are not addressed at all. An integrated analysis is therefore required to develop a collective projection of byproduct marketing potential for 1985. The collective projection based on combined results requires several additional considerations because the purpose of this projection is to identify as many plants as possible where the production of marketable FGD byproducts might be economically feasible.

All of the power plants that are potential sulfur or sulfuric acid marketing candidates in comparison with limestone scrubbing with sludge ponding are also potential candidates in comparison with limestone scrubbing with sludge fixation and landfill. Therefore, limiting the final projection to the latter comparison does not exclude any potential candidates. Likewise, limiting the final projection to the highest ACFL does not exclude any potential candidates. A power plant is not a reasonable marketing candidate if the potential market would be easily lost because other plants that are more competitive at a higher ACFL also select a marketing strategy. The final step in developing the combined marketing projection is a comparison of the potential for marketing FGD sulfur with the potential for marketing FGD sulfuric acid.

Combined Sulfur and Sulfuric Acid Results

The sulfur and sulfuric acid results presented earlier contain several conflicts between sulfur marketing and sulfuric acid marketing. These conflicts must be resolved to prepare a combined projection, otherwise, a single power plant might be projected to market both sulfur and sulfuric acid and a single acid plant might be projected in one case to purchase FGD sulfur and continue production and at the same time in another case to shut down and purchase FGD sulfuric acid.

The first conflict involves a power plant that is projected to be a potential marketer of both sulfur and sulfuric acid. The problem is somewhat simplified because the same acid plant is projected to be the consumer of either FGD sulfur or FGD sulfuric acid from this power plant. Based on the power plant's incremental production costs and the acid plant's delivered sulfur and avoidable production costs (including sulfur costs from other sources) FGD sulfur is projected to result in greater potential combined power plant and acid plant benefits. The selection of sulfur instead of sulfuric acid for this power plant reduces the potential 1985 FGD sulfuric acid production by about 85,000 tons/year.

The remaining marketing conflicts involve acid plants that are projected to be potential purchasers of both FGD sulfur and FGD sulfuric acid. These conflicts are more difficult to resolve than the previous case because the potential power plant sulfur suppliers are not the same as the potential power plant sulfuric acid suppliers. No matter which byproduct is selected for a given power plant and acid plant combination, the result is the effective elimination of that market for the other byproduct. Although in the case of sulfur the power plant production can equal any percentage of the acid plant requirements, this is not true for sulfuric acid. Model results indicate that even when the purchase of FGD acid alone is considered, acid plants cannot economically reduce production by arbitrary percentages. These percentages are limited by design (turndown ratio), the number of trains, and steam-generation requirements. Because of this, circumstances would have to be very unusual for a sulfuric acid plant to purchase significant amounts of both FGD sulfur and FGD sulfuric acid.

Four acid plants are projected to be potential purchasers of both FGD sulfur and FGD sulfuric acid. Based on power plant incremental production costs and acid plant delivered sulfur and avoidable production costs (including sulfur costs from other sources), the purchase of FGD sulfuric acid is projected to result in a greater potential benefit for one of the acid plants and the corresponding power plant supplier; FGD sulfur is projected to be a better choice in the other cases. The purchase of FGD sulfuric acid in the first case would eliminate the market for about 8000 tons/year of sulfur from another power plant. The purchase of sulfur in the remaining three cases would eliminate the market for about 228,000 tons/year of sulfuric acid from another power plant.

Additional model runs were required to determine if the two power plants projected to lose their potential market for one byproduct to the power plant producers of the other byproduct could find another market. The results indicate that the FGD sulfur producer would have no problem finding alternative markets that would be only slightly less profitable, but this is not expected to be the case for the potential FGD sulfuric acid producer because no alternative markets are indicated.

The combined projection for competitive FGD sulfur and sulfuric acid market distribution is shown in Table 7. The FGD sulfur marketing potential is projected to be about 165,000 tons/year from 11 plants and the FGD sulfuric acid marketing potential is projected to be just over 500,000 tons/year from 6 plants. The use of FGD sulfur instead of sulfur from current sources could result in a combined benefit for the utility and sulfuric acid industry of as much as $10,000,000 in 1985. Potential benefits from the use of FGD sulfuric acid are projected to be just slightly higher at $10,500,000 in 1985.

Strategy Selection Summary

The combined compliance strategy and potential byproduct marketing projection for 1985 is:

Compliance strategy	Number of plants
Complying fuel	2
Limestone scrubbing	64
Projected sulfur marketer	11
Projected sulfuric acid marketer	6
Total	83

As shown, 17 power plants out of the 83 considered are projected to be potential candidates for byproduct marketing in 1985. Of the 17, 11 are projected to be potential sulfur marketers with an estimated production of up to 165,000 tons/year. The remaining six plants are projected to be potential sulfuric acid marketers with an estimated production of up to 554,000 tons/year. The combined benefits to the utility and sulfuric acid industries are projected to be as much as $20,000,000 in 1985.

TABLE 7. COMPETITIVE PRODUCTION AND DISTRIBUTION

FGD SULFUR VERSUS FGD SULFURIC ACID

Power plant location	Tons	Consumer location	Tons
Sulfur			
Staten Island County, NY	7,000	Newark, NJ	7,000
Martin County, FL	28,000	Pierce, FL	28,000
Washington County, FL	20,000	Dothan, AL	7,000
		White Springs, FL	13,000
Sherburne County, MN	8,000	Dubuque, IA	8,000
Westmoreland County, PA	24,000	North Bend, OH	8,000
		Copley, OH	16,000
Montgomery County, MD	10,000	Baltimore, MD	10,000
Shelby County, AL	12,000	Tuscaloosa, AL	12,000
Williamson County, IL	11,000	East St. Louis, IL	11,000
Rusk County, TX	9,000	Fort Worth, TX	9,000
Henderson County, TX	7,000	Fort Worth, TX	7,000
Armstrong County, PA	29,000	Cleveland, OH	29,000
	165,000[a]		165,000[a]
Sulfuric Acid			
Person County, NC	103,000	Richmond, VA	36,000
		Wilmington, NC	26,000
		Norfolk, VA	41,000
Jasper County, IL	122,000	Tuscola, IL	122,000
Pike County, IN	51,000	Indianapolis, IN	51,000
Northhampton County, PA	182,000	Deepwater, NJ	95,000
		Edison, NJ	74,000
		Gibbstown, NJ	13,000
Delaware County, PA	53,000	Gibbstown, NJ	53,000
Titus County, TX	43,000	Shreveport, LA	43,000
	554,000[b]		554,000[b]

a. The potential revenue/savings to both industries combined is projected to be as much as $10,000,000 for an approximate average of $60/short ton of sulfur.

b. The potential revenue/savings to both industries combined is projected to be as much as $10,500,000 for an approximate average of $19/short ton of sulfuric acid.

DISCUSSION OF RESULTS

FGD Byproduct Sulfur

Effects of New Plants and Revised NSPS--

In the competitive production and distribution solution for FGD sulfur versus FGD sulfuric acid (Table 7), 11 plants are shown producing and marketing 165,000 tons of sulfur. Seven of these plants with 131,000 tons (or four-fifths of the market) are scheduled for initial operation in 1985 (by definition these plants are assumed to be subject to the revised NSPS). Furthermore, these 7 sulfur-marketing power plants come from 21 potential candidates in 1985, whereas the remaining 4 plants shown to be potential marketers of sulfur are from a field of 29 candidates in the 1980-1984 startup period. The increase in potential marketing plants from less than 14% of the candidates in 1980-1984 to over 33% in 1985 results from (1) the advantage of a dry-scrubbing system with final fly ash removal built into the SO_2 removal system in a new plant and (2) the higher cost of a separate ESP for fly ash removal under the revised NSPS.

The sharp increase in the number of candidates with the 1985 plants (21 versus 10 in 1984, 6 in 1983, 9 in 1982, and 2 each in 1981 and 1980), as previously stated, results from the assumption that the revised NSPS restrict the clean fuel compliance option.

Amount of Sulfur in Coal Burned--

As discussed in the process descriptions (Appendix A) the pre-1985 plants are assumed to have an existing ESP for separate removal of fly ash. This is a much greater advantage for the wet-scrubbing processes than for the ACP and tends to preclude pre-1985 plants from competitive sulfur production. However, four pre-1985 plants are projected to be potential FGD sulfur producers. The fuel sulfur content for these plants is consistently low. It ranges from 0.92 to 1.04 lb sulfur/MBtu, with an unweighted average of 0.97 lb sulfur/MBtu. The pre-1985 plants are potential marketers of sulfur primarily because of the high unit cost of treating relatively small quantities of sludge by fixation and landfill. Even though the sulfur produced has an increased unit cost at low volumes, the equivalent unit cost for the limestone process with fixation and landfill has an even greater increase at the lower volumes. This more than offsets the initial capital advantage of the limestone process because of the existing ESP. It is this improved incremental cost of sulfur at lower coal sulfur levels that makes the four pre-1985 plants competitive.

On the other hand, the coal sulfur content of the seven 1985 plants marketing sulfur has a higher and wider range of 1.25 to 3.20 lb sulfur/MBtu, and averages 2.09 lb sulfur/MBtu. Lower sulfur content in the fuels of these plants would probably improve their competitive positions. With the aforementioned advantage accruing to the 1985 plants, however, higher annual sulfur production levels are more competitive with limestone slurry processes than are competitive in the pre-1985 plants.

FGD Sulfuric Acid

Magnesia Process with Chloride Removal--

Higher capital and operating costs are approximately equal factors in making this process, as currently projected for 1985, noncompetitive with either limestone scrubbing with sludge ponding or limestone scrubbing with fixation and landfill, despite the fact that the magnesia process has the lowest raw materials costs of those included in this evaluation.

Magnesia Process Without Chloride Removal--

It was seen with sulfur byproduct projections that the new (1985) plants had a significant advantage over existing (pre-1985) plants. The opposite is true with FGD sulfuric acid from the magnesia process without chloride removal. Existing plants are assumed to have fly ash disposal facilities already installed. Therefore, an existing plant adding limestone scrubbing with fixation and landfill does not benefit by elimination of construction costs for the fly ash pond other than an allowance for land. In the new plant comparisons, however, fly ash removal and disposal facilities are not yet built. This results in a full credit to the limestone scrubbing process for elimination of the fly ash transportation and pond construction costs. This result is seen in Table 7, showing the maximum FGD sulfuric acid sales in competition with FGD sulfur. All six of the sulfuric acid marketing plants are pre-1985. After 1985 the magnesia process, even without chloride removal, becomes significantly less competitive in comparison with the limestone scrubbing process with fixation and landfill.

Amount of sulfur in coal burned--The unit cost advantage at low sulfur levels in the fuel for the ACP is not present for sulfuric acid production. The unit cost increases at low volumes for the magnesia process are not significantly lower than the corresponding increases for the limestone process with fixation and landfill.

FGD Sulfur Versus FGD Sulfuric Acid

In the final competitive production and marketing comparison, 554,000 tons of FGD sulfuric acid (equivalent to 181,000 tons of sulfur) is marketed and 165,000 tons of FGD sulfur is marketed. All of the sulfuric acid, however, depends upon pre-1985 conditions (existing plants) whereas four-fifths of the sulfur is from new (1985) plants under the revised NSPS.

Under 1980 cost conditions, FGD sulfuric acid from the magnesia process without chloride removal has a lower sulfur-equivalent incremental cost than FGD sulfur in all cases except for new plants with low sulfur throughput. The escalation of fuel oil No. 6 costs to 1985 levels, however, has significantly deteriorated the competitiveness of the magnesia process, even without chloride removal, in comparison with the ACP using coal for its FGD byproduct fuel.

CONCLUSIONS

Sharply increasing fuel costs (especially oil and natural gas) are a critical factor in the FGD sulfur and sulfuric acid processes. The projected increase in No. 6 fuel oil cost by the end of 1985 severely restricts the market potential of sulfuric acid from the magnesia process, even under the optimistic case with no chloride removal requirement.

Processes that can use coal as the FGD energy source will have increasing economic advantages over those which use fuel oil or natural gas. Even with a highly unlikely equal escalation rate for these three fuels, the gap per MBtu would widen. Despite projected increases in coal transportation costs, its economic advantages over fuel oil and intrastate natural gas will become even more substantial. Also, the future availability of natural gas and fuel oil for FGD application is uncertain. The economics of the magnesia process byproduct sulfuric acid would be greatly improved if coal could be substituted for fuel oil.

The necessity for chloride removal in the magnesia process will be a very important factor in its sulfuric acid production costs. The addition of chloride scrubbing and neutralization to the 1985 magnesia process, coupled with cost escalation (especially fuel oil), eliminated the FGD sulfuric acid market shown in previous projections.

In the ACP, simultaneous removal of SO_x and the remaining fly ash (after 85% upstream removal by mechanical collectors) in the same ESP presents an advantage for new (1985) plants when compared with alternative FGD processes which require separate high-efficiency ESP's and scrubbers.

Lower sulfur throughput favors FGD sulfur marketing since the cost increase per ton of sulfur removed at low levels is not as great as that for limestone scrubbing with fixation and landfill or the magnesia process.

The number of power plant candidates for FGD byproduct marketing will increase with the application of the revised NSPS. It is estimated that this will affect boilers with startup dates in and after 1985. Less than half of the boilers projected to come on-line between 1980 and 1984 are committed to FGD systems. The majority have selected a clean fuel compliance strategy which will have restricted applicability for future plants covered by the revised NSPS.

The potential for FGD sulfur and sulfuric acid marketing is extremely limited when limestone scrubbing with slurry ponding is a feasible alternative. Land limitations, potentially more stringent regulations, and other factors may, however, impose severe restrictions on ponding as it is currently practiced. An increasing number of limestone slurry processes are seen to be selecting landfill disposal methods. Potential for production and marketing of FGD byproducts increases when limestone slurry fixation and landfill are required. Although direct capital costs are usually lower for fixation and landfill, higher operating costs (principally labor) increase the overall process costs and thus reduce the incremental FGD byproduct costs.

The potential for producing and marketing FGD sulfuric acid from the magnesia process versus limestone scrubbing with fixation and landfill is greater for existing than new plants. For plants not yet built the full advantage of not building fly ash transportation and ponding facilities, which are not necessary with fixation and landfill, is realized whereas these facilities are presumed to be installed in existing plants.

Transportation costs, especially by rail, are becoming more important. Escalation of these costs will affect the marketing range of byproduct sulfur and, especially, byproduct sulfuric acid. In addition, substantial rail rate increases will affect the marketing range of competitive voluntary and nonvoluntary sulfur and sulfuric acid products recovered from sources such as Canadian and U.S. sour gas, refineries, and smelters.

Other nonvoluntary sulfur production is becoming a more important factor in the marketing economics of FGD byproduct sulfur. Voluntary production of Frasch sulfur once was the dominant source of U.S. sulfur. Nonvoluntary sources will constitute 65% of the U.S. sulfur capacity and almost 78% of North American capacity by 1981. How this will affect the price stability of the sulfur market is difficult to project at this time. Much will depend on market growth, especially from potential new uses such as sulfur substitution for asphalt in road-paving applications.

RECOMMENDATIONS

An FGD sulfur and sulfuric production and marketing forecast should be projected for 1990 or beyond. This projection to 1985 reflects only the beginning of the effects of the 1979 revised NSPS. In addition, the increased lead time required to analyze FGD options and implement decisions necessitates a more extended time frame.

Technology and economic developments in spray dryer FGD recovery processes should be followed closely.

Developments allowing the use of coal for FGD recovery processes now using fuel oil or natural gas should be followed closely and incorporated into future studies.

Future studies should include projections of fertilizer demand by geographical areas to expand the demand system beyond its current limitations of existing and announced sulfuric acid plants and to evaluate the economics of fertilizer production from FGD sulfuric acid near the point of use.

A specific byproduct marketing study should be made for the approximately 100 power units designated by the Department of Energy for conversion from oil to coal. Many of these plants are in high-population areas where disposal of wastes if FGD were required would be difficult. These are also areas of historically high sulfur costs.

Projected demand for sulfur for new uses such as partial or full replacement of asphalt in paving should be included.

The increased supply of refinery recovered sulfur should be projected because of the potential increase in use of high-sulfur crude oil.

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APPENDIX A

BYPRODUCT MARKETING SYSTEM DESCRIPTION

COMPUTER SYSTEM

The system description presented here is a highly simplified version of the comprehensive description presented in the users manual. For more details, reference to the users manual and the 1983 projection report is suggested.

The byproduct marketing system consists of a number of integrated computer programs, models, and data bases that can be used to make cost comparisons of FGD strategies designed to meet clean air regulations. For strategies that produce a salable byproduct, the marketability of the byproduct is determined and its effect on FGD costs is included in the cost comparisons. The system can use this data or user-supplied data to develop situations for comparison of alternative FGD strategies. For comparisons based on the use of clean fuel without FGD, an alternative clean fuel level (ACFL) is used to represent the cost differential between a complying fuel and a noncomplying fuel. In the cases of sulfuric acid and sulfur production, the system determines the incremental cost of the product. Incremental production cost is defined as the production cost per ton of sulfuric acid or sulfur above the cost of either limestone scrubbing or the ACFL value, whichever is lower, unless the revised NSPS apply. The ACFL value is not considered for those plants that are assumed not to have the option of a complying fuel.

Figure A-1 shows a simplified block diagram of the computer system. It consists of four subsystems. The supply (or power plant) subsystem includes data bases and programs which provide data on power plants, emission control regulations, raw materials costs (including limestone delivery cost), and FGD design and cost data. These are used to determine the scrubbing costs for the processes being considered on a boiler-by-boiler basis for each power plant in the data base. The demand (or acid plant) subsystem consists of programs and data bases on sulfur transportation costs and sulfuric acid plant operating costs that are used to determine acid plant avoidable production costs. Avoidable production cost is the expenditure that could be avoided by shutting down a sulfur-burning acid plant and marketing purchased acid. This cost reduction is the break-even price that can be paid for FGD sulfuric acid. For the sulfur demand, the break-even price that can be paid for FGD sulfur is the delivered price to the acid plant for either Calgary recovered sulfur or Port Sulphur Frasch sulfur. The transportation subsystem consists of data bases and programs to provide rail mileages,

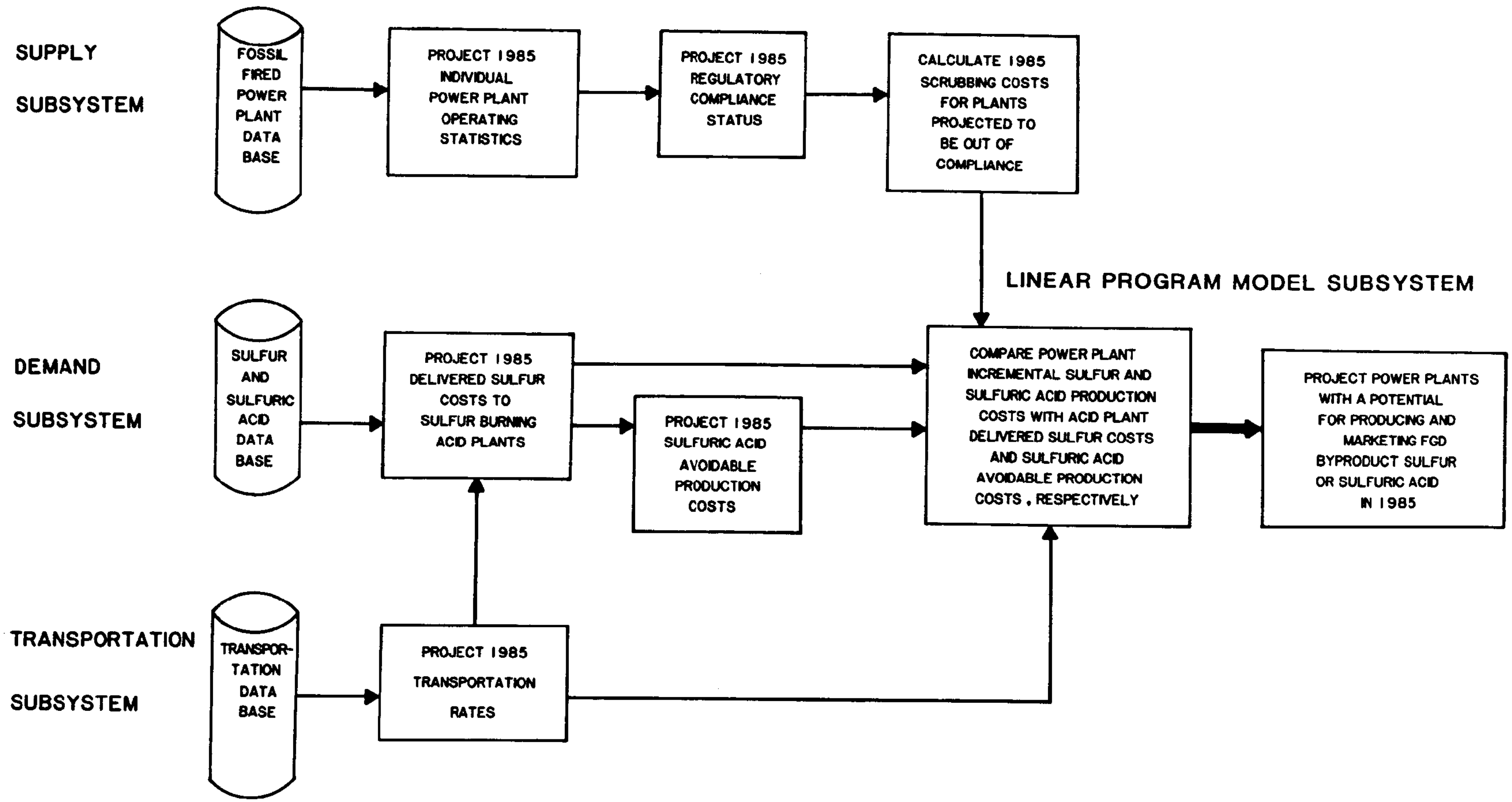

Figure A-1. Computerized FGD byproduct production and marketing system.

tariffs, and rate-basing information for power plants and acid plants from the other subsystems. It is used to calculate sulfuric acid and sulfur transportation costs. The fourth subsystem consists of a linear programming model and various optional report generators. It uses the results of the other three subsystems to select the least-cost option for each power plant considered for byproduct marketing.

FGD PROCESS DESCRIPTIONS

The three processes used in this study are the limestone process, the magnesia process for sulfuric acid production, and the Rockwell International aqueous carbonate process (ACP) for sulfur production. Two waste disposal variations of the limestone process are used--untreated ponding and fixation and landfill. The magnesia process is also used in two variations, with and without an additional prescrubber for chloride removal. The prescrubber is included in the revised magnesia process because of concern that under some conditions chloride buildup in the process could lead to reduced MgO utilization, severe corrosion, and to contamination of the regenerated off-gas with hydrochloric acid. The need of chloride control has not been demonstrated for all coals and all operating conditions, however. A variation of the process without chloride control is therefore included.

All of the FGD systems are based on a four-parallel-train design for the 500-MW base case, each with a forced-draft (FD) booster fan, fed from a common plenum. Reheat to 175^{o}F with indirect steam heat is provided for the wet-scrubbing processes. The designs are generic, based on current industry practice and vendor information.

In order to make equitable comparisons between processes, some equipment and land credits are made. Existing (pre-1985) plants are assumed to have ESP units and fly ash disposal facilities and these costs are not included. For limestone scrubbing with fixation and landfill in existing plants, it is assumed that the existing fly ash pond is used as the landfill site. Fly ash transportation and pond maintenance are applied as credits because the fixation and landfill process includes fly ash disposal. (TVA's Solid Wastes Section of the Water Quality Branch of the Office of Health and Safety has recently estimated wet ash-handling storage and disposal costs at $13.50/ton. This estimate was based on a 35-year lifetime and represents the lifetime levelized cost.) For the existing-plant magnesia process and ACP that require chloride disposal, an incremental pond cost is included, assuming that these wastes are discarded in the existing ash pond. For new (1985) plants ESP units to meet the 0.03 lb/MBtu NSPS are included for the wet-scrubbing processes. For the ACP an 85%-efficient mechanical collector is included ahead of the spray dryer. The remaining fly ash is removed in the sulfur-salt particulate collectors.

The limestone scrubbing process (Figure A-2) uses mobile-bed absorbers with presaturators and mist eliminators. A 15% solids slurry of crushed and ball-milled limestone at a stoichiometric ratio of 1.3

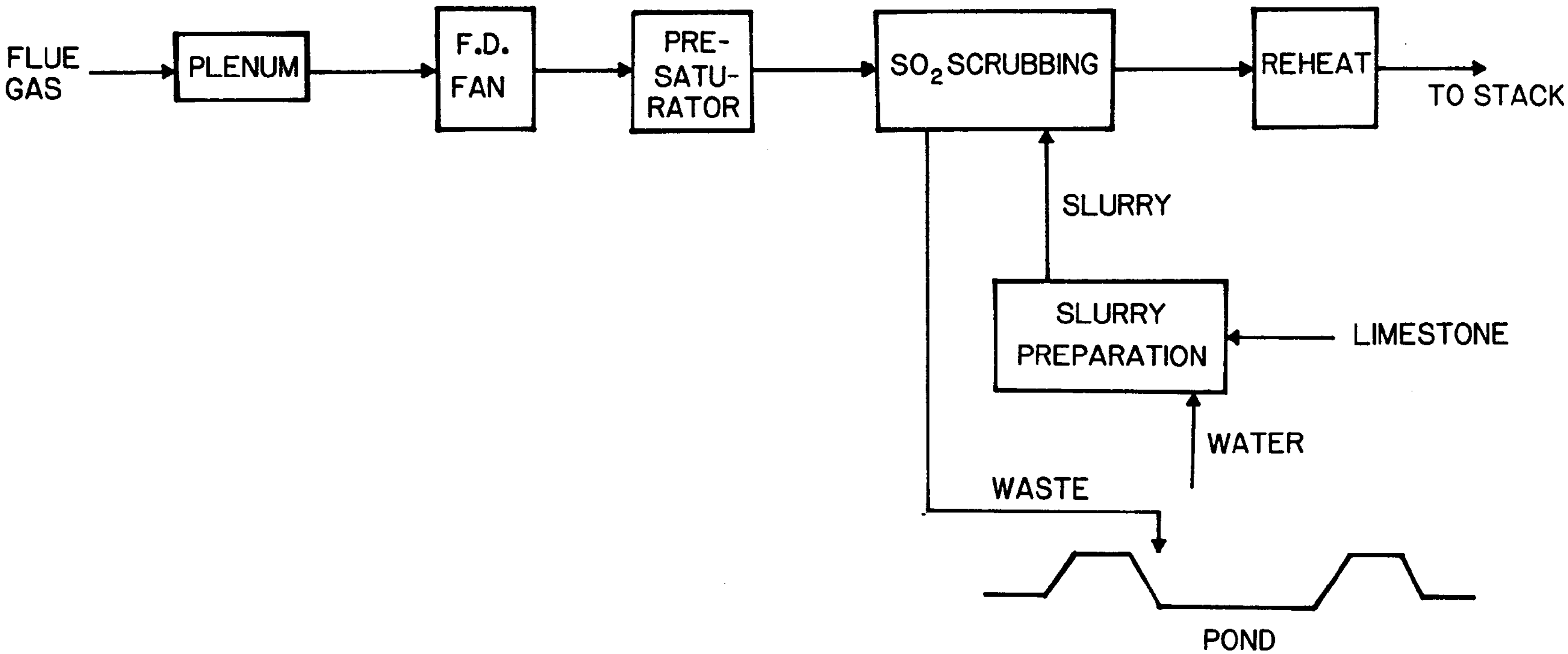

Figure A-2. Limestone scrubbing and ponding.

moles per mole of sulfur removed is used. In the ponding variation the 15% solids scrubber purge stream is pumped one mile to an earthen-diked, clay-lined pond where it settles to a final solids content of 40%. Excess water is returned to the FGD system. The pond is sized for the remaining life of the power plant and is designed for a depth that minimizes the sum of land and construction costs.

In the fixation and landfill variation (Figure A-3) the sludge is dewatered to 60% solids by thickening and filtration and then blended with dry fly ash and 4% lime (based on FGD waste solids). The resulting wastes are trucked one mile to a landfill site.

The magnesia process (Figure A-4) uses a spray grid column absorber. A venturi scrubber for chloride removal is used in place of the presaturator for the process with chloride control. Chevron mist eliminators are used on both the scrubber and absorber. The chloride scrubber uses absorber liquid and fresh water. The chloride scrubber waste stream is neutralized with limestone and pumped to the ash pond. The spray grid column uses a 15% solids slurry of MgO as the absorbent at a stoichiometry of 1.05 moles of MgO per mole of sulfur removed and an L/G ratio of 10 gal/kft^3. The spent slurry from the absorber, containing magnesium sulfite ($MgSO_3$) as the major component, is centrifuged to 85% solids, dried in an oil-fired dryer, and calcined in a fluid-bed reactor. The MgO is returned to storage and the SO_2 is processed to sulfuric acid. The magnesia scrubbing variation without chloride scrubbing is shown in Figure A-5. It has a presaturator instead of a chloride scrubber, no chloride neutralization system, and a reduced fan size.

The ACP (Figure A-6) is a dry-scrubbing process. It is based on spray dryer technology in which a solution of soda ash (Na_2CO_3) absorbent is atomized in the flue gas. Solution concentration is controlled to permit complete evaporation. The resulting sulfur salts are collected as a dry powder. No reheat is required in most applications because the flue gas is not saturated and remains sufficiently hot for plume buoyancy. The sodium-sulfur salts are reduced to sodium sulfide (Na_2S) using coal in a molten-salt reducer. The Na_2S is further processed in a series of carbonation reactions to hydrogen sulfide (H_2S), which is converted to sulfur in a Claus plant, and Na_2CO_3, which is reused in the process. The ACP has not yet been used in commercial application, so the design used in this evaluation is based on vendor and published information. However, a contract has been awarded to Rockwell International for a 100-MW demonstration facility at the Huntley plant of Niagara Mohawk in Buffalo. Construction on the 5-year project was started in 1979.

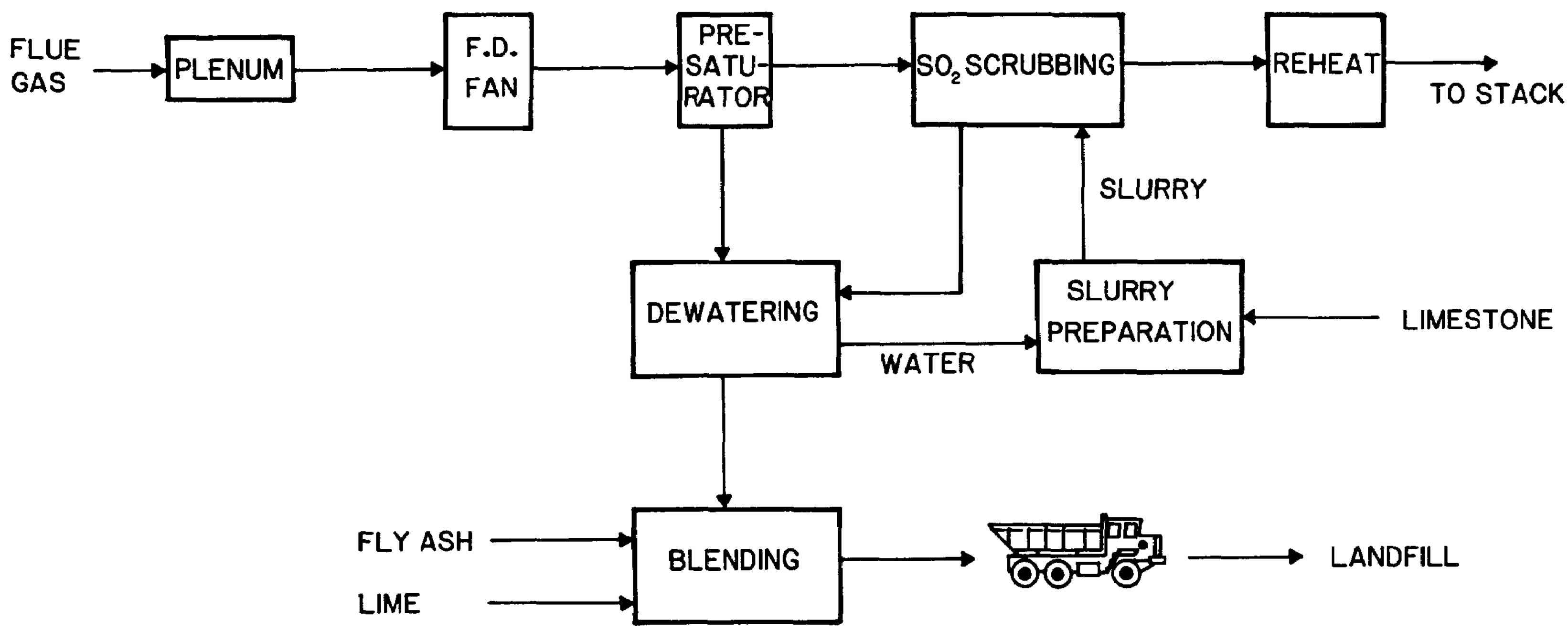

Figure A-3. Limestone scrubbing and landfill.

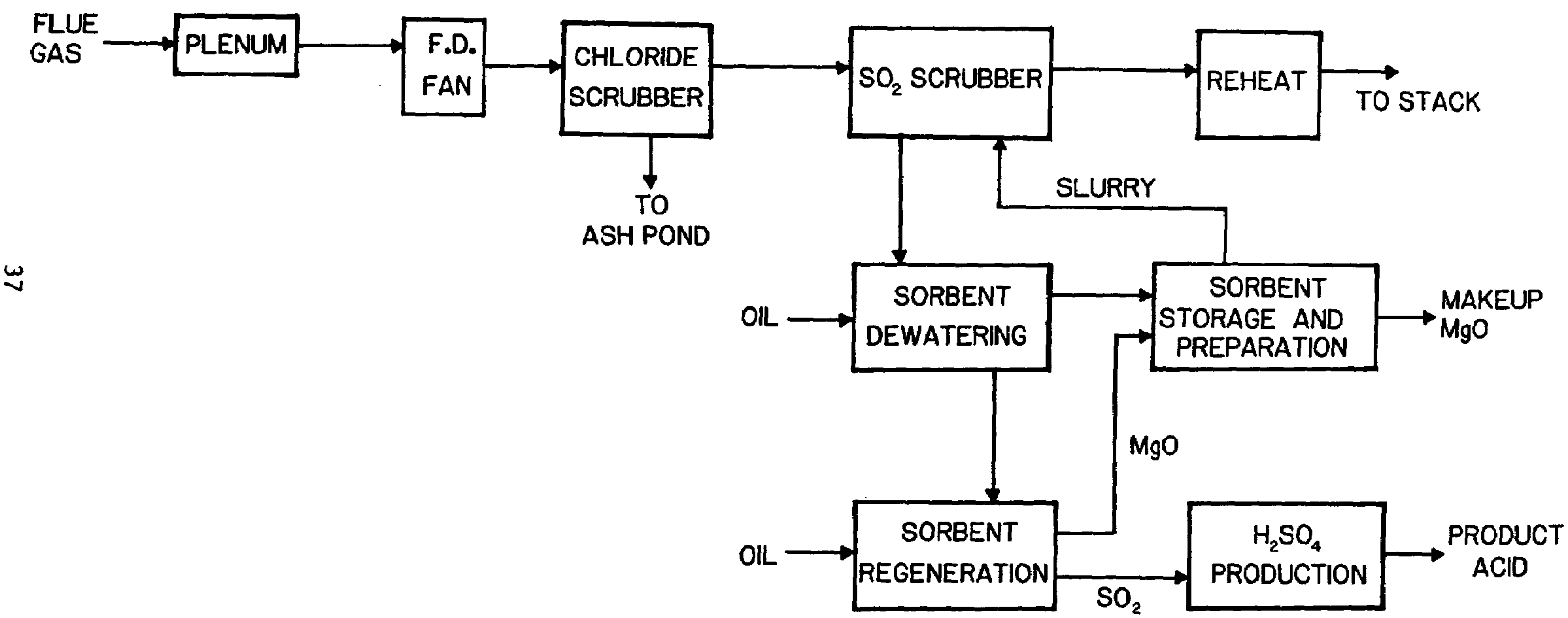

Figure A-4. Magnesia process.

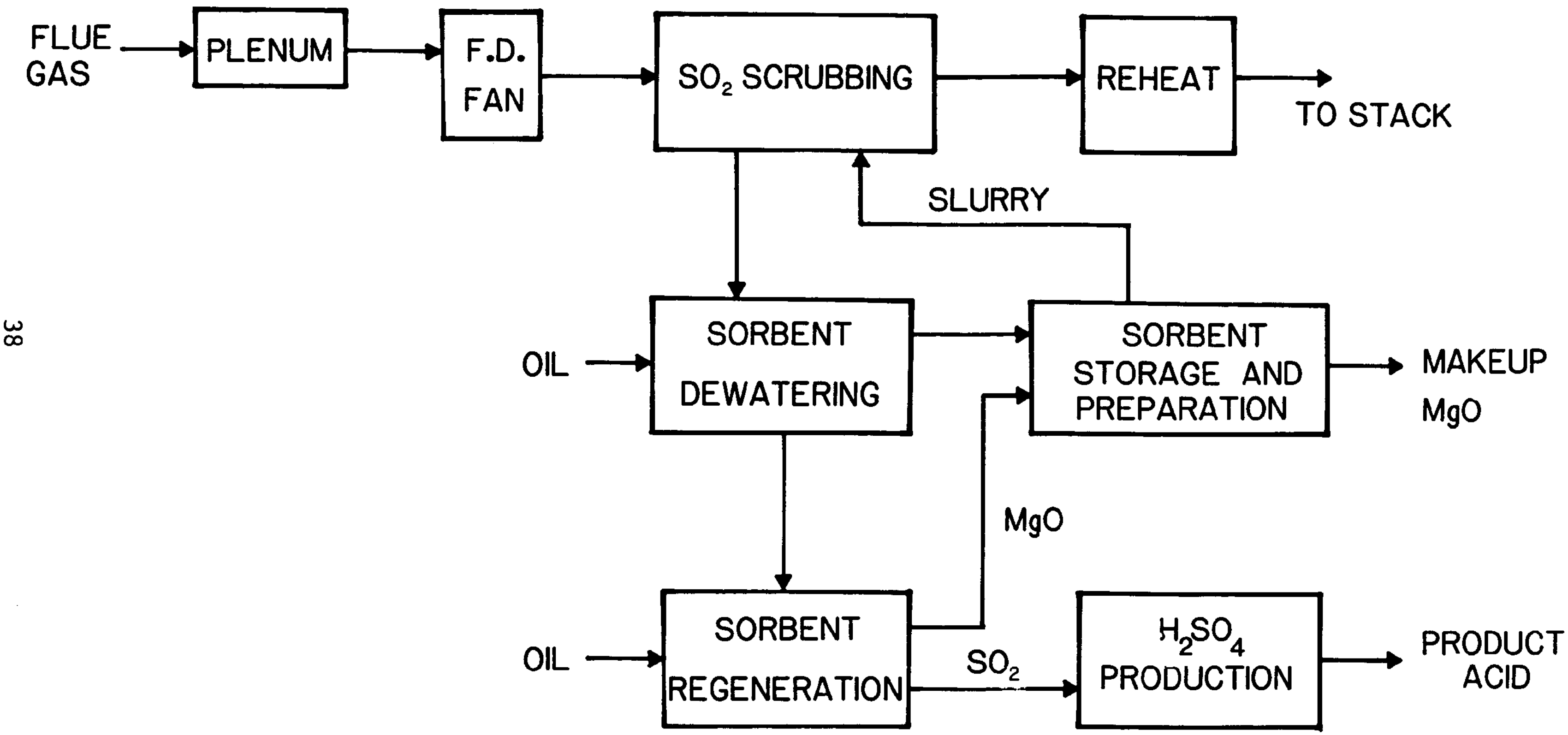

Figure A-5. Magnesia process without chloride scrubbing.

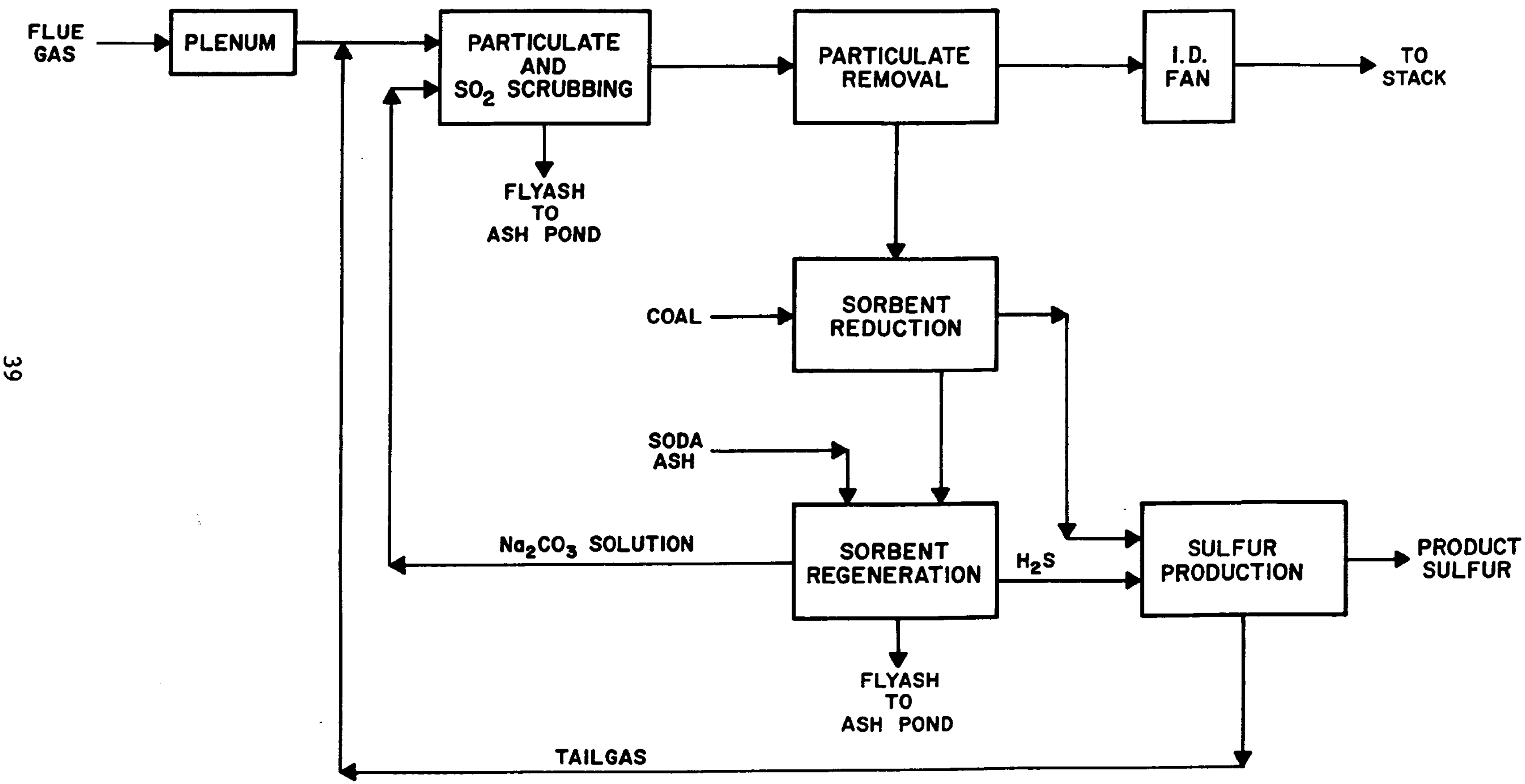

Figure A-6. Rockwell International ACP.

APPENDIX B

SYSTEM REVISIONS AND ADDITIONS FOR 1985

SCRUBBER COST GENERATOR

New Power Plants and Boilers Through 1985

Projected boilers scheduled for completion in the years 1980 through 1985 were added to the data base. A total of 170 new boilers was identified for this period and 50 are included in the 1985 model. The remaining 120 projected boilers were not considered for the following reasons.

Number of boilers not considered	Reason
69	Selected clean fuel for compliance
21	Committed to scrubbing
13	Incomplete fuel information
11	Plant location unknown
6	Plant size below 100-MW screen
Total 120	

Updated Regulations and Compliance Plans

The 1985 projection is based on regulatory data available from EPA through February 6, 1979. The major changes in State implementation plans (SIP's) were in Ohio and Florida. The Ohio SIP's had not been finalized at the time of the EPA listing used for the 1983 projection. The Florida SIP's have been liberalized in the latest listing. The revised NSPS are assumed to apply to all boilers coming on stream in 1985, based on estimated time between approval of plans and startup.

FGD Processes

The 1983 projection used the processes and data as they existed in the scrubber cost generator in the fall of 1978. There have been changes in technology, particularly for the magnesia process, since that time. The 1985 projection reflects most recent technology changes, many of which increased the capital and operating costs. The addition of chloride scrubbing and neutralization particularly added to the magnesia scrubbing costs. A variation of the magnesia process was added without chloride removal provisions for systems for which chloride scrubbing might not be required.

ACP

The ACP was substituted for the previously used Wellman-Lord/Allied Chemical methane reduction process for byproduct sulfur production. The ACP technology has not been demonstrated to the extent nor on the scale that the technology used in the 1983 projection had been demonstrated. Future process revisions to the ACP could affect the projected FGD sulfur market potential in the same way that magnesia process revisions affected the FGD sulfuric acid market potential. Therefore, the absolute quantities and margins of projected FGD byproduct sulfur sales may be somewhat uncertain.

Limestone

The technology of the limestone process with pond disposal is established. Thus, little change other than escalation of capital and operating costs through 1985 was made in its data base. Limestone scrubbing with fixation and landfill was added to the scrubber cost generator to provide for those circumstances where ponding of the limestone slurry is not possible. The fixation system is similar to a commercial fixation process such as that employed by IU Conversion Systems, Inc. (IUCS).

Cost Escalation

Capital costs were escalated through 1985 using the *Chemical Engineering* cost indexes. Operating costs were escalated through 1985 based on TVA projections.

TRANSPORTATION COST GENERATOR

Rail Rate Increase

Rail rates were projected through 1985 from actual rates in late 1979. They are expected to double in this 6-year period (approximately a 105% increase), with a projected annual escalation of 12.7%.

Barge Rate Increase

Barge rates were also projected through 1985 from actual late 1979 rates. Application of the waterways users tax and pass-on of this tax in rates are assumed. The 6-year increase is projected to be 76%--lower than the rail rate increase despite the waterways users tax inclusion. The average annual escalation over this period is projected at 9.9%.

Truck Transport

Highway transportation costs were added to the model to represent the most common method of limestone transportation. The late 1979 average trucking rate of $0.065 is escalated by 10% per year through 1985.

ACID PRODUCTION AND SULFUR COST GENERATOR

Sulfuric Acid Plant Data Base

The sulfuric acid plant capacity data were updated by comparing information from several sources. Additional plants to be in operation by 1985 were added and some plants indicated as closed were eliminated from the data base. Demand in 1985 is equated to 82% of the sulfur-burning acid plant capacity.

Sulfuric Acid Avoidable Production Cost

This cost, the expenditures per ton of sulfuric acid which can be avoided by shutting down the sulfur-burning acid plant and buying acid, was modified to conditions projected for 1985. The variable conversion cost was reduced significantly because of the increased byproduct steam credit. The sulfur price at Port Sulphur was increased from the 1983 projection of $62.50/short ton ($70.00/long ton) to $80.00/short ton ($89.60/long ton). This is roughly equivalent to the late 1979 listed price per long ton at Tampa ($95.50). Although Frasch sulfur prices increased sharply in 1979, the increasing influence of nonvoluntary recovered sulfur is expected to have a leveling effect on prices.

The trend in the United States toward nonvoluntary recovered sulfur is seen in Figure B-1. In 1970 voluntary Frasch production constituted over 59% of the U.S. production capacity. By 1981 the Frash capacity will be about 35% of the total U.S. capacity. Meanwhile nonvoluntary sulfur production capacity from refinery operations will have increased from about 19% in 1967 to almost 38% of U.S. capacity in 1981. Sour gas and other nonvoluntary capacity have retained about the same percentage of U.S. capacity. Overall, the nonvoluntary sources have increased their capacity share in the past 10 years from 40% to 65%.

As shown in Figure B-2 Canadian sulfur production capacity is all nonvoluntary. It is predominantly from sulfur removal from sour natural gas. The dominance of the Canadian sour gas sulfur source peaked in 1974 at 93% of the Canadian sulfur production capacity. By 1981 it is projected at about 78% of total Canadian capacity. The decline is due to a slight decline in sour gas sulfur capacity caused by dilution of sulfur content in the wells by reinjection of sweetened (sulfur removed) natural gas and an increase in refinery sulfur capacity from 3% in 1974 to 16% by 1981.

The combined North American (U.S. and Canada) situation (Figure B-3) shows nonvoluntary recovered sulfur increasing from a low of 58% of North American capacity in 1970 to 78% by 1981.

Canadian recovered sulfur already has a suppressing effect on the price (or rather marketable price) of Port Sulphur sulfur in the upper United States west of Chicago. The price of sulfur at production points near Calgary, Alberta, is traditionally substantially below the Port Sulphur level because of its nonvoluntary nature and freight and

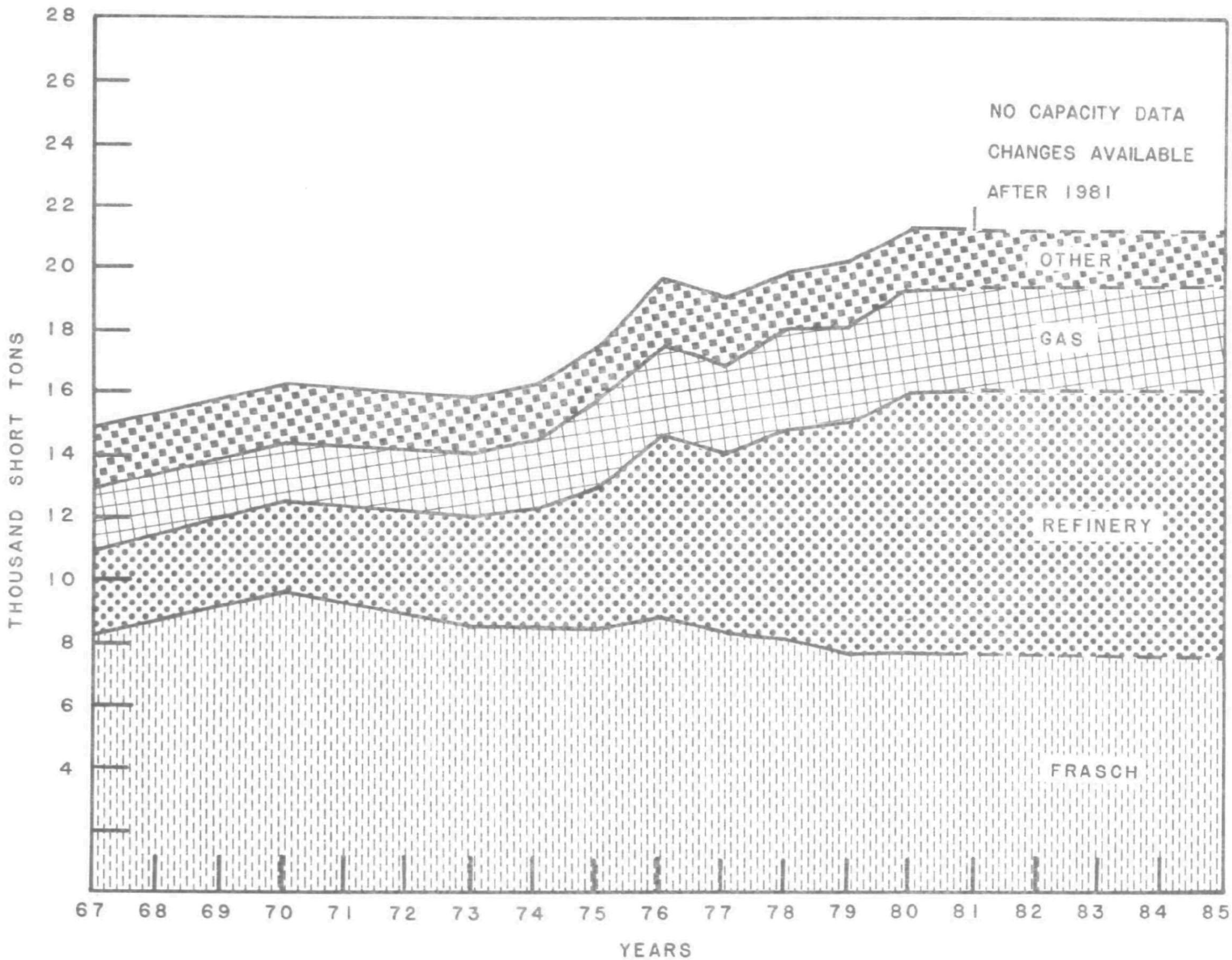

Figure B-1. Sulfur capacities by source (1967-1985) - United States.

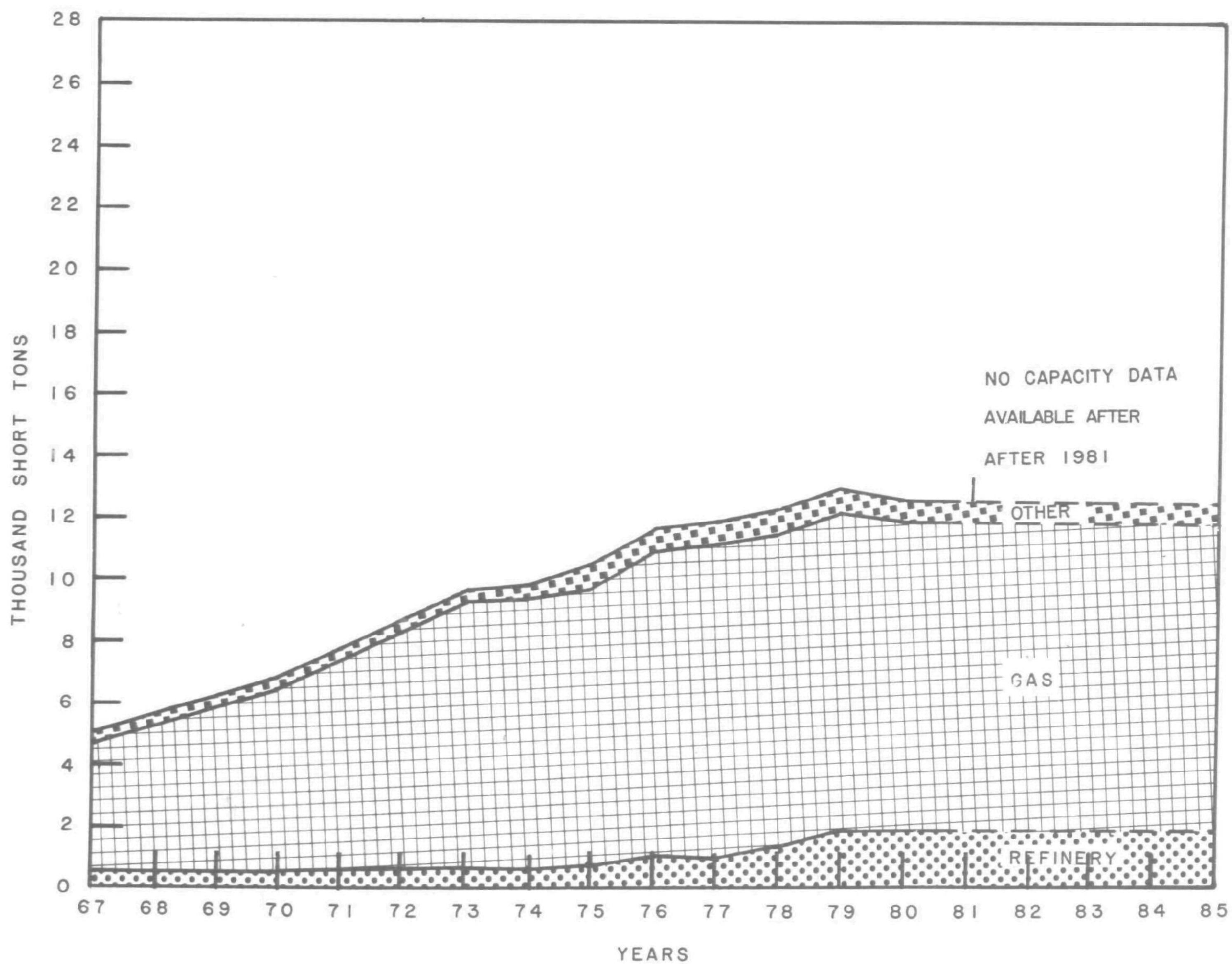

Figure B-2. Sulfur capacities by source (1967-1985) - Canada.

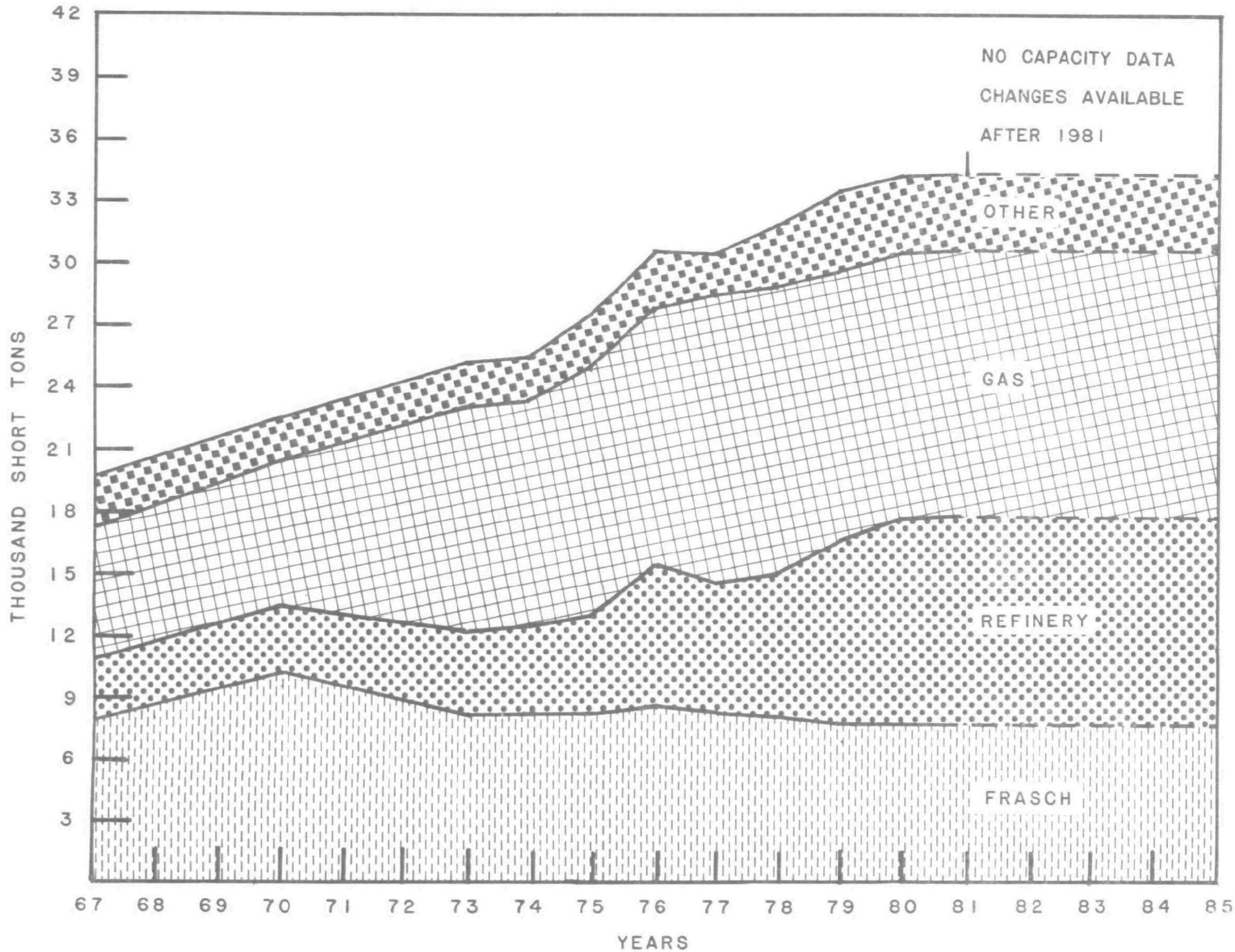

Figure B-3. Sulfur capacities by source (1967-1985) - North America.

handling costs. Figure B-4 shows the approximate competitive ranges for Canadian sulfur at prices of $35, $45, and $55/short ton less than Port Sulphur prices. The current competitive range for Calgary recovered sulfur is probably somewhere between the $35 and $45 limits shown. An f.o.b. advantage of $55/short ton would be required for Canadian sulfur to compete with Port Sulphur Frasch sulfur in the largest U.S. markets of central Florida, the lower Mississippi River, and North Carolina.

Canadian sulfur is projected for a $45/short ton price, f.o.b. Calgary, in 1985. It is substituted at this price plus delivery costs for those midwestern locations where it is competitive with the delivered cost of Frasch sulfur from Port Sulphur.

As in past projections, only the sulfur-burning acid plants are considered potential markets for FGD sulfuric acid (and, in the 1985 projection, for FGD sulfur). The relative capacity of sulfur-burning acid plants compared with other sulfuric acid sources has declined slightly in the United States in the past dozen years. The total capacity of sulfur-burning acid plants has increased substantially, however, as seen in Figure B-5. Both the share and the total amount of smelter sulfuric acid capacity have increased significantly but appear to be leveling off, as has sulfuric acid produced from refinery sludge.

The sulfuric acid production capacities for Canada by type of feedstock are shown in Figure B-6. The percentage of sulfuric acid capacity in Canada from sulfur feedstock has dropped from over 73% in 1967 to under 53% in 1981 even though the total amount of sulfur-burning capacity has increased. Smelter sulfuric acid and other unidentified feedstocks have increased in the same period from about 27% to 47% of total Canadian sulfuric acid capacity. There is no refinery sludge sulfuric acid production in Canada unless it is in the unidentified feedstock ("other") category shown.

Canadian total sulfuric acid capacity, however, makes up less than 10% of total North American capacity. Therefore, as seen in Figure B-7, the profile of capacities by feedstock for North America is very similar to that for the United States. The total capacity for the United States amounts to over 57 million tons of the roughly 65 million tons of North American capacity projected for 1981, the last year for which capacity change data are available.

The transportation and handling data as they apply to the delivered cost of sulfur through acid plants, and thus the avoidable production costs, have also been updated through 1985. Rail and barge transportation have escalated as shown for the transportation data base and handling at the terminal has been escalated at a much lower rate since much of this cost is related to fixed costs on existing capital investments.

Market Simulation Linear Programming Model

The most important change from previous studies is the inclusion of FGD byproduct sulfur in the marketing system. Canadian sulfur is included

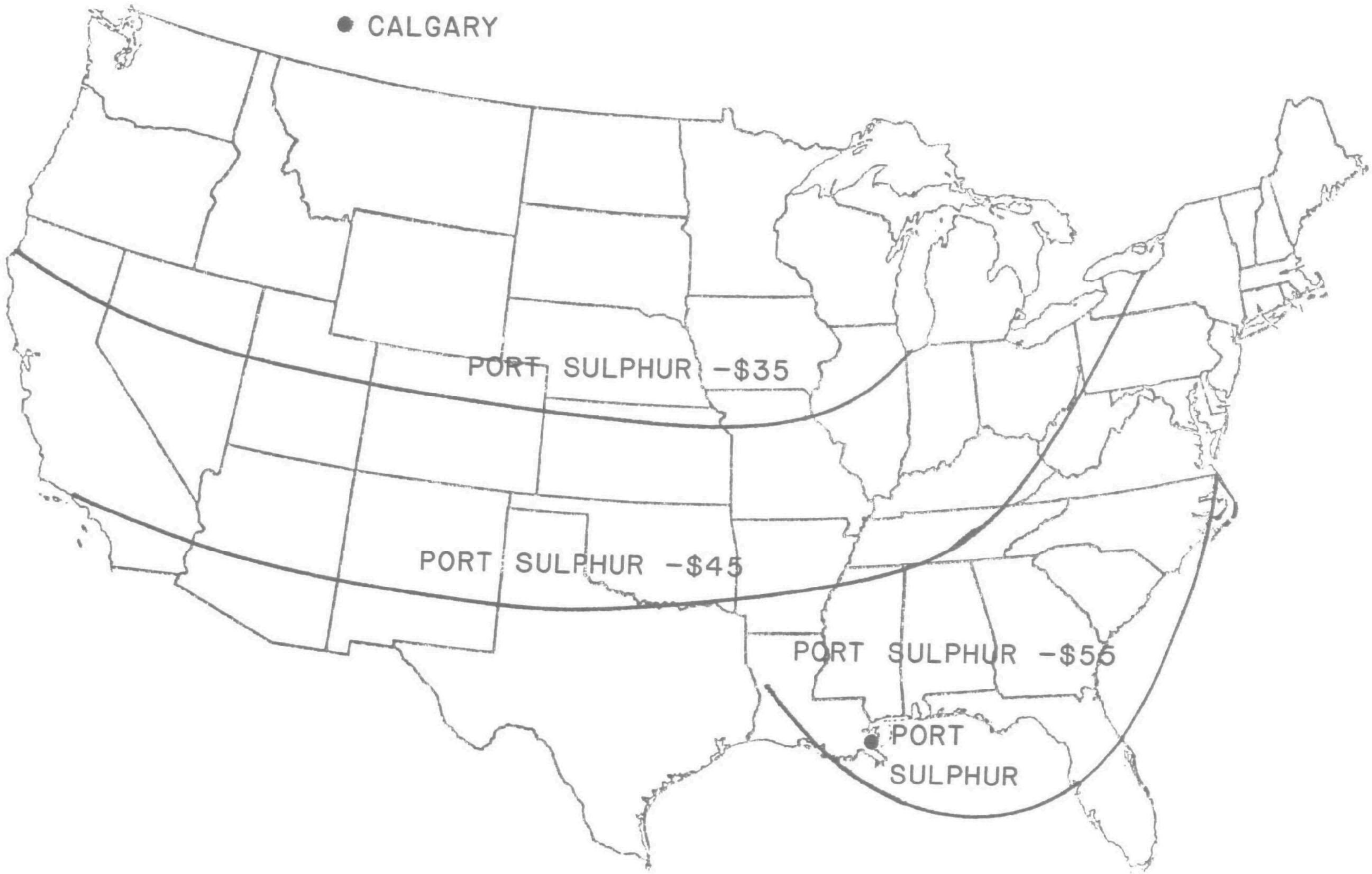

Figure B-4. Cost-competitive ranges for Canadian sulfur at different f.o.b. Canadian sulfur prices (short ton) below Port Sulphur price.

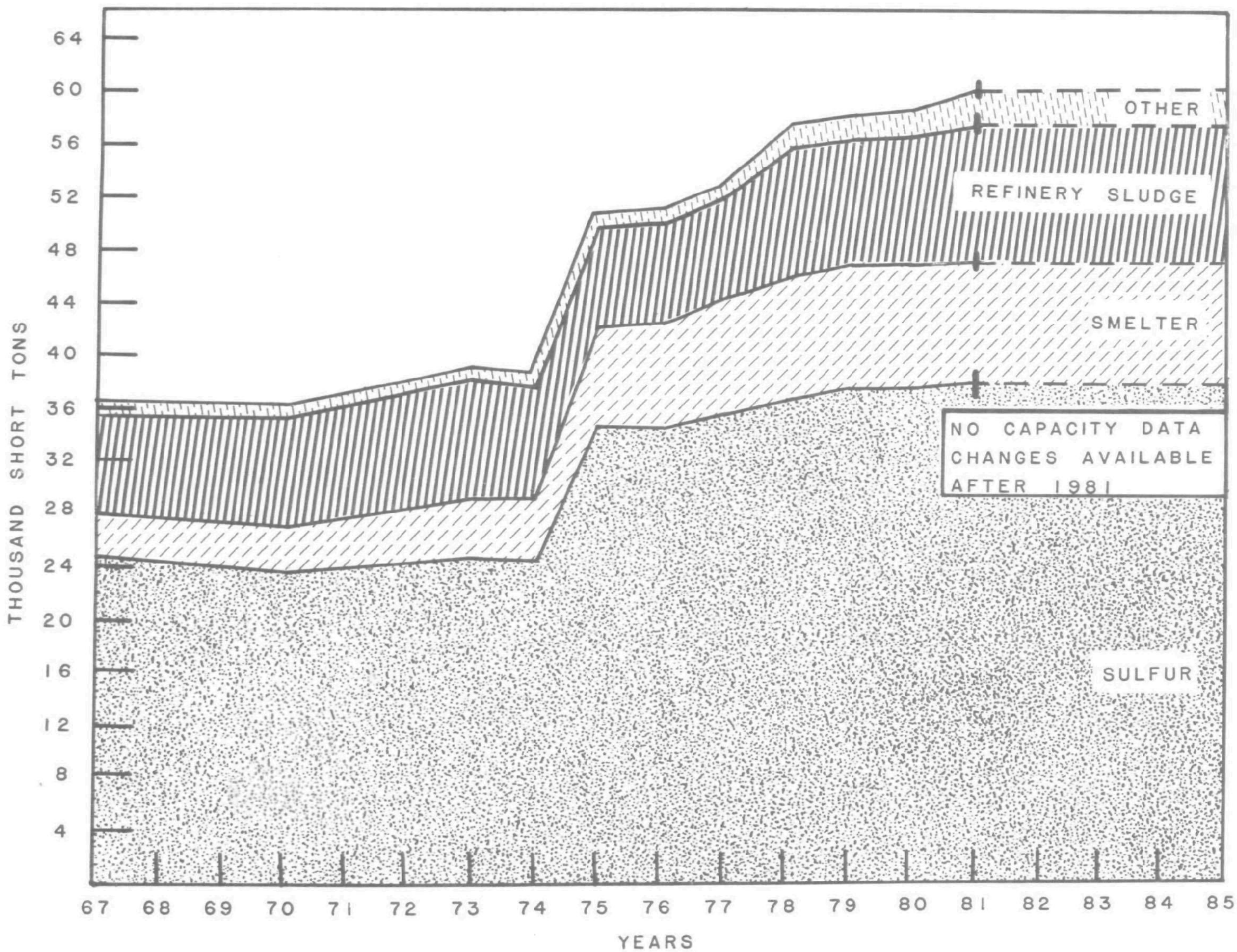

Figure B-5. Sulfuric acid capacities by feedstock (1967-1985) - United States.

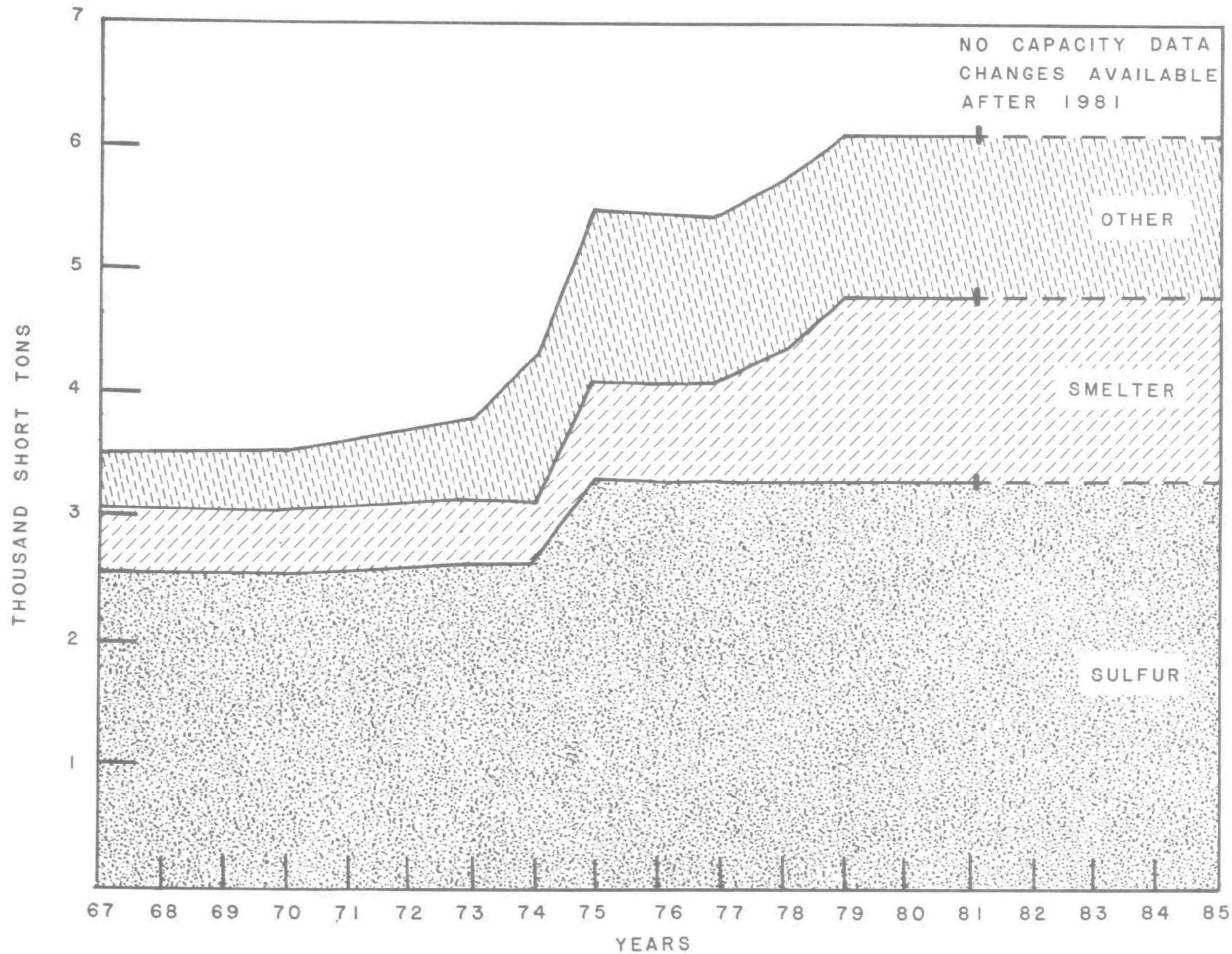

Figure B-6. Sulfuric acid capacities by feedstock (1967-1985) - Canada.

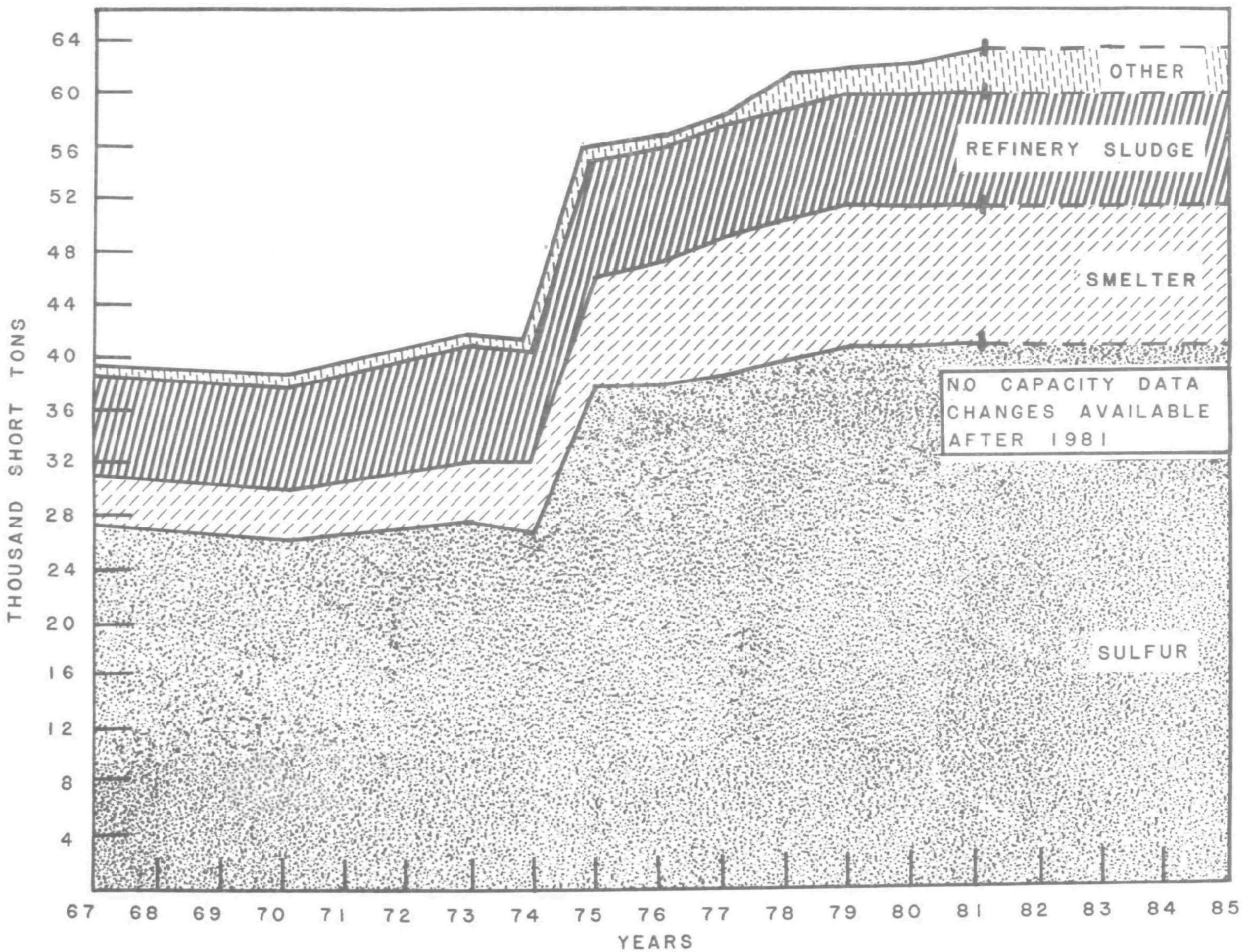

Figure B-7. Sulfuric acid capacities by feedstock (1967-1985) - North America.

as a competitive source at $45/short ton, Calgary, along with Frasch sulfur at $80/short ton, Port Sulphur. Other FGD sulfur marketing conditions are a minimum annual production rate screen of 5,000 short tons and a maximum incremental production cost screen of $100/short ton. An incremental production cost higher than the Port Sulphur rate is used to allow for possible power plant marketing advantages because of location. Significant changes to the sulfuric acid marketing data are screens of a minimum of 40,000 short tons of annual FGD production and a maximum incremental production cost of $45/short ton.

The ACFL of $0.50/MBtu used in the 1983 projection was dropped, the $0.70 and $1.00 ACFL were retained, and a $1.25 ACFL level was added. Provisions were also made to reflect the revised 1979 NSPS for 1985 boilers. The new regulations require a minimum of 70% sulfur removal, and thus force an FGD comparison regardless of the ACFL since the option to use a clean fuel compliance strategy alone no longer exists with the revised NSPS.

TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
1. REPORT NO. EPA-600/7-80-131	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Projection of 1985 Market Potential for FGD Byproduct Sulfur and Sulfuric Acid in the U.S.		5. REPORT DATE July 1980 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) W.E.O'Brien, W.L.Anders, and J.D.Veitch		8. PERFORMING ORGANIZATION REPORT NO. TVA EDT-115
9. PERFORMING ORGANIZATION NAME AND ADDRESS TVA, Office of Power Div. of Energy Demonstrations and Technology Muscle Shoals, Alabama 35660		10. PROGRAM ELEMENT NO. INE624A 11. CONTRACT/GRANT NO. EPA Interagency Agreement D9-E721-BI
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 1/79-4/80 14. SPONSORING AGENCY CODE EPA/600/13
15. SUPPLEMENTARY NOTES IERL-RTP project officer is Julian W. Jones, MD-61, 919/541-2489.		

16. ABSTRACT

The report projects the 1985 market potential for flue gas desulfurization (FGD) byproduct sulfur and sulfuric acid in the U.S. The projection is 165,000 tons of sulfur from 11 power plants and 554,000 tons of acid from 6 power plants, with a combined benefit to the affected industries of $20 million. FGD technology improvements and cost increases, particularly for fuel oil, enhanced the FGD sulfur market potential and decreased the FGD sulfuric acid potential, relative to previous projections. The 1979 revised New Source Performance Standards (NSPS), and the requirement (in many cases) for FGD waste treatment, improved the potential for both products. The revised NSPS, which preclude low-sulfur coal as an option, greatly increase the FGD market potential for plants coming on line after the mid-1980s. Fuel-oil cost escalation is important in reducing FGD sulfuric acid market potential, as are process modifications for chloride control. Limestone scrubbing with waste sludge ponding remains the economically predominant option. The limestone scrubbing advantage is decreased, however, when extensive waste treatment and landfill are required.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Marketing	Pollution Control	13B	05C
Flue Gases	Calcium Carbonates	Stationary Sources	21B	
Desulfurization	Scrubbers		07A,07D	13I
Sulfur	Sludge		07B	
Sulfuric Acid	Ponds			08H
Byproducts			14G	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to Public	Unclassified	68
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)