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Potential Production and Marketing of FGD Byproduct Sulfur and Sulfuric Acid in the U.S. (1983 Projection)

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Potential Production and Marketing of FGD Byproduct Sulfur and Sulfuric Acid in the U.S. (1983 Projection)

by

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ABSTRACT

A computer-based marketing evaluation of sulfur and sulfuric acid as flue gas desulfurization byproducts from U.S. coal-burning power plants was updated to 1983 from the previous evaluation which used a 1978 base. Least-costs of compliance were calculated using comparisons between clean fuel premiums of $0.50 and $0.70 per MBtu, limestone scrubbing, and scrubbing systems with byproduct sulfur and sulfuric acid production. Market potential of sales to sulfur-burning acid plants was also determined. At the $0.50 clean fuel premium, sulfuric acid production was the least-cost method at five plants, four of which had combined sales of 800,000 tons per year. At the $0.70 premium, sulfuric acid production was the least-cost method at 26 plants, 7 of which had sales totaling 1,200,000 tons per year. New boilers coming online by 1983 accounted for 60% of the sales. Market potential was relatively insensitive to sulfur price. Sulfur production was not selected at any plant but reduction of total FGD costs by 3% to 24% would make it competitive with sulfur delivered from Port Sulphur at 16 plants with a total production of 266,000 tons. The results indicate the need of a longer time projection and continued update of the model data bases.

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EXECUTIVE SUMMARY

INTRODUCTION

Flue gas desulfurization (FGD) is the most practical approach for controlling sulfur oxides (SO_x) emissions for both future and existing power plants. The use of a higher cost clean fuel is another method, but proposed emission regulations are expected to begin to eliminate clean fuel as a total alternative for future plants. [This study does not include, however, the revised new source performance standards (NSPS) proposed in the September 19, 1978, Federal Register since it is an update to 1983 conditions and no boilers online by 1983 will be affected by the new regulation.] Most current FGD processes are wet-scrubbing systems which produce a waste sludge or a potentially salable byproduct such as sulfur or sulfuric acid. Determination of the most economical strategy for a particular application is often a difficult decision involving many complexly interrelated factors.

For several years the Tennessee Valley Authority (TVA), in conjunction with the U.S. Environmental Protection Agency (EPA) and others, has conducted economic studies related to FGD processes. As a part of these studies a computer-based byproduct marketing system was developed to evaluate the potential of marketing sulfur byproducts. It compared the economics of clean fuel and several FGD processes, including limestone scrubbing with waste sludge production, magnesia scrubbing with sulfuric acid production, and the Wellman-Lord/Allied Chemical scrubbing system which produces sulfur. The computer system contains data on over 900 U.S. power plants and the locally applicable regulatory information required to calculate scrubbing costs for each power plant. In the case of sulfuric acid production, the marketability of the acid is determined using data on U.S. sulfur and sulfuric acid transportation and the U.S. sulfuric acid manufacturing industry. General or specific cost comparisons can be made by assuming different alternative clean fuel level (ACFL) costs versus costs for the different scrubbing methods, including the possibilities and effects of byproduct marketing. The ACFL is a premium in dollars per MBtu assigned to fuel costs to represent a premium paid for low-sulfur coal. It includes additional transportation costs for obtaining a low-sulfur coal from a more distant source than that for a higher sulfur coal.

A definitive TVA report on system analysis of FGD byproduct sulfuric acid economics projected to 1978, Potential Abatement Production and Marketing of Byproduct Sulfuric Acid in the U.S. (hereafter referred to as Potential Abatement Production), was issued by EPA in 1978 (EPA-600/7-78-070, TVA Bulletin Y-122). The study is used as the basis for this update summary report and should be used as background.

Power plant abatement compliance decisions must be made to conform with anticipated conditions several years in advance. Securing regulatory agency approval and increased construction periods combine to extend the effects of decisions into a more distant and less certain future. In order to provide decision-making information, projects of this nature must use the latest available data and project as far in the future as can be reasonably substantiated.

This report is the first annual update report for Potential Abatement Production, and incorporates the latest available data for continuing refinement of the computer programs of the original byproduct marketing model. The results reported here are projected to 1983, using data available through September 1978. In addition, a manual analysis of FGD byproduct sulfur marketing as an alternate to FGD byproduct sulfuric acid marketing is included.

RESULTS

FGD Byproduct Sulfuric Acid

Potential 1983 Supply and Demand--

For 1983, 94 power plants with 165 boilers were considered to be out of compliance and were included in all model runs. In the $0.50 ACFL solution potential power plant supply was 800,000 tons, eastern smelter supply was 400,000 tons, and the western and Canadian supply was 700,000 tons and 200,000 tons respectively. The total potential supply of the $0.50 ACFL run was 2,100,000 tons. In the $0.70 ACFL solution potential power plant supply increased to 4,600,000 tons; potential smelter supply was the same as for the $0.50 ACFL solution. Total potential supply for the $0.70 ACFL solution was 5,900,000 tons. Total potential demand for both the $0.50 and the $0.70 solutions was 23,300,000 tons.

1983 $0.50 ACFL Solution--

In the 1983 $0.50 ACFL solution only five power plants were candidates for marketing. The solution indicated a market potential for four of the five plants considered. Because the number of plants was limited and because they were also included in the $0.70 ACFL solution, a detailed analysis was limited to the $0.70 solution.

1983 $0.70 ACFL Solution--

In the 1983 $0.70 ACFL solution 26 out of a total of 94 power plants were considered for marketing analysis as follows:

	Number of plants
All clean fuel	43
All limestone scrubbing	24
Mixed clean fuel and limestone scrubbing	1
Potential magnesia scrubbing	26
Total	94

The solution indicated a market potential for 7 of the 26 plants and total sales of 1,200,000 tons. At two plants market potential was limited to a part of the projected production and a mixed magnesia-scrubbing and clean fuel strategy was selected. A summary of the strategy selection process for plants in the solution is shown below.

	Number of plants
Magnesia scrubbing	5
Mixed magnesia scrubbing and clean fuel	2
All clean fuel	1
All limestone scrubbing	18
Total	26

Projected new boilers were a factor at six of the seven plants selected for marketing. They contributed almost 60% of the sales even though they constituted only 15% of the total number of boilers considered for marketing. The eastern and Canadian smelter supply was absorbed by the market in the 1983 solution. No sales potential for the western supply through transshipment terminals was indicated because of higher transportation costs.

The solution would be fairly stable in the event of a sulfur price reduction. Only 200,000 tons out of a total of 1,200,000 tons would be affected by a $20 per long ton sulfur price reduction.

FGD Byproduct Sulfur

There is considerable interest in elemental sulfur as a potential power plant FGD byproduct. Marketing advantages over sulfuric acid include over three times the equivalent sulfur concentration; nonhazardous, noncorrosive properties; easy stockpiling characteristics; less market competition in many locations; and recoverable energy, in the production of sulfuric acid, of approximately 8 MBtu per short ton of sulfur. The market for FGD byproduct sulfur is wider and potentially greater than the market for FGD byproduct sulfuric acid. Sulfur can be marketed as a raw material to all acid plants regardless of their size and production costs. FGD byproduct sulfuric acid marketing is typically limited to relatively small, high-production-cost acid plants.

Although no byproduct sulfur sales were shown in either the 1983 or the 1978 solutions, a sensitivity analysis showed that it would become competitive in certain locations with a relatively slight (10%) reduction in total FGD costs. At one power plant, for example, a reduction of 8.5% (1.18 M$ per year) of the total FGD cost (13.91 M$ per year) would result in the reduction in incremental cost required to enter the market in competition with sulfur delivered from Port Sulphur.

Of 16 plants that have relatively low estimated sulfur production costs compared with limestone scrubbing, the first plant would become competitive with a reduction in total FGD costs of only 3.1%. The other 15 plants would enter the market with reductions ranging from 5.4% to 23.7%. The combined production of these plants would be 265,723 short tons per year, equivalent to over 800,000 tons of sulfuric acid. This represents slightly over 3.0% of the projected 1983 sulfuric acid demand.

Marketing sensitivity to FGD byproduct sulfur is based on sulfur delivered from Port Sulphur at $70 per long ton plus delivery and handling expenses escalated to 1983. At the level of projected 1983 Port Sulphur delivered costs, Canadian sulfur recovered from sour gas could be more competitive in the Midwest and Great Plains where 6 of the 16 plants are located.

CONCLUSIONS

The overall effect of the 1983 update was a reduction of power plant FGD byproduct sulfuric acid sales compared with the 1978 projection. An increasing lead time associated with compliance strategy selection was apparent. A 5-year forecast appears to impose unjustified constraints on a realistic analysis of future marketing potential.

In the 5-year projection the relative marketing potential from projected boilers as opposed to existing boilers was greater than expected. Previous projections of only 1.5 to 2 years minimized the longer operating life advantage of projected boilers over existing boilers. Projected boilers are expected to dominate future solutions.

Although boilers reported to be in compliance are excluded from the model on the basis that strategy selection is final, this will not be necessarily true for projected boilers if the strategy selected is clean fuel. Proposed regulations, higher clean fuel premiums, and scrubbing technology improvements will alter the choice of clean fuel as a total compliance strategy for future boilers.

A reduction in the total supply considered because of alternate strategy selections as well as the higher FGD costs due to inflation were primarily responsible for reduced sales in the 1983 solution. Projections beyond the strategy selection lead time for future boilers (which are expected to be predominately coal fired) could increase future sales projections. The limited supply potential prevented a determination of the individual effect of increased transportation costs on sales projections. Nor could the individual effect of the suppressed escalation of avoidable production costs resulting from an updated steam credit be determined.

As FGD, transportation, and sulfuric acid avoidable production costs increase, correspondingly higher ACFL values will be required to fully analyze potential market interactions for extended projections to the extent that clean fuel can be used as an SO_x emission control approach.

FGD byproduct sulfur is not yet competitive with FGD byproduct sulfuric acid. A relatively small reduction (10% or less at nine power plants) in total FGD byproduct sulfur costs, however, could result in emergence of competitive FGD sulfur production. Sulfur is easier to store and handle than sulfuric acid. It also has marketing advantages in some locations.

RECOMMENDATIONS

An extended time frame is needed to lend more practical meaning to FGD byproduct marketing studies. Lead time required between decision and plant completion has increased substantially in recent years. It is critical, therefore, that projections be estimated as far in the future as is practical. Efforts should be made to obtain more recent data for better forecasts than have been available through conventional channels.

Emphasis should be placed on projected boilers since they dominate the 1983 solution and are expected to be the most likely candidates for FGD byproduct marketing.

Application of more stringent environmental regulations should be analyzed for effects on model solutions. Use of clean fuel may be eliminated as a single compliance strategy alternative for boilers coming online after 1984.

The model should be expanded to calculate scrubbing and marketing economics for projected boilers regardless of compliance by using clean fuel. New technology and higher clean fuel costs could significantly alter the economics of using clean fuel compared with the use of noncomplying fuels and scrubbing.

ACFL values greater than $0.70 per MBtu should be included in model runs projected beyond 1983.

Greater emphasis should be given to potential transportation advantages by water traffic. Backhaul potential should also be analyzed where applicable.

Projections of avoidable construction costs for future sulfuric acid plants should be developed. The current model only considers the costs that can be avoided by shutting down an existing or projected sulfuric acid plant operation. For future considerations it should also include all costs that can be avoided by <u>not building</u> and operating new plants.

Updated analysis of the potential for FGD byproduct sulfur should be continued. Technological changes affecting this, and other FGD processes, should be incorporated into the model as information becomes available.

POTENTIAL PRODUCTION AND MARKETING OF FGD BYPRODUCT SULFUR AND SULFURIC ACID IN THE U.S. - 1983 PROJECTION

INTRODUCTION

Air quality regulations have made it necessary for industries burning fossil fuels to greatly reduce the quantities of pollutants emitted in flue gas. Sulfur oxides (SO_x), the major gaseous pollutants in flue gas, have received particular attention, especially in the power industry with its many large, coal-burning plants (Kaplan and Maxwell, 1977). The use of naturally occurring low-sulfur fuel is not a universally applicable solution and coal-cleaning processes are not technically mature; therefore, most current emission control technology is directed toward flue gas desulfurization (FGD) processes.

The majority of the FGD processes now in use are scrubbing systems producing insoluble sulfites and sulfates which are either discarded as waste or processed to produce sulfur or a useful compound. The most widely used and technically advanced scrubbing systems use limestone or lime as an absorbent and produce a waste sludge of calcium sulfur salts. Others, designed to produce regenerated absorbent and a salable byproduct, include magnesia scrubbing which produces sulfuric acid and the Wellman-Lord/Allied Chemical system which produces sulfur.

Determination of the most suitable and economical emission control strategy for a particular application is often an important and difficult decision based on many complexly interrelated factors. For the past decade the Tennessee Valley Authority (TVA), in conjunction with the U.S. Environmental Protection Agency (EPA), has conducted design and economic evaluations of FGD systems to develop a systematic analysis of scrubbing costs applicable to general and specific situations in the power industry.

An important portion of these studies has been the development of a byproduct marketing analysis system to relate the effects of power industry manufacture of sulfuric acid from flue gas SO_x to FGD costs and to the U.S. sulfuric acid manufacturing industry. The first study (Waitzman et al., 1973) developed a limited computerized production-transportation-marketing analysis system which revealed both the complexity of such analytical techniques and the great potential benefit of an expanded computerized system in FGD studies.

In subsequent studies (Bucy et al., 1976; Corrigan, 1974) the computerized system was expanded and applied to other sulfur byproducts. In 1978 the result of a greatly expanded byproduct marketing system analysis was published as Potential Abatement Production and Marketing of Byproduct Sulfuric Acid in the U.S. (Bucy et al., 1978), hereafter referred to as Potential Abatement Production. This analysis incorporated data on over 900 U.S. power plants, comprehensive data on U.S. air quality regulations, extensive rail and barge transportation data, and manufacturing data on U.S. sulfuric acid producers. The data were used in the integrated program system of the byproduct marketing system to determine the economics of byproduct sulfuric acid manufacture in comparison with other emission control strategies under specific conditions in the power, transportation, and sulfuric acid industries. The results were based both on an analysis of FGD costs versus different clean fuel costs and on a determination of the marketability of the byproduct acid at the conditions used. The system may thus be used to determine the economics of FGD systems in a particular application or for a wide range of more general studies involving different economic or regulatory conditions.

The comprehensive Potential Abatement Production was based upon the latest data available at the time of the study. Federal Power Commission (now FERC, Federal Energy Regulatory Commission) power plant data from the period 1969-1973 were used. Other information was generally from the period 1970-1975. The data were projected by standard techniques to 1978 for use in the byproduct marketing system. Potential Abatement Production thus represents a projection to 1978.

This report utilizes data available through late 1978 and projects through 1983. Boilers online by the end of 1983 are assumed to not be affected by the revised new source performance standards (NSPS) proposed in the September 19, 1978, Federal Register. Since this report is based on projected 1983 conditions the new NSPS proposed regulations are not used. It is a summary report dealing only with the effects and results of the updated system. A full treatment of the background of the byproduct marketing system and the U.S. sulfuric acid industry is provided in Potential Abatement Production. The computer system is fully described in the Computerized FGD Byproduct Production and Marketing System: Users Manual (Anders, in press). The design and economic premises used to calculate FGD system costs are described in Detailed Cost Estimates for Advanced Effluent Desulfurization Processes (McGlamery et al., 1975).

A comprehensive description of the computer byproduct marketing system is presented in Appendix A. Also included in Appendix A is a brief description of the FGD processes included in the system. A review of the system description is essential to understanding the method by which the byproduct marketing results are generated.

A description of the data elements of the computer system that were updated from the 1978 projection to the 1983 projection is given in Appendix B. New boilers, updated regulations, capital and operating cost escalation, transportation (rail and barge) cost projections, sulfuric acid plant demand data base update, sulfur terminal selection, sulfuric acid avoidable cost update (including a major change in steam credit), smelter update, and modifications to the market simulation linear programing model are included.

RESULTS

FGD BYPRODUCT SULFURIC ACID

Potential 1983 Supply and Demand

For 1983, 94 power plants with 165 boilers were calculated to be out of compliance and were included in all model runs. The potential power plant FGD byproduct sulfuric acid production considered in any model run is a function of the alternative clean fuel level (ACFL) used. At the 1983 ACFL values of $0.50 and $0.70 per MBtu, the potential production considered from power plants alone was 800,000 tons and 4,600,000 tons respectively. The surplus Canadian production considered was 200,000 tons. The net western smelter surplus considered was 700,000 tons and the eastern smelter incremental production considered was 400,000 tons. The total potential production (supply) considered in the 1983 $0.50 and $0.70 ACFL solutions from all sources--power plants, eastern smelters, western smelters, and Canada--was 2,100,000 tons and 5,900,000 tons respectively. The total potential consumption (demand) considered in the 1983 model runs was 23,300,000 tons at 86 acid plant locations.

1983 $0.50 ACFL Solution

In the 1983 $0.50 solution only 5 power plants of the 94 estimated to be out of compliance were candidates for marketing. The solution indicated a market potential for four of the five plants and total sales were indicated to be 300,000 tons. The four plants, along with the consumers selected, are shown in Table 1. The fifth plant was included on the basis of a direct comparison between magnesia-scrubbing costs and the ACFL (limestone-scrubbing costs were higher than the $0.50 ACFL). No sales potential for this plant was indicated in the solution as a result of a $25.23 per ton incremental cost. The number of plants in the $0.50 ACFL solution was limited to five and the same five plants were also selected for marketing in the $0.70 ACFL solution. Because of this, a detailed analysis of 1983 results was limited to the $0.70 ACFL solution.

TABLE 1. FOUR POWER PLANTS MARKETING ACID IN THE 1983 $0.50 ACFL SOLUTION

Plant location	MW[a]	Tons of acid	Consumer	Location	Tons of acid
NC	1,440	67,000	Royster	Norfolk, VA	15,000
			Swift	Wilmington, NC	26,000
			Weaver	Norfolk, VA	26,000
MI	800	75,000	American Cyanamid	Joliet, IL	26,000
			American Cyanamid	Kalamazoo, MI	19,000
			Swift	Calumet City, IL	30,000
TX	1,410	102,000	Olin	Pasadena, TX	102,000
KY	500	71,000	American Cyanamid	Hamilton, OH	71,000
Total		315,000			315,000

a. MW = megawatts = million watts.

1983 $0.70 ACFL Solution

Model Generation Prescreen Strategy Selection--

In the $0.70 ACFL model, 26 power plants of the 94 estimated to be out of compliance were candidates for marketing. At 43 plants either limestone-scrubbing costs were greater than $0.70 per MBtu or incremental costs based on a magnesia-ACFL comparison were greater than $30 per ton. A clean fuel strategy was selected for these plants. At 24 plants, limestone-scrubbing costs were less than $0.70 per MBtu but the potential acid production was less than 66,000 tons per year. A limestone-scrubbing strategy was selected for these plants. At one plant, a mixed strategy of clean fuel and scrubbing was indicated. Because the potential production of acid from the partial scrubbing was less than 66,000 tons per year, a mixed strategy of clean fuel and limestone scrubbing was selected for this plant. The remaining 26 plants were selected for inclusion in the equilibrium solution for analysis of marketing potential. A summary of the results of the $0.70 ACFL model generation prescreen strategy selection is shown below.

	Number of plants
All clean fuel	43
All limestone scrubbing	24
Mixed clean fuel and limestone scrubbing	1
Potential magnesia scrubbing	26
Total	94

The potential production from these 26 plants was 4,600,000 tons of FGD byproduct sulfuric acid as shown in Table 2.

TABLE 2. TWENTY-SIX POWER PLANTS INCLUDED IN 1983

$0.70 ACFL SOLUTION FOR ANALYSIS OF MARKET POTENTIAL

Plant location	MW considered	Incremental cost, $/ton acid	Tons of acid considered
NC	1,440	0.00	67,592
IL	550	22.61	74,394
OH	680	37.76	137,133
OH	787	28.34	363,075
OH	413	27.70	67,243
IL	1,271	26.31	321,051
MI	1,283	22.59	197,390
MI	1,185	13.09	117,946
PA	525	51.66	69,209
KY	800	26.27	132,361
FL	1,280	12.15	196,573
TX	2,820	0.00	156,384
IL	2,342	20.24	402,939
IN	438	46.35	73,221
IN	1,239	25.96	156,607
KY	2,011	6.43	338,976
KY	682	40.22	161,584
KY	495	24.37	99,482
MS	877	37.84	67,862
PA	650	24.65	82,161
PA	615	37.44	68,664
IN	2,587	13.39	334,927
SC	595	29.51	100,205
TX	951	27.77	159,425
FL	1,136	27.83	226,708
MI	3,247	13.26	449,826
Total			4,622,938

Equilibrium Solution--

The 1983 \$0.70 ACFL equilibrium solution indicated a market potential for 7 of the 26 plants considered and total sales of 1,200,000 tons.

No market potential was indicated in the equilibrium solution for 19 of the plants included in the solution and previously shown in Table 2.

One plant included in Table 2 was considered in the 1983 solution on the basis of a direct comparison between magnesia-scrubbing costs and the ACFL (limestone-scrubbing costs were greater than \$0.70 per MBtu but incremental unit costs for acid production compared with the ACFL were less than \$30 per ton). No sales potential was indicated in the solution for this plant; projected incremental unit cost of the acid was \$24.37 per ton. A clean fuel strategy was selected for this plant.

The remaining 18 plants with no sales indicated were considered in the solution on the basis of an incremental cost resulting from a limestone- versus magnesia-scrubbing cost comparison. A limestone-scrubbing strategy was selected for these plants.

Two of the seven plants selected for marketing had a potential market for only part of their projected production. In both cases there was an acceptable match between the market potential and the use of a mixed scrubbing and clean fuel strategy. These plants (shown previously in Table 2) were selected for a combined magnesia-scrubbing and clean fuel strategy as shown below.

Plant location	MW[a] scrubbed	MW using clean fuel	Tons of acid
MI	800	385	75,000
MI	2,430	817	335,000

a. MW = megawatts = million watts

A summary of the strategy selection for plants in the equilibrium solution is shown as follows:

	Number of plants
All clean fuel	1
All limestone scrubbing	18
Mixed clean fuel and magnesia scrubbing	2
Magnesia scrubbing	5
Total	26

Strategy Selection Summary--

There were a total of 94 power plants considered in the 1983 $0.70 ACFL model. Of these, 68 plants were not candidates for marketing analysis. After the model was solved and the foregoing equilibrium solution generated the strategies for the remaining 26 plants, the strategy selection for all 94 plants became:

	Number of plants
All clean fuel	44
All limestone scrubbing	42
Mixed clean fuel and limestone scrubbing	1
Mixed clean fuel and magnesia scrubbing	2
Magnesia scrubbing	5
Total	94

The seven power plants with marketing potential indicated were ranked using the following four criteria: (1) the balance between the production capacity of each power plant and its potential market, (2) the balance between the acid capacity of each consumer and the byproduct acid supply from both power plants and smelters, (3) the potential sales margin per ton of acid from each power plant, and (4) the sales indicated in the $0.50 solution. The power plants and acid plants selected and the projected sales are shown in Table 3. The order of the power plants in the table reflects the results of the ranking analysis.

TABLE 3. SEVEN POWER PLANTS MARKETING ACID IN THE 1983 $0.70 ACFL SOLUTION

Ranked order	Plant location	MW	Tons of acid	Consumer	Location	Tons of acid
1	NC	1,440	67,000	Royster	Norfolk, VA	15,000
				Swift	Norfolk, VA	26,000
				Weaver	Norfolk, VA	26,000
2	KY	2,011	339,000	Allied	Nitro, WV	101,000
				American Cyanamid	Hamilton, OH	71,000
				Army Ammun. Plant	Radford, VA	125,000
				Marion	Indianapolis, IN	42,000
3	TX	2,820	156,000	Olin	Pasadena, TX	156,000
4	MI	800	75,000	American Cyanamid	Joliet, IL	38,000
				American Cyanamid	Kalamazoo, MI	7,000
				Swift	Calumet City, IL	30,000
5	MI	2,430	335,000	Du Pont	North Bend, OH	131,000
				Du Pont	Cleveland, OH	150,000
				Allied	Cleveland, OH	54,000
6	FL	1,280	197,000	Kerr-McGee	Cottondale, FL	11,000
				Royster	Mulberry, FL	186,000
7	IL	550	74,000	USI Chemical	Tuscola, IL	74,000
Total			1,243,000			1,243,000

Projected Boilers--

There were 26 projected boilers at 22 plants included in the 165 boilers at 94 power plants considered in the 1983 model. Of the 26 boilers, 9 were eliminated from consideration in the model generation prescreen. They were at five plants selected for limestone scrubbing because of limited production potential and at four plants selected for clean fuel. The remaining 17 projected boilers were at 13 of the 26 plants included in the equilibrium solution.

Projected boilers were a factor at six of the seven plants selected for marketing. At the 7 plants a total of 10 projected boilers were selected for magnesia scrubbing compared with 7 existing boilers selected. The production and sales from projected boilers considered in the equilibrium solution was 700,000 tons and from existing boilers only 500,000 tons.

The remaining seven projected boilers considered in the equilibrium solution were at plants with no sales indicated. One of the seven boilers was at the plant with incremental costs based on a magnesia-ACFL comparison and therefore selected for clean fuel. The remaining six boilers were at six plants selected for limestone scrubbing.

In summary, projected boilers contributed almost 60% of the 1983 sales even though they made up only 15% of the total number of boilers considered for acid sales. Existing boilers were 85% of the total number of boilers considered in 1983 but they contributed only 40% of projected sales.

Smelter Sales--

The eastern smelter incremental production projected for 1983 was absorbed by the market in the equilibrium solution. The eastern smelters and the consumers selected are shown in Table 4. The Canadian incremental production projected for 1983, also absorbed by the market as before, is shown in Table 5.

No marketing potential through transshipment terminals for the western smelter projected production was indicated in the solution. This loss of market potential for the western supply is a result of the relatively higher rate of increase in projected rail costs compared with projected avoidable production costs of sulfuric acid.

TABLE 4. THIRTEEN EASTERN SMELTERS MARKETING ACID IN THE 1983 $0.70 ACFL SOLUTION

Smelter	Location	Tons of acid	Consumer	Location	Tons of acid
N.J. Zinc	PA	26,000	Du Pont	Gibbstown, NJ	26,000
St. Joe Minerals	MO	14,000	Monsanto	E. St. Louis, IL	14,000
AMAX	IL	12,000	Monsanto	E. St. Louis, IL	12,000
AMAX	MO	7,000	Monsanto	E. St. Louis, IL	7,000
Engelhardt Zinc	OK	9,000	Pennsalt	Tulsa, OK	9,000
St. Joe Minerals	PA	54,000	Eastman	Rochester, NY	5,000
			3-M	Copley, OH	49,000
Cities Service	TN	200,000	Army Ammun. Plant	Tyner, TN	99,000
			Army Ammun. Plant	Radford, VA	34,000
			Reichold	Tuscaloosa, AL	41,000
			Home Guano	Dothan, AL	8,000
			Columbia Nitrogen	Moultrie, GA	18,000
ASARCO	TX	16,000	El Paso Products	El Paso, TX	16,000
AMAX	IL	48,000	Monsanto	E. St. Louis, IL	48,000
ASARCO	TX	13,000	Stauffer	Ft. Worth, TX	13,000
ARMCO	OH	2,000	Allied	Cleveland, OH	2,000
Climax Molybdenum	PA	8,000	Allied	Cleveland, OH	8,000
Climax Molybdenum	IA	10,000	USI Chemical	Dubuque, IA	10,000
Total		419,000			419,000

TABLE 5. MARKET DISTRIBUTION OF CANADIAN INCREMENTAL ACID IN 1983 $0.70 ACFL SOLUTION

Terminal	Tons of acid	Consumer	Location	Tons of acid
Buffalo	200,000	American Cyanamid	Bound Brook, NJ	49,000
		Du Pont	Cornwell Hgts., PA	56,000
		Essex	Newark, NJ	12,000
		Du Pont	Gibbstown, NJ	57,000
		Cities Service	Monmouth Jct., NJ	26,000
Detroit	0			
Total	200,000			200,000

Sensitivity of the Sulfur Price--

The 1983 $0.70 solution was based on a sulfur price of $70 per long ton ($62.50 per short ton) f.o.b. Port Sulphur. Analysis showed the solution to be fairly stable even if the sulfur price were to be reduced by $20 per long ton. Only two of the seven power plants producing and marketing sulfuric acid would be affected. A $20 per long ton sulfur price reduction would affect 1983 solution markets amounting to 200,000 tons of the 1,200,000 tons in the solution.

Comparison of 1978 and 1983 Results

Revisions to the marketing model (explained in Appendix B) to allow 5-year projections to 1983 produced results that were significantly different from 1978 results. Projected scrubbing cost escalations eliminated the 1983 $0.35 ACFL model. Updated compliance status reduced the number of candidates in the $0.50 and $0.70 ACFL models. Both the 1978 and 1983 $0.70 ACFL models contain the same plants included in the respective $0.50 ACFL models. For these reasons, detailed comparisons between the 1978 and 1983 models were limited to the $0.70 ACFL.

Model Generation and Equilibrium Solutions--

In the 1978 model, 187 plants with 833 boilers were considered to be out of compliance and were included in all model runs. Limestone-scrubbing costs greater than the $0.70 ACFL and potential sulfuric acid production of less than 66,000 tons per year eliminated 127 plants (the direct magnesia-ACFL comparison was not used). The remaining 60 plants with a total potential production of 10,800,000 tons were included in the equilibrium solution. The solution indicated a market potential for 29 of the 60 plants and total sales of 5,600,000 tons. These plants are shown in Table 6.

TABLE 6. TWENTY-NINE POWER PLANTS MARKETING ACID IN THE 1978 $0.70 ACFL SOLUTION

Plant location	MW	Tons of acid
NY	1,200	75,016
IL	616	126,448
IL	590	77,549
IL	602	96,692
TX	836	125,523
OH	1,255	379,768
IL	1,271	281,208
NC	2,286	105,209
FL	964	192,742
GA	1,792	253,367
GA	1,820	255,939
KY	1,011	148,978
NY	1,511	126,735
PA	650	72,342
PA	1,600	241,426
PA	940	72,786
IN	1,062	147,606
AL	910	68,824
TX	634	95,195
FL	1,136	250,963
TN	1,482	301,246
TN	1,723	223,146
KY	2,558	628,358
TN	2,660	572,320
OH	1,831	254,335
MO	1,150	67,997
MO	1,100	176,480
VA	845	68,606
MO	527	108,149
Total		5,594,953

Only nine plants with sales in the 1978 solution were included in the 1983 solution and only three of the nine had sales indicated. Boilers projected for 1983 were a factor in the 1983 sales at the three plants having sales in both 1978 and 1983. At two of the three plants, boilers projected for 1983 were the sole basis for 1983 sales, rather than the existing boilers that were the basis for sales in 1978.

The 26 plants with 1978 sales excluded from 1983 sales can be grouped by compliance status, scrubbing cost escalations, the size-age screen, and insufficient production potential. In the first group, 12 plants were projected to be in compliance in 1983 because of adoption of other scrubbing strategies, use of complying fuels, or application of less stringent regulations. These 12 plants had sales of 2,800,000 tons in 1978. Updated compliance status therefore eliminated 50% of the 1978 sales from the 1983 model. Six plants were considered in the 1983 solution but had no sales. In the 1978 solution these six plants had sales of 1,200,000 tons, 21% of the 1978 total. Five plants did not pass the 1983 $0.70 ACFL screen. Sales at these plants were 600,000 tons, 11% of the 1978 total. Escalated scrubbing costs therefore eliminated 33% of the 1978 sales from the 1983 model. Two plants with sales of 500,000 tons were excluded by the size-age screen. The size-age screen thus eliminated 9% of the 1978 sales from the 1983 model. One plant with sales of 100,000 tons in 1978 had a potential production in 1983 of less than 66,000 tons; insufficient production thus eliminated 2% of the 1978 sales from the 1983 model.

The plants with projected 1978 sales that were excluded from sales in the 1983 model are summarized as follows:

Number of plants	Reason for exclusion from 1983 consideration or sales	1978 sales, tons	% of total 1978 sales
12	Alternate strategies, complying fuels, or less stringent regulations	2,800,000	50
6	Included in solution but no sales because of incremental costs	1,200,000	21
5	1983 limestone-scrubbing costs >$0.70 per MBtu or magnesia-ACFL incremental costs >$30 per ton	600,000	11
2	Size-age screen	500,000	9
1	Potential production <66,000 tons per year	100,000	2
26	Total	5,200,000	93

The 1983 sales were about 22% of the 1978 sales. The total loss of 1978 sales described above amount to 93%. The 93% loss of 1978 sales was partially offset by a gain of 15% from the plants added for 1983.

Projection and Cost Escalation Effects--

The supply and demand patterns for both the power plants and smelters (Tables 3-5) in the 1983 solution emphasize the localized nature and limited amount of market interaction compared with the 1978 solution. These were due to the continuing effects of the relatively higher projected rates of cost escalation for scrubbing and transportation as compared with avoidable production costs.

In addition to the direct effects of cost escalation, an indirect effect on the 1983 projection resulted from the fact that boilers online or scheduled to be online before the end of 1978 had 5 fewer years remaining life in 1983. The individual effects of escalation and aging are difficult to identify separately but the combined effects can be illustrated by incremental costs. Six power plants that had sales indicated in the 1978 solution were included in the 1983 solution but had no sales. These plants with their comparative incremental costs per ton of acid for 1978 and 1983 are shown in Table 7. Even if transportation costs had been held constant the changes in FGD incremental costs alone would probably have eliminated these plants from any market potential.

TABLE 7. INCREMENTAL COSTS OF SIX POWER PLANTS

WITH SALES IN THE 1978 $0.70 ACFL SOLUTION BUT NO SALES

IN THE 1983 $0.70 ACFL SOLUTION

Plant location	Incremental cost, $/ton 1978	1983
OH	12.47	28.34
IL	11.47	26.31
PA	8.85	24.65
PA	18.47	37.44
TX	16.12	27.77
FL	16.72	27.83

Strategy Selection Summary, 1978 and 1983--

The 1983 projection can be summarized as being a reduction in both the number of plants and the potential sales compared with the 1978 model. The reasons for the reduction have been discussed in detail. A summary of the strategy selections made on the basis of the 1978 and 1983 byproduct marketing model results at the $0.70 ACFL is shown as follows:

	Number of plants 1978	1983
All clean fuel	71	44
All limestone scrubbing	77	42
Mixed clean fuel and limestone scrubbing	10	1
Mixed clean fuel and magnesia scrubbing	0	2
Magnesia scrubbing	29	5
Total	187	94

FGD BYPRODUCT SULFUR

There is considerable interest in elemental sulfur as a potential power plant FGD byproduct. It has marketing advantages over sulfuric acid which include:

1. Over three times the equivalent sulfur concentration, resulting in significant freight and storage cost reductions.

2. Nonhazardous, noncorrosive properties.

3. Easy stockpiling characteristics for prolonged periods of low demand.

4. Less market competition than with a sulfuric acid FGD byproduct in many locations.

It also has an added value of recoverable energy, in the production of sulfuric acid from sulfur, of approximately 8 MBtu per short ton of sulfur converted to sulfuric acid. Thus far, however, the FGD costs for producing sulfur by the Wellman-Lord/Allied Chemical system have been higher than those for the limestone-scrubbing process or the magnesia-scrubbing process with byproduct sulfuric acid. There were no markets for FGD sulfur in either the 1983 or 1978 solutions. Its marketing potential, however, warrants closer analysis.

The market for FGD byproduct sulfur is wider and potentially greater than the market for FGD byproduct sulfuric acid. Sulfur can be marketed as a raw material to all acid plants regardless of their size and production costs. FGD byproduct sulfuric acid marketing is typically limited to relatively small, high-production-cost acid plants.

In this 1983 projection there were 16 power plants whose FGD byproduct sulfur incremental costs (above the limestone-scrubbing cost) were projected to be under $250 per short ton. These plants were selected to illustrate the FGD sulfur marketing sensitivity to potential cost reductions.

The incremental FGD byproduct sulfur cost of the 16 lowest plants in the 1983 projections does not look promising as compared with 1983 Port Sulphur Frasch sulfur projected at $62.50 per short ton ($70 per long ton). All of these plants would have to reduce their incremental sulfur production costs to less than 50% of the 1983 projection in order to compete with sulfur from Port Sulphur.

On the other hand, a closer look at the actual FGD costs involved indicates a more encouraging future potential for FGD byproduct sulfur production. Basing the needed cost reduction on unit incremental costs can be misleading. Consider, for example, a power plant producing FGD byproduct sulfur which would have to reduce its incremental cost to less than one-third of the 1983 projection in order to compete with Port Sulphur sulfur on a delivered cost basis. On the basis of the total costs of FGD (13.91 M$ per year in this example), however, a reduction of only 8.5% (1.185 M$ per year) of the total production cost of the FGD process producing byproduct sulfur will accomplish the reduction in incremental cost required to enter the elemental sulfur market in competition with sulfur delivered from Port Sulphur.

Table 8 lists the 1983 projected power plants with the lowest sulfur production costs, cumulative tonnage from these plants if they adopt a sulfur-producing FGD system, and the reduction in total FGD cost required to enter the market competitively.

The first plant is shown to become competitive with a reduction in total FGD costs of only 3.1%. The other 15 plants progressively enter the market with reductions in their respective total FGD costs ranging from 5.4% to 23.7%. The combined market of these plants at the cost reduction levels shown is 265,723 tons per year, equivalent to over 800,000 tons of sulfuric acid. This represents approximately 3% of the 1983 projected sulfur demand. Table 8 also shows that almost half of this annual tonnage becomes competitive with reductions in total FGD costs of less than 10%. A graphic presentation of these data is shown in Figure 1 which is a plot of percent reduction in total FGD costs versus cumulative sulfur tonnage competitive with estimated 1983 Port Sulphur delivered cost.

It should be noted that three of the power plants are projected to be marketing FGD byproduct sulfuric acid in 1983. Two of these plants have a significant annual net revenue from these sales and the third has a very small net revenue. In order to meet the competitive alternative of byproduct sulfuric acid in these three cases, the sulfur delivered price would have to be additionally reduced by the amount of net revenue from projected byproduct sulfuric acid. This results in an adjustment in the required reduction in FGD costs.

TABLE 8. MARKETING SENSITIVITY TO FGD

BYPRODUCT SULFUR COST REDUCTION - 1983

State	Cumulative potential 1983 sulfur market, short tons	% reduction in total FGD costs required to market byproduct sulfur production[a]
KS	30,029	3.1
IL	45,751	5.4
IN	58,236	6.0
TX	69,489	6.2
FL	74,981	6.2
WV	85,821	7.3
IA	87,713	7.9
NC	94,677	8.5
NM	102,332	8.8
NC	122,593[b]	9.0
TX	169,469[b]	11.2
WI	184,876	14.9
DE	196,643	15.1
KY	226,463	18.1
IL	248,763[b]	18.2
UT	265,723[c]	23.7

a. Not adjusted to compete with alternative of FGD byproduct sulfuric acid.
b. Marketing FGD byproduct sulfuric acid in 1983 model solution.
c. Includes only marketable portion (46%) of potential FGD byproduct sulfur production from this power plant.

In one instance this adjustment increases the required FGD cost reduction from 9.0% to 12.8%. Another power plant must reduce costs by 15.8% to reflect this adjustment from a required reduction of 11.2% to meet sulfur competition only (as shown in Table 8 and Figure 1). Table 9 shows the effects of this adjustment for competitive byproduct sulfuric acid sales. Figure 2 is a graphic presentation of these data.

It should be noted that marketing sensitivity to FGD byproduct sulfur data is presented primarily for illustration purposes. Competition is based on sulfur delivered from Port Sulphur at $70 per long ton plus delivery and handling expenses escalated to 1983.

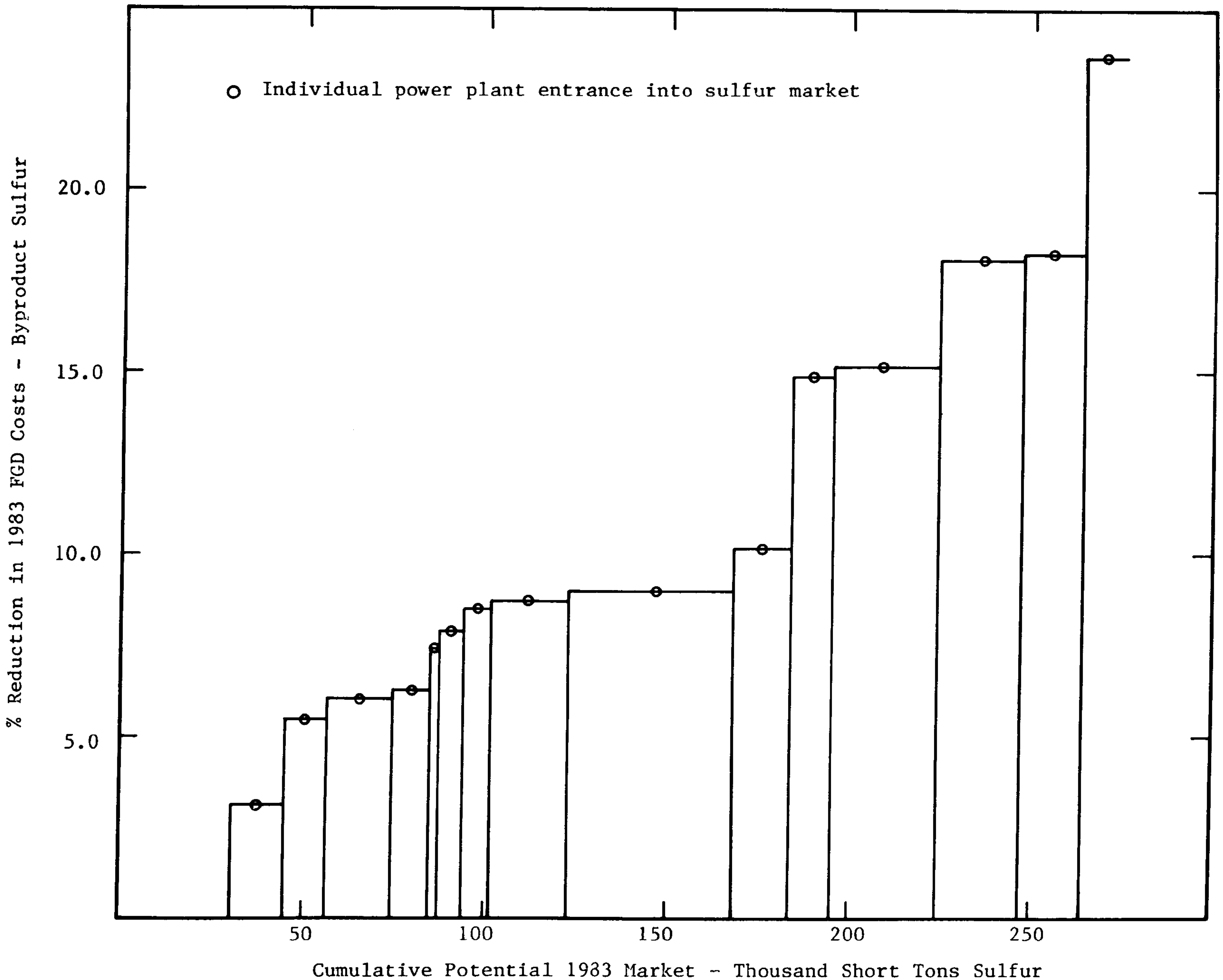

Figure 1. Marketing sensitivity to FGD byproduct sulfur cost reduction - 1983.

TABLE 9. MARKETING SENSITIVITY TO FGD

BYPRODUCT SULFUR COST REDUCTION - 1983

(Adjusted for byproduct sulfuric acid competition)

State	Cumulative potential 1983 sulfur market, short tons	% reduction in total FGD costs required to market byproduct sulfur production
KS	30,029	3.1
IL	45,751	5.4
IN	58,236	6.0
TX	69,489	6.2
FL	74,981	6.2
WV	85,821	7.3
IA	87,713	7.9
NC	94,677	8.5
NM	102,332	8.8
NC	122,593	12.8[a]
WI	138,000	14.9
DE	149,767	15.1
TX	196,643	15.8[a]
KY	226,463	18.1
IL	248,763	18.4[a]
UT	265,723[b]	23.7

a. Adjusted to compete with alternative of FGD byproduct sulfuric acid.

b. Includes only marketable portion (46%) of potential FGD production from this power plant.

At the level of projected 1983 Port Sulphur delivered costs, Canadian sour gas recovered sulfur could be more competitive than the Port Sulphur source. This is especially true of Midwestern and Great Plains locations. Six of the 16 plants in the illustration are in these areas and may be in the range of competitive Canadian sulfur supplies.

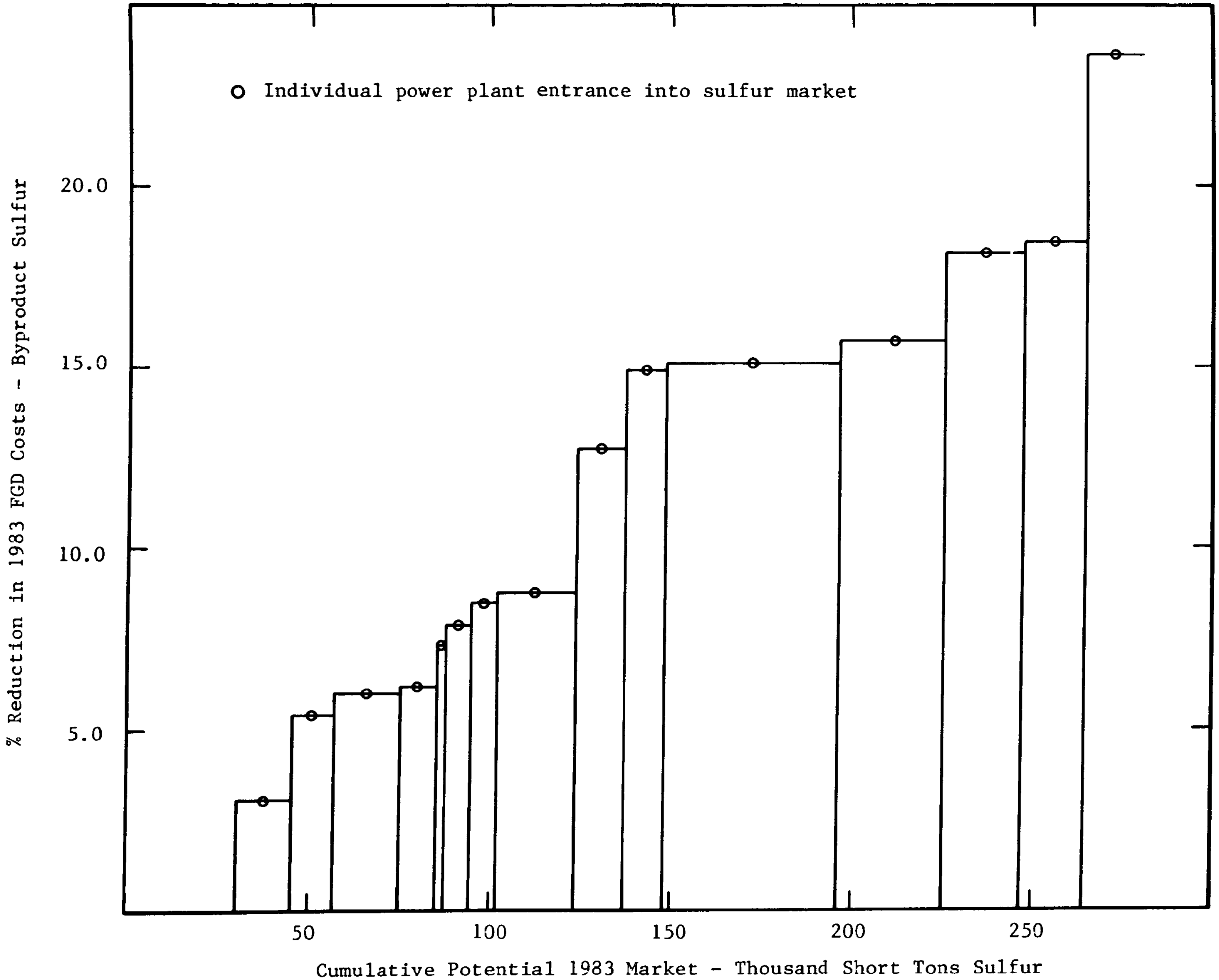

Figure 2. Marketing sensitivity to FGD byproduct sulfur cost reduction - 1983. (Adjusted for byproduct sulfuric acid competition.)

CONCLUSIONS

The overall effect of the 1983 update was a reduction of power plant FGD byproduct sulfuric acid sales compared with the 1978 projection. The 1978 model was generally based on data from the period 1970 to 1975. Although the 1983 model was based on updated data through late 1978, the model structure itself was essentially unchanged. Some of the assumptions and constraints used for the 1970 to 1978 time period may be unnecessarily limiting for extended future projections.

The time period of model development and prior model runs was characterized by uncertainty. Many power plants developed a "wait and see" posture until more stable conditions evolved. Much of the uncertainty has been resolved and previous sales candidates have chosen other strategies as indicated in the update. At the same time, again as a result of more stable conditions, alternate compliance strategies for projected boilers are being selected concurrently with construction plans. (Based on the updated data, 23 projected boilers that have already selected limestone scrubbing and 49 projected boilers that have already selected clean fuel would otherwise have been included in the model.) The elimination of candidates, because of alternate strategy selection, affected the 1983 solution more than all of the other updated conditions. The limited potential production for marketing that resulted made the effects of other changes difficult to assess.

An increasing lead time associated with compliance strategy selection was apparent from the 1983 projection. Even a 5-year forecast appears to impose unjustified constraints on a realistic analysis of future marketing potential.

The 5-year projection to 1983 illustrated, as expected, that projected boilers are more likely candidates than existing boilers for the potential production and marketing of FGD byproduct sulfuric acid. Existing boilers have fewer remaining years of useful life over which to amortize FGD capital costs. In addition, capital investment is higher for FGD retrofit installations. The 1983 model in effect delayed FGD implementation 5 years for the boilers in the 1978 model. This delay significantly altered the economics of strategy selection for existing boilers. They are expected to contribute even less to sales in extended future projections. Based on the 1983 results, the relative marketing potential of projected boilers was greater than expected and they should completely dominate more extended projections. The greater than expected effect can be attributed to previous model projections of only 1.5 to 2 years in which the advantages of projected boilers were minimized.

In the current model boilers for which a strategy has already been selected are not considered; strategy selection is assumed to be final. While the selection of a scrubbing strategy may be final, this is not necessarily true of a clean fuel strategy, especially for future plants. There are several factors that could greatly alter both the choice and the economics of a clean fuel strategy. For example, improvements are being made in existing technology and new scrubbing processes are emerging, regulations recently proposed by EPA will eliminate clean fuel as a total compliance alternative for future plants (power plants projected to come online after 1984 will come under the revised NSPS proposed in the September 19, 1978, Federal Register) and clean fuel premiums are expected to increase.

In addition to a reduction in the total supply considered, higher FGD costs due to escalation were also responsible for the reduced sales indicated in the 1983 solution. Projections beyond the strategy selection lead time for projected boilers, which are expected to be predominately coal fired, could increase future sales projections. Transportation costs were also escalated but the escalation in avoidable production costs that would be expected was suppressed by the updated heat credit. The limited supply potential prevented a determination of the overall effects on sales projections of either the escalated transportation costs or the suppressed escalation of avoidable production costs resulting from the updated steam credit.

As FGD, transportation, and avoidable production costs for sulfuric acid increase, correspondingly higher ACFL values will be required to fully analyze potential market interactions for extended projections. Limiting the 1983 model to the $0.70 ACFL is not estimated to have affected sales. At a $1.00 ACFL value only 14 additional plants would have been included in the model. The incremental costs of these plants made additional sales highly unlikely.

The 1983 solution was relatively insensitive to a $20 per long ton potential sulfur price reduction. The distribution of 200,000 tons of acid from two power plants would be affected by such a reduction. Sales could possibly be obtained for this 200,000 tons at other less profitable demand points.

As in the 1978 solution, no byproduct sulfur was produced and marketed in the 1983 solution. There are, however, indications that it is not as noncompetitive as it appears from an examination of incremental FGD byproduct sulfur costs above limestone-scrubbing FGD costs. There were only 16 power plants in the 1983 projection with incremental costs of less than $250 per short ton of sulfur (compared with $62.50 per short ton at Port Sulphur). However, a 10% reduction in total FGD costs could make nine of these plants competitive with Port Sulphur or FGD byproduct sulfuric acid. A technological advance in FGD byproduct sulfur production which reduced total FGD costs by 10% or more could result in commercial feasibility at some locations.

Transportation is already a major factor in FGD byproduct marketing considerations. The advantage of barge over rail transportation is increasing and access to water transportation is becoming increasingly important. A reduction in acid transportation costs by the use of barge shipments could offset some of the effects of other cost escalations and increase future production and marketing potential.

RECOMMENDATIONS

Projections should be developed to a more extended time frame. The increasing lead time required to analyze options and implement decisions almost mandates a minimum of 10-year forecasts. Emphasis in the next 2 years should be directed toward obtaining the best available data for a 1990 projection.

Efforts should be made to obtain more recent data for forecasting (including power plant projections) than have been available through conventional channels.

Emphasis should be placed on projected boilers. They dominate the 1983 solution and are expected to be the most likely candidates for FGD byproduct marketing.

Application of more stringent environmental regulations should be analyzed for their effects on model solutions.

The model should be expanded to calculate scrubbing and marketing economics for projected boilers regardless of compliance as a result of clean fuel usage. There are several factors that could significantly alter the economics of using clean fuel compared with the use of noncomplying fuel and scrubbing. Foremost among these factors is the future application of the revised NSPS calling for 85% to 90% sulfur removal from the fuel supply. Decisions based on current information and technology should not preclude the consideration of future possibilities involving clean fuel and scrubbing strategies.

ACFL values greater than $0.70 per MBtu should be included in future model runs.

Greater emphasis should be given to potential transportation advantages by water traffic. Backhaul potential should be analyzed where applicable.

Projections of avoidable construction costs for future sulfuric acid plants should be developed. The current model only considers the costs that can be avoided by shutting down an existing or projected sulfuric acid plant operation. For future considerations it should also include all costs which can be avoided by not building and operating new plants. Purchase of FGD sulfuric acid byproduct is, of course, an alternative to the construction of new sulfuric acid plants as demand increases.

Updated analysis of the potential for FGD byproduct sulfur should be continued. Technological changes affecting this and other FGD processes should be incorporated into the model as information becomes available.

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APPENDIX A

SYSTEM DESCRIPTION

CONTENTS

APPENDIX A

SYSTEM DESCRIPTION

BYPRODUCT MARKETING COMPUTER SYSTEM

The byproduct marketing system consists of a number of integrated computer programs, data bases, and models which can be used to compare costs of different emission control strategies. Five strategies are now programed in the system: the use of clean fuel instead of FGD, limestone scrubbing with sludge waste disposal, limestone scrubbing with gypsum production, magnesia scrubbing with sulfuric acid production, and the Wellman-Lord/Allied Chemical system which produces sulfur. In the case of magnesia scrubbing the system determines the marketability of the acid produced using programs and data bases on sulfuric acid transportation costs and on the U.S. sulfuric acid manufacturing industry. In this investigation the use of clean fuel, limestone scrubbing with sludge waste disposal, and magnesia scrubbing with sulfuric acid production were compared and costs for the Wellman-Lord/Allied Chemical system were determined.

The byproduct marketing system is shown diagrammatically in Figure A-1. It can be divided into four subsystems. The supply subsystem consists of data bases and programs which provide data on power plants, emission control regulations, raw material costs, and FGD design and cost data. These can be used to determine scrubbing costs on a boiler-by-boiler basis for each power plant in the data base. The demand subsystem consists of programs and data bases on sulfur transportation costs and acid plant operating costs which are used to determine acid plant avoidable production costs. The transportation subsystem consists of data bases and programs to provide rail mileages, tariffs, and rate-basing information as well as data from the other subsystems. It is used to calculate acid transportation costs. The fourth subsystem consists of a linear program model generator, a linear program model solution generator, and various optional report generators. It uses the results of the other three subsystems to select the least-cost option for each power plant included in the system.

The data used in the system have been compiled from a wide range of U.S. Government, TVA, and published sources (Bucy et al., 1978; McGlamery et al., 1975). The data include over 3,500 boilers representing over 900 power plants and all acid plants and smelters in the 37 Eastern States for which there exists a railroad rate-basing system (Figure A-2) necessary to the transportation subsystem. Excess acid supply from the 11 Western States and Canada is included in the linear programing model as a manually calculated factor. The calculation of scrubbing costs is based on design and economic premises developed by TVA and EPA to compare the economics of scrubbing systems (McGlamery et al., 1975).

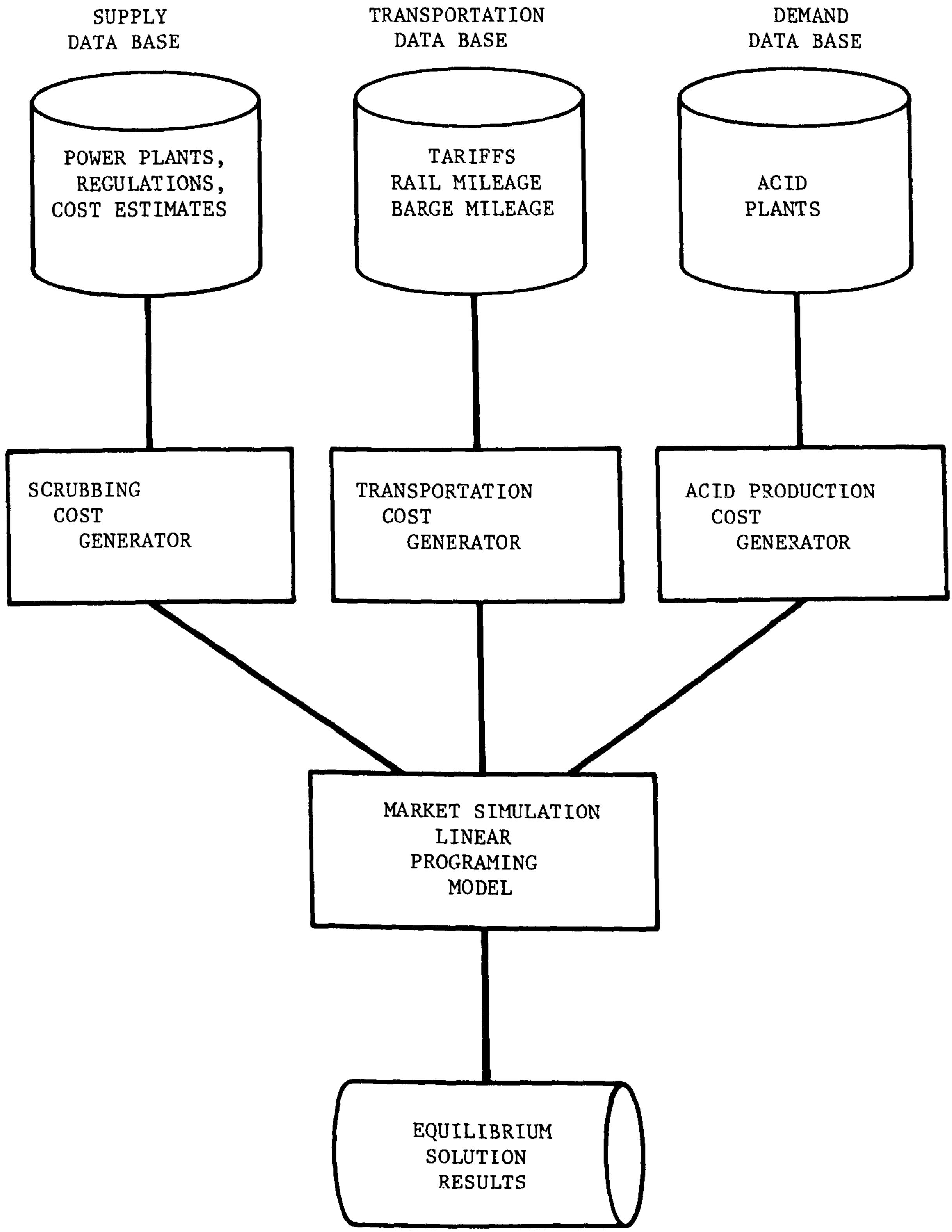

Figure A-1. Byproduct marketing model.

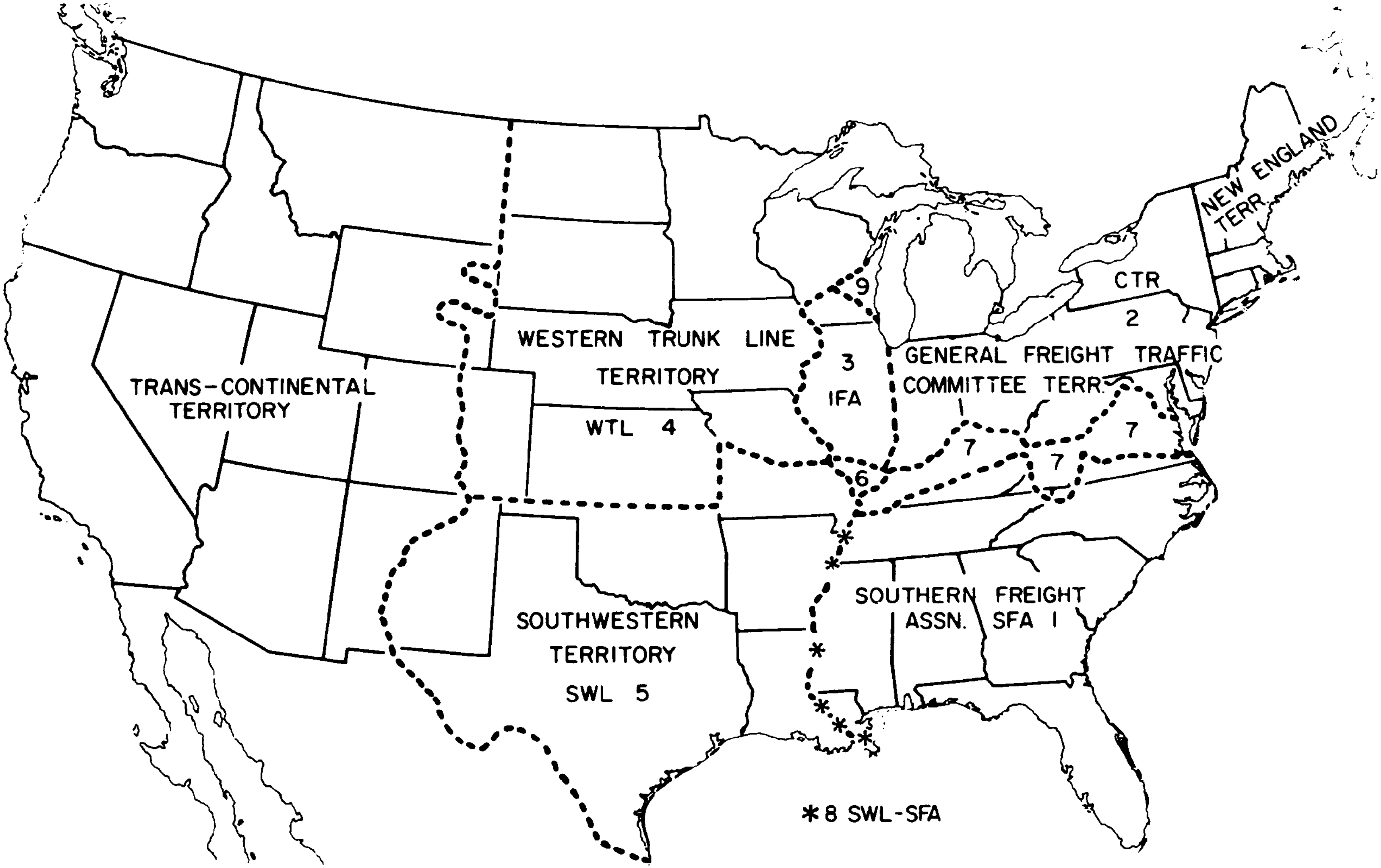

Figure A-2. Railroad rate territories.

The byproduct marketing system is designed on the basis of several assumptions important to a conceptualization of the evaluation process. (1) The cost of sulfuric acid produced in the magnesia-scrubbing system is based on the incremental cost difference between the magnesia system and the limestone (including sludge disposal) or clean fuel strategy used for comparison, plus the cost of transportation to the consumer. (2) All byproduct acid is assumed to be sold to acid plants manufacturing acid from sulfur which can reduce their costs by buying acid, at a price determined as described above, instead of manufacturing it themselves. (3) It is assumed that total acid consumption is unaffected by byproduct acid production. All byproduct acid is assumed to replace acid manufactured from sulfur. As a corollary, smelters are assumed to be producers of necessity. All smelters are assigned an acid production based on their compliance with applicable emission regulations and this is included in the total supply. (4) The marketing model does not consider elements of profit or maximization of benefits for a particular industry. Each model solution is an optimum situation in which all acid producers, transportation networks, and acid plant consumers are integrated into a system that provides for the greatest byproduct acid revenue within the restrictions imposed by the program design. (5) The additional cost assigned to the ACFL as compared with noncomplying fuel is also used as a screening technique in the model. By assigning particular ACFL values the structure of the model, in terms of power plants included and comparisons made, can be varied to compare the effects of different costs of compliance.

FGD PROCESS DESCRIPTIONS

All of the FGD systems used in this evaluation are scrubbing processes in which the flue gas is contacted with a suspension or solution of absorbent in water. The SO_x in the flue gas reacts with the absorbent to form sulfur salts. A purge stream is removed and fresh absorbent added to maintain equilibrium concentrations in the scrubber system. All of the processes are in use or have been tested in full-scale operation (Herlihy, 1977). The FGD systems are assumed to be installed downstream from existing air heaters and particle removal equipment. All FGD equipment is provided, including raw material handling systems, auxiliary processing equipment to produce and store byproducts, and waste disposal facilities.

The limestone FGD system consists of a scrubbing system in which a suspension of finely ground limestone is contacted with the flue gas to form calcium sulfite and calcium sulfate. The purge stream is pumped to a disposal pond without further treatment. The system is characterized by large raw material and land requirements, and relatively low energy, capital, and operating costs.

The magnesia FGD system is a similar scrubbing process using magnesia as the absorbent. The magnesium sulfite formed is removed from the purge stream, dried, and calcined to regenerate magnesia and sulfur dioxide. The magnesia is returned to the scrubber system and the sulfur dioxide is processed to sulfuric acid in an onsite acid plant. The system is characterized by lower raw material and land requirements and higher energy, capital, and operating costs, relative to the limestone system.

The Wellman-Lord/Allied Chemical system uses a sodium sulfite-bisulfite solution as the absorbent. Sodium carbonate is used as the raw material to replace sodium losses due mainly to oxidation of sulfite to sulfate in the scrubber system. Sodium sulfate is removed as a purge stream by selective crystallization. The bisulfite-rich stream is then thermally treated to regenerate sodium sulfite and sulfur dioxide. The sulfur dioxide is converted to sulfur by an onsite Allied Chemical proprietary reduction process. The characteristics of the system are similar to the magnesia system.

APPENDIX B

MODEL UPDATE

CONTENTS

APPENDIX B

MODEL UPDATE

SCRUBBING COST GENERATOR UPDATE THROUGH 1983

Power Plant and Boiler Screen

During the continuing expansion and refinement of the overall model it became apparent that some limitation should be placed on the calculations of compliance and scrubbing costs for power plants in the data base. Elimination of plants that could be predetermined to be very poor candidates for a scrubbing strategy would allow computing costs to be reduced and at the same time allow additional emphasis to be placed on the more logical candidates. A size and age screen was developed to accomplish this. All individual boilers of less than 25 MW or over 20 years old in the 5-year model projected to 1983 were automatically eliminated from consideration. In addition, all plants of less than 100-MW total capacity were also eliminated from consideration. In the 1978 projection model runs, 800 power plants with 3,382 boiler units were included in the power plant data base. All of these plants and boilers were considered in scrubbing cost calculations. Of these, 187 plants with 833 boiler units were projected to be out of compliance. In the 1983 projection model runs, after adding the power plants and boiler units scheduled to come online between 1978 and the end of 1983, 896 plants with 3,830 boiler units were included in the power plant data base. Because of the size-age screen, only 363 power plants with 712 boiler units were considered for scrubbing cost calculations. Of these, 94 plants with 165 boilers were projected to be out of compliance.

New Power Plants and Boilers Through 1983

In support of the scrubbing cost generator projection of FGD costs to 1983, the power plant data base was updated to include power plants and boilers projected from the data to come online between the end of 1978 and the end of 1983. There were 147 projected boilers identified at 108 plant sites. The plant site location for 13 boilers was not identified. Because location is mandatory for marketing analysis (primarily for transportation costs) these 13 boilers were eliminated from the model. Location in the 11 Western States eliminated 25 projected boilers from direct consideration. Transportation rates within the 11 Western States and between these states and the 37 Eastern States were impractical to automate. Therefore transportation rates for western locations cannot be determined by the transportation cost generator. A separate manual analysis for western supply and demand locations is required so they are eliminated from the automated model. The summary results of the manual analysis are included for marketing consideration in the equilibrium solution using transshipment terminals that are within the automated transportation area. According to PEDCo, Environmental, Inc., (Gregory et al., 1978) 23 boilers were already committed to other FGD processes and were eliminated. Incomplete fuel data resulted in the elimination of 10 projected boilers. The total plant size screen eliminated one projected boiler. Finally, 49 boilers were eliminated because they were calculated to be within the applicable emission limits based on the reported fuel to be used. The net result was the elimination of 121 boilers at 86 plants leaving 26 projected boilers at 22 plant sites for consideration in the model.

Updated Regulations and Compliance Plans

In the 1978 model, regulations from EPA were based on June 30, 1976, data. In the 1983 model, regulations were updated to July 15, 1977, the latest state regulations available from EPA at the time of the power plant data base update.

The compliance status of power plants was also updated. A special emissions and compliance report from the EPA emissions data base was used for the compliance status update. This report was based on regulations assumed to be in effect December 31, 1978.

The revised NSPS as proposed in the September 19, 1978, Federal Register was not used in this update. The data are projected only through 1983. Few, if any, of these boilers will be under the revised NSPS regulation. The pre-September 1978 NSPS was, therefore, used in conjunction with applicable State Implementation Plans (SIP).

Compliance status and applicable regulations are important factors in any byproduct marketing model. All power plants reported by EPA to be in compliance are automatically eliminated from the model regardless of data base regulations and fuel data. Power plants are also eliminated that are calculated to be in compliance based on the applicable regulations and the reported fuel to be used.

Cost Escalation

Capital cost escalation to 1983 was based upon projections of the Chemical Engineering (1974, 1975, 1976) cost indexes. The same data and projection method was used as for the 1978 projection models. Operating costs escalated to 1983 were based on TVA projections of individual operating costs shown in Table B-1.

Because of the different raw materials, utilities, and operating costs required for each of the scrubbing processes, the escalated cost data increased magnesia-scrubbing costs to a greater degree than limestone-scrubbing costs. Magnesia scrubbing is an energy-intensive process as compared with limestone scrubbing, which is a raw material intensive process. The costs shown in Table B-1 illustrate that magnesia process energy costs (No. 6 fuel oil, for example) are projected to increase at a greater rate than limestone process raw material costs (limestone, for example).

TABLE B-1. PROJECTED 1983 UNIT COSTS FOR RAW MATERIALS, LABOR, AND UTILITIES

	Unit cost, $
Raw Materials	
Limestone	Variable[a]
Lime	50.00/ton
Magnesium oxide	315.00/ton
Vanadium pentoxide catalyst	2.90/liter
Sodium carbonate	119.00/ton
Antioxidant (sodium process scrubbing)	3.50/lb
Sulfuric acid	62.50/ton
Labor	
Operating labor	12.50/hr
Analyses	20.00/hr
Utilities	
Fuel oil, No. 6	0.49/gal
Natural gas	3.50/kft^3
Steam (500 psig)	2.50/klb
Process water	0.14/kgal
Electricity	0.036/kWh
Heat credit (coal-fired basis)	2.50/MBtu
Water treatment	1.20/kgal
Sludge transportation fee (offsite disposal variation)	Variable[a]

a. Site-specific data determined from programed calculations.

The net result was a higher incremental cost for magnesia scrubbing in comparison with limestone scrubbing in the 1983 projection. No detailed analysis was made of scrubbing costs for 1978 compared with those projected for 1983, but there was a general increase in limestone-scrubbing costs of approximately 0.02 mills per kWh for the plants in the 1983 projection compared to the same plants in the 1978 projection. The corresponding increase in magnesia-scrubbing costs for these plants was 0.03 mills per kWh.

TRANSPORTATION COST GENERATOR UPDATE THROUGH 1983

Transportation costs have escalated significantly in recent years. This escalation is expected to continue at an increasing rate through 1983. The bases for projecting transportation rate increases from 1975 (the base year used for the 1978 projection) to 1983 are as follows.

Actual Rail Rate Increases, 1973-1977

Increases in rail rates for the 5-year period were as follows:

Year	Rate increase, %
1973	3.0
	1.9[a]
1974	1.9
	4.0[a]
	3.3[a]
	10.0[a]
1975	7.0
	5.0[a]
	2.5[a]
1976	7.0
1977	4.0
	5.0[a]

a. Multiple rate increases in the same calendar year.

The rail rate increases shown over the 5-year period amount to a historical average annual increase of 11.2%.

Projected Rail Rate Increases, 1978-1983

Advice from the TVA Division of Navigation Development and Regional Studies indicates that rail rate increases will accelerate in the next few years. This information is based primarily on the expected impact of the "Railroad Revitalization and Regulatory Reform Act of 1976" (PL 94-210).

This act, commonly referred to as the "4-R Act," is designed to ". . . permit railroads greater freedom to raise or lower rates for rail services in competitive markets" and ". . . promote separate pricing for distinct rail and rail-related services" (PL 94-210).

The average annual rail rate increases from 1978 through 1983 has been projected at 13.5%. The increase in special rates for separate commodities may be significantly higher.

Actual and Projected Rail Rates

A graphic presentation of actual and projected rail rate increases is shown in Figure B-1. The 11-year increase from 1973 through 1983 is 246%. Using January 1, 1973, as the index year at 100, the 1983 rate becomes 346 as shown.

Actual Barge Rate Increases, 1973-1977

Increases in barge rates over this period were as follows:

Year	Rate increase, %
1973	0
1974	21.4
1975	0
1976	9.0
1977	8.0

These recent historical rate increases are equivalent to an average annual increase of 7.4%.

Projected Barge Rate Increases, 1978-1983

It is anticipated that barge rate increases will accelerate somewhat in the next few years because of general inflationary trends. The projected annual rate from inflation is 8.5%.

Recent legislation of October 24, 1978, will further increase the cost of barge transportation. The law imposes a fuel tax on users of the inland waterways system. Application of this tax is contingent upon the U.S. Corps of Engineers' Alton Project (Lock and Dam 26) being in progress by October 1, 1980. It provides for a user tax on fuel used for commercial traffic on the inland waterways system in the following schedule.

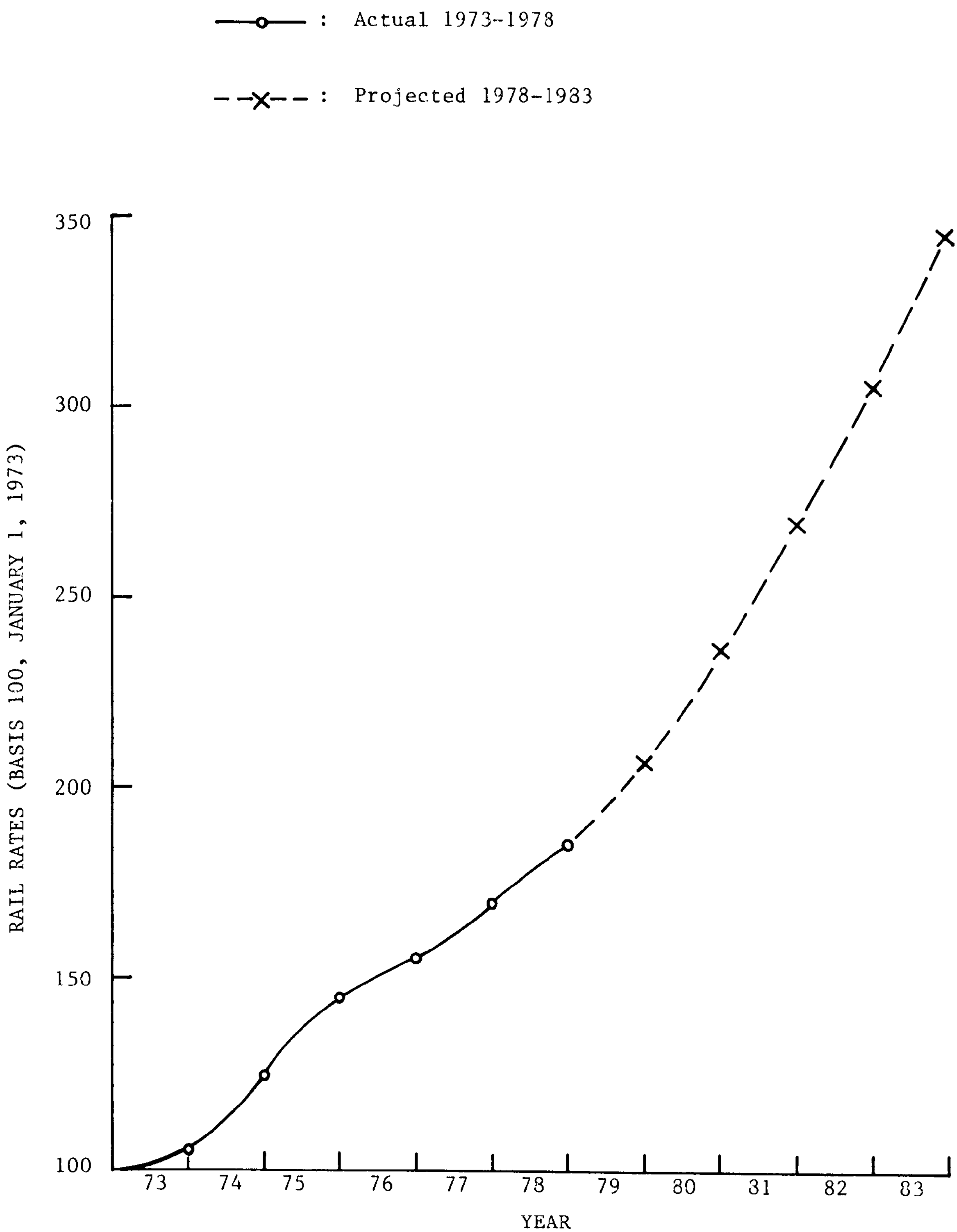

Figure B-1. Rail rate increases, actual and projected, 1973-1983.

Effective date of tax	Users fuel tax, cents/gal
October 1, 1980	4
October 1, 1981	6
October 1, 1983	8
October 1, 1985	10

This tax expense will undoubtedly be passed along in barge rates. A recent study, Impacts of a Waterways User Charge on the Economy of Tennessee, (Memphis State University, 1978) surveyed the towing industry to determine the effects of various user fuel tax levels on their costs. It revealed the following aggregate results.

Estimated effect of fuel tax on barge operating costs			
Tax, cents per gallon	8	24	40
Increase in operating costs, % (mean of 14 respondents)	7.3	22.3	36.4

Each cent of user fuel tax is seen to amount to almost a 1% increase in towing cost. For this study, a 1% cost increase for each cent per gallon of tax is assumed.

The cost increase due to the proposed user fuel tax, coupled with the projected inflation increase, results in the following annual barge rate increases.

Year	Barge rate increases, %
1979	12.84
1980	8.50
1981	10.67
1982	10.67
1983	10.67

Actual and Projected Barge Rates

The actual and projected barge rates from 1973 through 1983 are shown in Figure B-2. The increase over the 11-year period is 137%. Using January 1, 1973, as the index year at 100, the 1983 rate is seen to be 237.

Transportation Cost Inflation Over 1975

The 1978 projection used a transportation inflation factor of 1.15 over 1975. The 1983 rail transportation cost projection is 2.37 times the 1975 rate. The 1983 barge transportation cost projection is 1.95 times the 1975 rate. This is an average transportation cost increase of approximately 88% over the 1978 projection. It represents an average annual increase of 13.4% from 1978 through 1983.

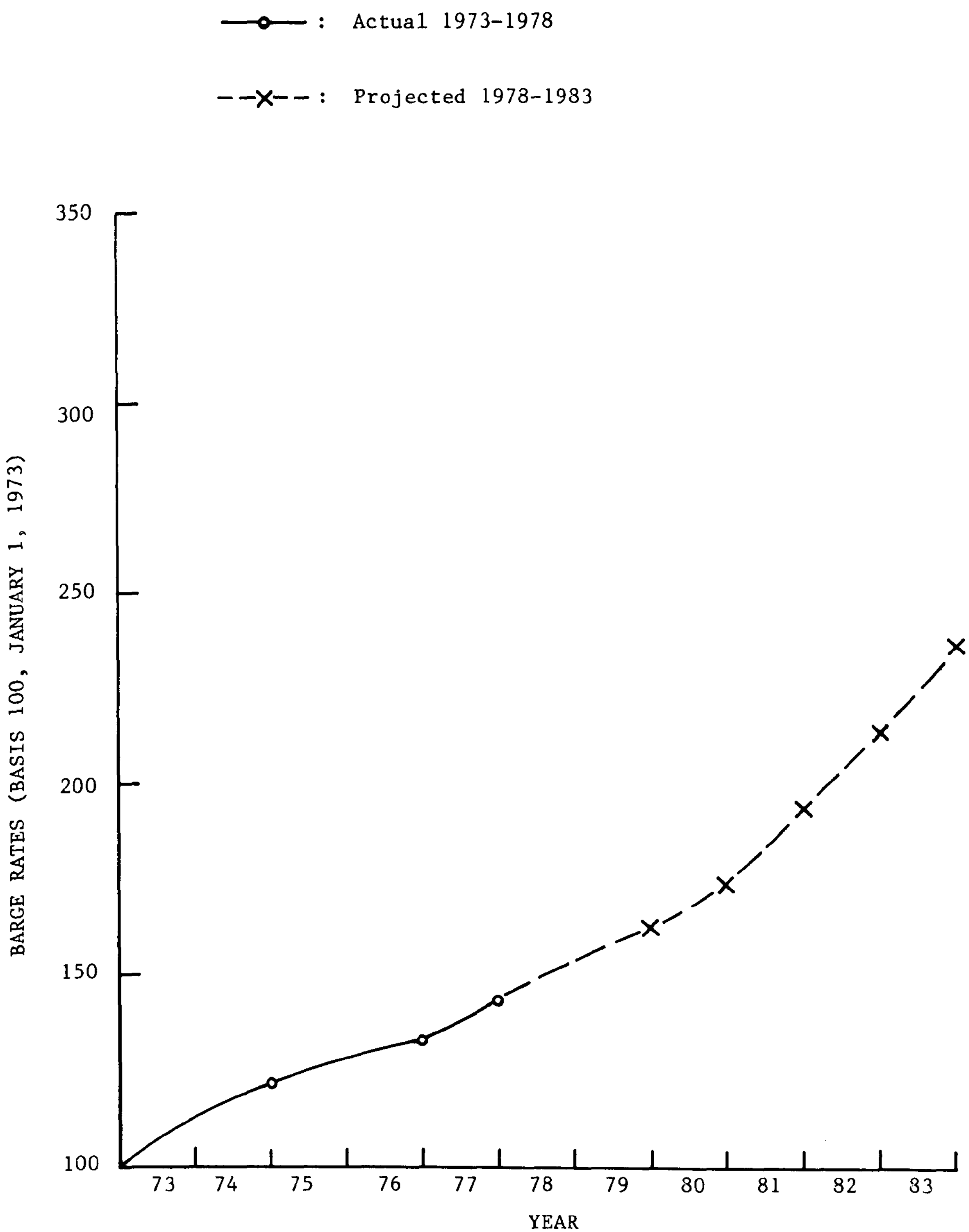

Figure B-2. Barge rate increases, actual and projected, 1973-1983.

ACID PRODUCTION COST GENERATOR UPDATE THROUGH 1983

Sulfuric Acid Plant Demand Data Base

The projection for 1983 indicates that there will be 86 sulfur-burning sulfuric acid plants representing a potential demand of 23,300,000 tons. The 1978 projection included 90 sulfur-burning plants with a potential demand of 32,200,000 tons of sulfuric acid.

The reduction of potential sulfuric acid demand from the 1978 projection to the 1983 projection amounted to 8,900,000 tons. It resulted from two update changes in the 1983 projection. The first involved identification of five acid plants which will have been shut down and the addition of one new plant. The second update change was a reduction of the potential demand to 75% of sulfur-burning acid plant capacity. This is a reflection of current market conditions projected to 1983. The total U.S. production of sulfuric acid for the fiscal year ending June 30, 1978, was reported at 35,076,000 tons by the U.S. Department of Commerce (1978). This is less than 69% of capacity. The projected market growth is estimated to increase the output (demand) to 75% of capacity in 1983.

Sulfur Terminal Selection

Previously the sulfur barge terminal selection for rail delivery to each sulfur-burning acid plant was based on the lowest rail cost from the terminal to the acid plant. The 1983 projection model was modified to choose the barge terminal which results in the lowest combination of barge plus rail freight from Port Sulphur to the acid plant.

Sulfuric Acid Avoidable Costs

Some very significant changes resulted from the updating of the avoidable production costs associated with sulfur-burning acid plants. The adjustment of byproduct steam credit had the most effect. This update recognizes the projected 1983 equivalent energy cost for replacement of byproduct steam and the necessity of installing and operating a boiler to replace the acid plant byproduct steam required in other operations at the acid plant site.

The boiler to replace acid plant byproduct steam requirements could be oil or coal fired. An analysis of investment and operating cost requirements (Johnson, 1978) indicated the selection of an oil-fired boiler for the steam production capacities involved. Capital and maintenance cost disadvantages of the coal-fired boiler option more than offset potential fuel cost savings. Fixed annual conversion costs (operating labor, supervision, overhead) eliminated by termination of sulfuric acid plant operations are offset by the new fixed annual steam production cost of the replacement boiler, resulting in a net fixed annual conversion cost of zero.

Other process utilities which, with the byproduct steam credit, constitute the "variable conversion cost/ton ($/ton)" element of avoidable cost in the 1978 projection were updated to 1983 projected values. The net variable conversion cost (termed "fixed conversion cost/ton" in the 1978 projection) was reduced to a minus $6.33 per ton of sulfuric acid in the 1983 projection as a result of the updated value for byproduct steam production. This generally offset other avoidable production cost increases and thus had the effect of reducing demand for FGD byproduct sulfuric acid.

Sulfur consumption per ton of acid produced was updated from the 1978 projection value of 0.30 to 0.33. This reflects conversion from long to short tons and improved recoveries resulting from compliance regulations and design improvements.

Plant investment was updated to reflect a greater proportion of newer, higher cost plants. The scale factor was decreased from 0.734 to 0.65 because of the emergence of higher capacity, single-train plants with a greater investment advantage per ton of capacity over smaller plants constructed in the same time period.

The sulfur price per short ton at Port Sulphur was escalated to $62.50 ($70 per long ton) from the 1978 projection of $53.57 ($60 per long ton). The transportation cost inflation update from 1.15 over 1975 in the 1978 projection to 2.16 over 1975 for 1983 was discussed in detail in the Transportation Cost Generator Update section.

Table B-2 lists the values used in the 1983 projection.

TABLE B-2. MAJOR ELEMENTS OF SULFURIC ACID AVOIDABLE COSTS

No.	Description of variable	Example value
1	Tons of S/ton H_2SO_4	0.33
2	H_2SO_4 plant investment ($/ton/yr)	34.75
3	Capacity for this plant (kton/yr)	247.5
4	Scale factor for determining investment for other sized plants	0.65
5	Variable conversion cost/ton ($/ton)	-6.33
6	Fixed annual conversion cost ($/yr)	0
7	Taxes and insurance rate	0.025
8	Time preference rate for money	0.10
9	Compound maintenance rate	0.05
10	Economic useful life (yr)	30
11	Port Sulphur price ($/ton S)	62.50
12	Proportion of 330 ton/day capacity estimate	0.75
13	Year considered	1983
14	Transportation cost inflation over 1975	2.16
15	Retrofit cost for compliance	4.41

NOTE: All tons are short tons.

Smelter Update

Sulfuric acid plants burning smelter off-gas are included in the sulfuric acid data base along with sulfur-burning acid plants. Although they are considered in the equilibrium solution as producers in competition with power plant FGD byproduct acid rather than potential consumers, they are processed by the acid production cost generator and were included in the update.

The projection for 1983 included 13 eastern smelters representing a potential supply of 400,000 tons. The 1978 projection included 14 eastern smelters with a potential supply of 800,000 tons. The reduction of potential incremental smelter production resulted from two update changes. The first involved identification of one smelter projected to be shut down. This accounts for the reduction in the number of smelters from 14 to 13. The second update involved projected smelters and the market equilibrium position which is discussed in detail in Potential Abatement Production. The 1978 model solution was based upon a 1975 market equilibrium position. Smelters existing in 1975 were projected to have an incremental production in 1978 based on capacity and compliance. Smelters coming online after the 1975 base of market equilibrium were projected to have an incremental production in 1978 of 60% of capacity compared with the 1975 base.

The 1983 model solution was based upon a 1978 market equilibrium position. Because no new smelters were projected to come online between 1978 and the end of 1983, all incremental smelter production in the 1983 solution was based solely on existing plant capacity and compliance status. The net effect of shutting down one smelter and of projecting no new smelters between 1978 and the end of 1983 was a reduction from 800,000 to 400,000 tons.

MARKET SIMULATION LINEAR PROGRAMING MODEL UPDATE THROUGH 1983

Size Screen for Potential Power Plant Acid Producers

In generation of the model it is possible (because of power plant size, fuel usage, or because a mixed strategy of clean fuel and scrubbing is used) that a magnesia-scrubbing process with a low, uneconomical sulfuric acid output could be adopted. To eliminate this possibility, a size screen was included which excludes all magnesia-scrubbing options producing less than 66,000 tons per year of sulfuric acid. These plants revert to a limestone-scrubbing option and are not included in the equilibrium solution. This screen was used in both the 1978 projection and the 1983 projection.

Direct Comparison of ACFL and Magnesia-Scrubbing Costs

In the 1978 projection models, a plant was considered in the equilibrium solution only if limestone scrubbing was less than the ACFL. Incremental costs for market analysis were always on the basis of magnesia-scrubbing costs compared with limestone-scrubbing costs. When limestone-scrubbing costs exceeded the ACFL, the plant was preselected for a clean fuel strategy regardless of the incremental cost of magnesia scrubbing compared with the ACFL.

In the 1983 projection models generated for this report, a plant was considered in the equilibrium solution under an additional condition. If the ACFL was less than limestone-scrubbing costs, the ACFL was then compared directly with magnesia-scrubbing costs. If the resulting incremental unit cost of acid did not exceed $30 per ton, the plant was included for consideration in the equilibrium solution. This change was made to allow for the possibility that a power plant could recover the difference between magnesia-scrubbing and using clean fuel by the sale of byproduct sulfuric acid.

Comparison of Previous and Current Model Generation

Three separate models were generated for the 1978 projections based on ACFL values of $0.35, $0.50, and $0.70. Only two models using $0.50 and $0.70 were generated for 1983. The $0.35 ACFL was not used in this study because of projected scrubbing cost escalations.

The manual analysis of potential Canadian and western market interaction that was done for the 1978 projection models was essentially the same for 1983. A potential net supply was considered in the equilibrium solution. The net Canadian projected production in the 1983 projection models was 200,000 tons and the net western projected production was 700,000 tons.

TECHNICAL REPORT DATA

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16. ABSTRACT

The report updates to 1983 a 1978-base, computerized marketing evaluation of sulfur and H_2SO_4 as flue gas desulfurization (FGD) byproducts from U.S. coal-burning power plants. Least-costs of compliance were calculated using comparisons of clean fuel with 50¢ and 70¢/million Btu premiums, limestone scrubbing, and scrubbing systems with byproduct sulfur and H_2SO_4 production. Market potential of sales to sulfur-burning H_2SO_4 plants was also determined. At the 50¢ premium, H_2SO_4 production was the least-cost method at five plants, four of which had combined sales of 800,000 tons/yr. At the 70¢ premium, H_2SO_4 production was the least-cost method at 26 plants, 7 of which had sales totaling 1.2 million tons. New boilers coming online by 1983 accounted for 60% of the sales. Market potential was relatively insensitive to sulfur price. Sulfur production was not selected at any plant, but reduction of total FGD costs by 3-25% would make it competitive with sulfur delivered from Port Sulphur at 16 plants with a total production of 266,000 tons. Results indicate the need of a longer time projection and continued updating of the model data bases.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Sulfuric Acid	Pollution Control	13B	
Flue Gases	Marketing	Stationary Sources	21B	05C
Scrubbers	Forecasting	Clean Fuel	07A,13I	
Desulfurization	Mathematical Models		07D	
Byproducts			14B	12A
Sulfur	Coal		07B	21D
Limestone	Combustion		08G	

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