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MARKETING H_2SO_4 FROM SO_2 ABATEMENT SOURCES --THE TVA HYPOTHESIS

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ABSTRACT

A hypothetical study was made on marketing abatement sulfuric acid from stack gas sulfur dioxide removal processes and acid production facilities assumed to be installed at selected coal-burning steam plants in the Tennessee River Valley of the southeastern United States. The study objective was to create a computer model to determine the net sales revenue in dollars to the utility by assigning a zero dollar value for the acid at the steam plants, computing the transportation cost of shipping the acid to older existing acid producers in the Midwest and Southern States, and selling the acid to them at or below their basic manufacturing cost. The Tennessee Valley Authority (TVA) power production system was used as the utility model. From a total of about 18,000 MW coal-burning power generation capacity in the TVA system, about 10,000 MW was considered for sulfuric acid production and about 2 million tons of sulfuric acid per year would be produced. Assuming TVA would be the only utility producing abatement acid, a net sales revenue of $5 to $9 per ton (0.2-0.3 mills/kWh or $0.50-0.75/ton of coal burned) was indicated. The computer model developed for the study is capable of being expanded to include other utilities in the United States. Such an expansion of the study is suggested.

CONTENTS

FIGURES

TABLES

CONVERSION TABLE

EPA policy is to express all measurements in Agency documents in metric units. When implementing this policy results in undue cost or difficulty in clarity, the National Environmental Research Center-Research Triangle Park (NERC-RTP) provides conversion factors for the particular nonmetric units used in the document. For this report these factors are:

British		Metric
Multiply	By	To Obtain
gallon	3.785	liters
pound	4.536×10^{-1}	kilograms
tons/hour	2.520×10^{-1}	kilograms/second
tons/hour	9.0718×10^{2}	kilograms/hour
short tons[a]	9.0718×10^{-1}	metric tons
long tons[a]	1.016	metric tons
Btu	2.520×10^{-1}	kilogram-calories
°F -32	5.555×10^{-1}	°C
tons/day	1.05×10^{-2}	kilograms/second

[a] All tons of acid are short tons and all tons of sulfur are long tons unless otherwise indicated.

MARKETING H_2SO_4 FROM SO_2 ABATEMENT SOURCES

THE TVA HYPOTHESIS

SUMMARY AND CONCLUSIONS

Processes for removal of sulfur dioxide from stack gases have been developed to the point that several are being tested in full-scale installations. The flue gas desulfurization (FGD) processes result in large quantities of byproduct sulfur equivalents. Throwaway FGD processes such as lime or limestone scrubbing result in a sludge consisting primarily of calcium sulfite, calcium sulfate, or calcium carbonate. Regenerable FGD processes such as magnesia scrubbing, catalytic oxidation, and sodium scrubbing processes can produce byproducts such as elemental sulfur or sulfuric acid with known commercial uses. Currently the major interest is in lime or limestone scrubbing, but recovery methods are also receiving attention. One of the deterrents to more widespread consideration of processes that produce useful products is the question of available markets. This study has been carried out to evaluate the marketability of sulfuric acid, one of the potential major products from recovery processes being developed.

The TVA power system was used as the utility model for the production and distribution of sulfuric acid. The use of the TVA power system as the focal point of the study should in no way be construed to imply that a decision has been made for TVA to enter into the production of sulfuric acid or that TVA believes that FGD processes capable of producing acid or elemental sulfur are sufficiently demonstrated to merit commercial application at this time. In this hypothetical study no attempt was made to select a process or to estimate the production costs; a zero value was assumed at the point of production. The most appropriate plants for manufacture of acid were identified, a marketing approach was established; and a production-distribution model was developed to minimize cost of sulfuric acid to current producers and maximize net sales revenue to TVA. Net sales revenues were estimated for a base case and several variations from the base case.

Competition from other abatement acid sources was not included in the study, but the model could be expanded to estimate the effect of additional sources of supply. It could be expected that additional abatement acid sources would have a deleterious effect on the net sales revenue since all sources would be competing for a limited market. Furthermore, the producers of Frasch (mined) sulfur could be expected to protect their markets (sulfur-burning acid plants) until revenues dropped below their mining costs. If excessive volumes of abatement acid are involved, net sales revenue could be expected to decline to zero or result in a cost for disposal.

The current sulfuric acid industry was reviewed to estimate acid plant production capacity, consumption patterns were identified, and transportation methods were determined. Of approximately 31 million tons (all tons of acid are short tons and all tons of sulfur are long tons unless otherwise indicated) of acid produced in 1972, only about 13 million tons was marketed externally (merchant acid) by the producers. With a growth rate of 4 to 6% per year, some acid could be expected to enter new markets, but existing markets also will have to absorb abatement acid.

Because of unit age, and expected future operating schedules, plus prior commitments to low-sulfur fuel (Bull Run plant) or stack gas scrubbing (Widows Creek No. 8), it was determined that only 9,979 MW of TVA's 18,109 MW of coal-fired power generation has some potential for being equipped with sulfur dioxide removal processes producing sulfuric acid. Assuming reliable sulfuric acid-producing systems could be installed by 1975 (in reality, this would not be possible since a minimum of 30 to 36 months is expected for design and installation of a proven, demonstrated system) and based on expected operating schedules and Federal emission guidelines applicable to new units, about 1,980,000 tons of acid might be produced by the existing TVA system in 1975. This would be about 5% of the total U.S. acid production.

Of the various current sources of sulfuric acid, the most vulnerable one appears to be acid produced with raw material sulfur purchased from an external supplier. The strategy used in this study to penetrate existing markets was to replace purchased sulfur with abatement acid by supplying the acid at a cost less than the producer's avoidable processing cost.

In an 11-state area adjacent to the TVA power system 61 existing acid plants were identified as potential sales points for abatement acid. Using a computer program, the costs for sulfur including transportation charges, the production costs for each plant (recognizing age and efficiency), and the transportation costs for moving acid from seven TVA power plants to the 61 acid plants were applied to calculate the maximum net sales revenue to dispose of the 1.98 million tons of acid. For the base case with sulfur at $25 per long ton f.o.b. Port Sulphur, Louisiana, all barge transportation, a market demand equal to 100% of acid plant operating capacity, and with a zero value at the point of production, net sales revenue of $8.76 per ton was indicated. Such a net sales revenue might reduce the cost of operating a power plant sulfur dioxide control system by 10 to 20%. If a credit is added for the estimated increased cost for installation and operation of tail gas cleanup systems on existing acid plants, the net sales revenue might be expected to increase by approximately $3 per ton of acid. For a more realistic situation with mixed rail and barge transportation and reduced market demand equivalent to an average 75% on-stream time for existing acid plants, the net revenue is $6 per ton without credit for tail gas cleanup.

The revenue from sale of abatement acid is directly proportional to sulfur price; an increase of $5.00 per long ton of sulfur is equivalent to approximately $1.42 net sales revenue per ton of acid. Shipment of 80% acid instead of 98% increases transportation and handling costs by about $1 per ton of acid.

Another idea with wide implications involves using the abatement acid directly to produce more valuable phosphoric acid (P_2O_5) for fertilizers. Since TVA presently must purchase wet-process phosphoric acid for its own needs at the National Fertilizer Development Center at Muscle Shoals, Alabama, additional revenue could be derived by using some of the abatement sulfuric acid to produce wet-process phosphoric acid internally passing the purchase cost savings back to the sulfuric acid system.

In summary, it appears that under the circumstances assumed in this study the potential sulfuric acid from the TVA system could be incorporated gradually into the market as long as there was no significant competition from other abatement sources. Competition from other sources would definitely result in lower acid value. It is conceivable that sufficient competition could result in a negative acid value if it became necessary to neutralize the acid or otherwise pay for its disposal.

Probably the most important result from the study is the development of a versatile, practical, computer program which can be used to extend the market investigation to the entire United States and the initiation of a data file on sulfuric acid and sulfur sources and end points both of which can be made available to others.

RECOMMENDATIONS

Using an expanded data file and the computer model developed during the study, it is recommended that an evaluation of optimum points of supply from all U.S. abatement acid sources to the existing markets and to future markets should be made. The future markets might include new fertilizer production capability close to the point of acid production. Specifically, an expanded investigation should be carried out in predefined phases to realistically:

1. Determine the quantities of byproduct sulfuric acid which could be produced in all U.S. power plants and smelters.

2. Describe the most economical market distribution-transportation system including storage costs.

3. Define the competitive costs of sulfuric acid producers using both Frasch and abatement elemental sulfur as raw material; costs of acid plant pollution control included.

4. Predict as a function of the above the possible net sales revenue for market disposal strategies covering the existing acid market and the growth market with possible relocation of phosphate fertilizer production facilities adjacent to the byproduct acid source.

5. Evaluate the economic, social, and environmental consequences of wide-scale use of acid-producing abatement methods and possible alternatives in accordance with the provisions of the National Environmental Policy Act of 1969.

INTRODUCTION

For the past several years, numerous sulfur dioxide control systems for power plant stack gases have been under investigation by both industry and government. Until recently efforts have centered mostly on process development; however, with control applications now beginning to accelerate from the demonstration stage toward commercial practice, attention is being turned to byproduct disposal. The byproducts of these systems are both waste and salable materials such as calcium sludge, gypsum, liquefied sulfur dioxide, ammonium sulfate, elemental sulfur, and sulfuric acid of various concentrations. Since the effects of waste (throwaway) materials on the environment and salable materials on existing and future markets need further definition, studies are being initiated to guide potential users of sulfur dioxide removal technology.

With funding provided by the Clean Air Act of 1970 and subsequent continuations, the Office of Research and Development, Environmental Protection Agency, Research Triangle Park, North Carolina, initiated a study to determine the economics of marketing sulfuric acid which could be produced from fossil fuel-fired steam plants. The objective of the study is to create a model for estimating the net sales revenue to a utility from marketing the acid produced. For simplification, the cost of removing the sulfur dioxide and producing the sulfuric acid is considered independent from this evaluation; a zero acid value is assumed at the point of production.

The Office of Agricultural and Chemical Development of TVA was selected to perform the study since TVA is active in power generation, chemical development, and fertilizer marketing, and has experienced personnel to carry out the program.

The study assumes that an acceptable sulfur dioxide removal and sulfuric acid production process is commercially available and would be installed at several TVA steam plants; however, the study is hypothetical and should in no way be construed to imply that a decision has been made for TVA to enter into the production of sulfuric acid nor that TVA believes that technology is adequately developed for pratical application. The developed model, hopefully, will be a useful tool to assist utilities and other pollution sources in making such a decision in the future.

The model is to be based on the existing sulfuric acid production, distribution, and marketing patterns with consideration given to expected changes in such patterns due to the introduction of abatement acid into the existing market. In this initial analysis, it is assumed that TVA would be the only new source producing abatement sulfuric acid in or near the marketing region considered. Abatement acid from other utilities would certainly influence the evaluation; however, for the derivation of the basic model, only TVA's production is considered. The basic model should be applicable and expandable to other utilities in the United States. Also, the results of the study and information from other proposed investigations should give a clearer economic relationship between the various byproduct systems of elemental sulfur, sulfuric acid, gypsum, and calcium sludges.

BACKGROUND

SULFUR DIOXIDE REMOVAL PROCESSES

The sulfur dioxide removal processes that are being developed include several which could produce sulfuric acid as a marketable product. Among these are the magnesia scrubbing process being developed by Chemical Construction Corporation - Basic Chemicals, and others, the catalytic oxidation process by Monsanto Company, and the sodium sulfite process by Davy Powergas Company. The demonstration-size plants in the United States using technology from these processes are listed below:

Table 1. SO_2 REGENERABLE PROCESS DEMONSTRATIONS

Process	Demonstration	Utility company	Product
MgO scrubbing	150 MW oil (1972)	Boston Edison	98% H_2SO_4
	97.5 MW coal (1974)	Potomac Electric Power	98% H_2SO_4
	125 MW coal (1973)	Philadelphia Electric	98% H_2SO_4
Sodium sulfite scrubbing	115 MW coal (1975)	Northern Indiana Public Service	Sulfur
Catalytic oxidation	110 MW coal (1974)	Illinois Power	80% H_2SO_4

Sulfuric acid is marketed at several concentrations--98% and higher, 93%, and about 80%. Of the above three sulfur dioxide removal systems, two--the magnesia scrubbing process and sodium sulfite--can produce acid at a concentration of 98% and higher. The third process--catalytic oxidation--produces acid at a concentration of about 80%. The 80% acid contains more impurities than the 98% acid. Any of these acids could be considered in this study, but the transportation and storage costs will be greater for the dilute acid because of the larger volumes required. In addition, the value of the impure 80% acid is generally less to users.

Regardless of which sulfur dioxide removal and sulfuric acid production process is used, abatement sulfuric acid production cost from facilities with expected lives at least as great as the scrubber system will most likely be between \$40 and \$110 per ton compared with \$10 to \$20 per ton when burning elemental sulfur. Although producing acid from a fossil fuel-fired steam plant is an expensive way to make acid, the sulfur dioxide would be removed for pollution abatement reasons and, therefore, the cost of acid production should be chargeable to pollution abatement. The net sales revenue received from the sale of the byproduct acid is considered a credit in comparing acid-producing processes with those producing a waste or other byproduct.

THE NATURE OF THE SULFURIC ACID INDUSTRY

In order to gauge the effect of abatement sulfuric acid on the current production, consumption, and transportation patterns, it is necessary to define the nature of the existing industry. Some background on the sulfuric acid industry was given in the EPA-TVA magnesia scrubbing report[1] and is used in part in the following discussion.

Current Production

In 1972 approximately 31 million tons of sulfuric acid were produced in the United States.[2] This represents an increase of 5.5% over 1971.[2] Sulfuric acid manufacturing capacity in 1972 was about 39 million tons with approximately 60% committed to captive use. Only about 12.5 million tons was externally marketed out of 29.4 million tons produced in 1971. As shown in Figure 1, states having the most capacity for acid manufacture include Florida, Louisiana, Texas, New Jersey, and Illinois. Capacity by states in 1970 is shown in Table 2.

Table 2. SULFURIC ACID PLANT CAPACITY (1970)
(short tons/day)

State	Capacity	State	Capacity
Alabama	1,610	Mississippi	1,067
Arizona	2,627	Missouri	3,303
Arkansas	737	New Jersey	6,913
California	6,774	New Mexico	446
Colorado	1,483	New York	583
Delaware	1,050	North Carolina	3,480
Florida	23,661	Ohio	3,180
Georgia	1,369	Oklahoma	630
Idaho	3,470	Pennsylvania	2,177
Illinois	6,944	Rhode Island	50
Indiana	2,066	South Carolina	324
Iowa	1,877	Tennessee	4,421
Kansas	747	Texas	9,855
Kentucky	550	Utah	2,133
Louisiana	12,600	Virginia	1,983
Maine	223	Washington	333
Maryland	2,260	West Virginia	470
Massachusetts	330	Wisconsin	67
Michigan	1,301	Wyoming	360
Grand total	114,294		

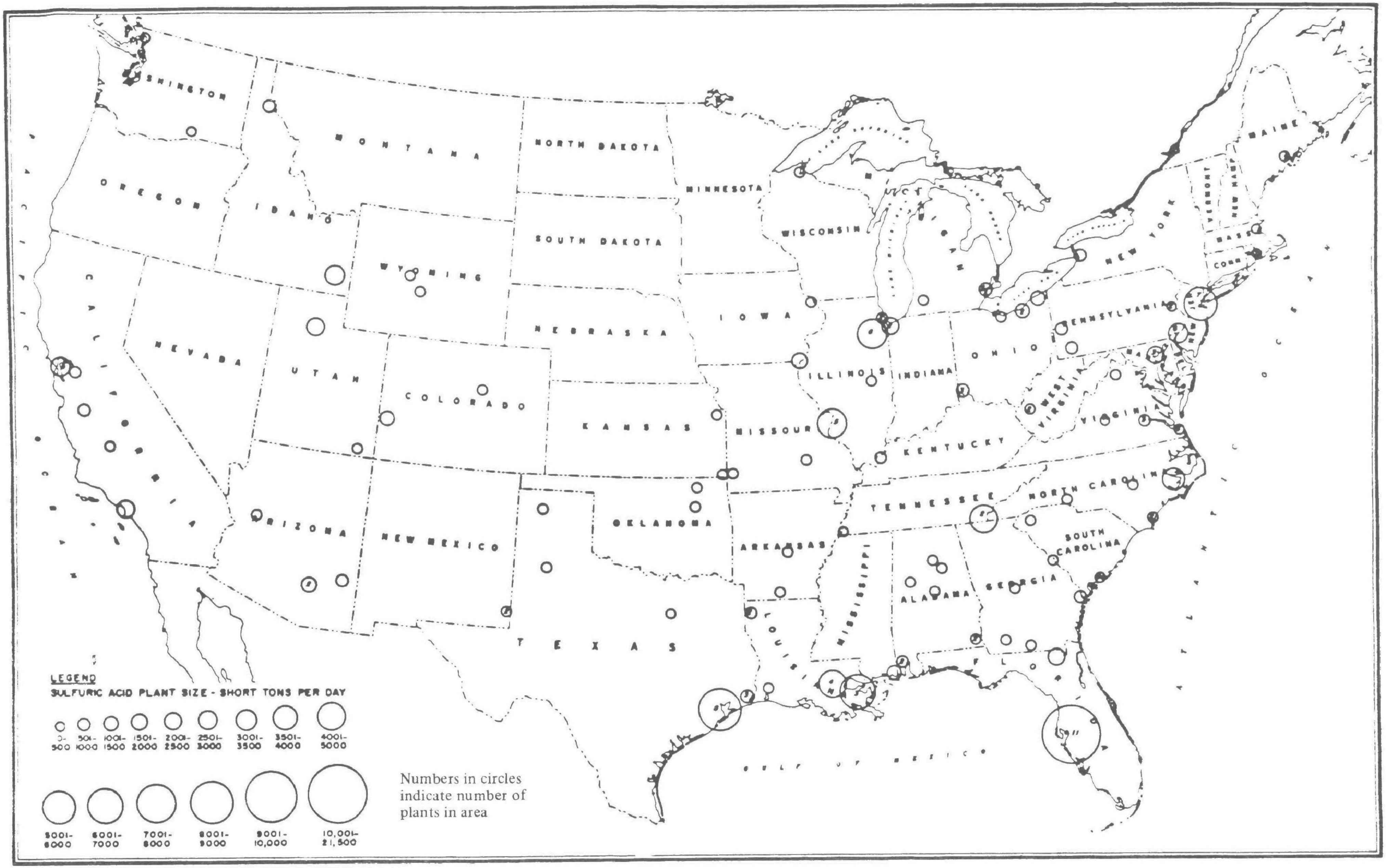

Figure 1. SULFURIC ACID MANUFACTURING CAPACITY (1970)

The size of the individual acid plants has increased over the years with some plants being as large as 3000 tons per day.[3] Such plants are usually parts of fertilizer complexes and are captively owned and operated. Many of these plants range in age from modern, large, newly constructed facilities to small plants built in the 1930's and 1940's. A few of the old chamber process plants are still in operation but the vast majority of plants use the more modern and efficient contact process. Except for plants built very recently, most existing sulfuric acid plants do not have adequate pollution control facilities. Svenson[4] pointed out that many such plants are confronted with a difficult situation in this regard. Most (85%) of these sulfuric acid plants use brimstone (elemental sulfur) as the raw material; however, the direct use of pyrites, smelter gas, and hydrogen sulfide is increasing.

The operating cost of most contact acid plants is heavily weighted with raw material costs. When burning elemental sulfur at $30/ton delivered, the acid manufacturing cost would consist of approximately $10/ton of acid for raw material and $3-10/ton for conversion and capital costs, with the lower value prevailing in new, large units.

Current Consumption

The major end uses of sulfuric acid in the United States in 1970 are shown in Table 3. Fertilizer consumption represented 54% of the sulfuric acid consumed. The long-range growth in acid consumption is estimated to be about 4 to 6% per year, which is closely tied to the fertilizer growth pattern.

Although most of the sulfuric acid consumed in fertilizer manufacture is concentrated, high quality-material, wet-process phosphoric acid produced by reacting sulfuric acid with phosphate rock can be made with off-grade acid. For the other end uses of sulfuric acid, high purity and high concentration are almost mandatory.

As is apparent from Table 3 sulfuric acid has a wide variety of uses, some of which are based on excellent physical properties, but most on cost. Sulfuric acid is very often preferred over other mineral acids, chemicals, or different process technology because it is the least expensive alternative. For example, in phosphate rock acidulations and phosphoric acid manufacture, the major end use, sulfuric acid is the lowest cost acidulant available. There was a period in the late 1960's when this was under challenge as sulfur prices rose to very high levels; however, the sulfur shortage was short in duration and supply soon exceeded demand.

Table 3. SULFURIC ACID END USE PATTERN (1970)

End uses	Thousand short tons (100% basis)
Fertilizer	
Phosphoric acid products	13,750
Normal superphosphate	1,240
Cellulosics	
Rayon	520
Cellophane	170
Pulp and paper	600
Petroleum alkylation	2,400
Iron and steel pickling	800
Nonferrous metallurgy	
Uranium ore processing	300
Copper leaching	350
Chemicals	
Ammonium sulfate	
Coke oven	500
Synthetic	480
Chemical byproduct	190
Chlorine drying	150
Alum	600
Caprolactam	260
Dyes and intermediates	370
Detergents, synthetic	400
Chrome chemicals	100
HCl	150
HF	880
TiO_2	1,440
Alcohols	1,800
Other chemicals	380
Industrial water treatment	200
Storage batteries	140
Other processing	470
Total	28,640

Sulfuric acid is an excellent drying agent and is used in such applications as chlorine and nitric acid drying, chloral production, and in nitration reactions. The acid is an effective catalyst for many hydrocarbon and organic chemical syntheses, such as formations of petroleum alkylate and olefins and a paraffin, or the Beckman rearrangement of cyclohexane oxime to caprolactam for nylon fiber manufacture. It has been suggested that this characteristic is associated with its strong affinity for water. Sulfuric acid readily forms organic sulfates with many hydrocarbons which are easily hydrolyzed to yield desirable organics; this property is useful in the manufacture of phenol and certain alcohols.

The acid has a high boiling point which limits volatilization losses in leaching, acidulation, and pickling operations. It is commonly specified as an electrolyte for batteries, used as a bath in cellulose processing, consumed in the manufacture of chromates, used in hydrogen fluoride production from fluorspar, and serves to process ore for titanium dioxide and uranium manufacture.

Sulfuric acid is made and used in a variety of concentrations which are usually indicated as follows:

% H_2SO_4 or °Baume: The simplest description of sulfuric acid concentration is % H_2SO_4. However, because of the distinct relationship between specific gravity and strength (up to 93%) and the simplicity of measuring specific gravity by hydrometer, most acid concentrations up to 93% are expressed as °Baume. From 93 to 100%, acids are referred to by concentration.

Monohydrate: This is 100% H_2SO_4.

Oleum: Acids stronger than 100% H_2SO_4, containing free SO_3, are called oleums or fuming acids and are usually described in terms of SO_3 content. For example, a 20% oleum consists of 20% SO_3 and 80% H_2SO_4; however, in terms of acid content equivalent, it is expressed as 104.50% H_2SO_4. Oleum is not considered as a product in this study.

Table 4 shows a few typical acid strengths and their major end uses.[3]

The major U.S. markets for sulfuric acid are concentrated on the East and Gulf Coasts. More than half the acid consumed in the United States is used in Florida, Louisiana, Texas, Illinois, and New Jersey; Florida uses one-fourth of the total. Because acid transportation costs are relatively high (as compared with sulfur), acid production is usually close to the point of consumption. (See Figure 1.)

Table 4. TYPICAL SULFURIC ACID STRENGTHS AND MAJOR END USES[3]

% H_2SO_4	°Be	% oleum (% SO_3 content)	Uses[a]
35.67	30.8	-	Batteries
62.18-69.65	50-55	-	Normal superphosphate and fertilizers
77.67	60.0	-	Normal superphosphate and fertilizers; isoproply and secbutyl alcohols
80.00	61.3	-	Copper leaching
93.19	66.0	-	Phosphoric acid, TiO_2
98-99	66.4[b] 66.3[b]	-	Phosphoric acid, alkylation, ethyl alcohol, boric acid
100.00	66.2[b]	-	Alkylation
104.50	-	20	Caprolactam (Beckmann, rearrangement); explosives and nitrations, chlorine and nitric acid drying; surface-active agents, synthetic petroleum sulfonates, and other sulfonations; blending with weaker acids
106.75	-	30	
109.00	-	40	
111.25	-	50	
113.50	-	60	
114.63	-	65	
122.50	-	100	

[a] These data do not imply that only the indicted concentrations are used for the applications shown.

[b] At concentrations approaching 100% H_2SO_4, specific gravity begins to decrease.

Transportation

Location of power plants equipped with sulfur dioxide removal and sulfuric acid production facilities and the methods of transportation will have a major influence on abatement sulfuric acid economics (for location of major U.S. power plants burning coal or oil, see Figure 2). Rail or truck transportation is normally used for short hauls. For longer distances, the use of barges on the inland waterways would be more economical.

In a report on the sulfur industry, M. H. Farmer[5] presented the following information about transportation costs:

> Sulfuric acid moves by tank truck, barge and railroad tank car. Because of the much higher transportation costs, when considered on a sulfur equivalent basis, sulfuric acid is seldom shipped more than 150 miles. Furthermore, acid is normally shipped in approximately 100% concentration even though actual use often involves much lower concentrations, ranging down to 10% and even lower.

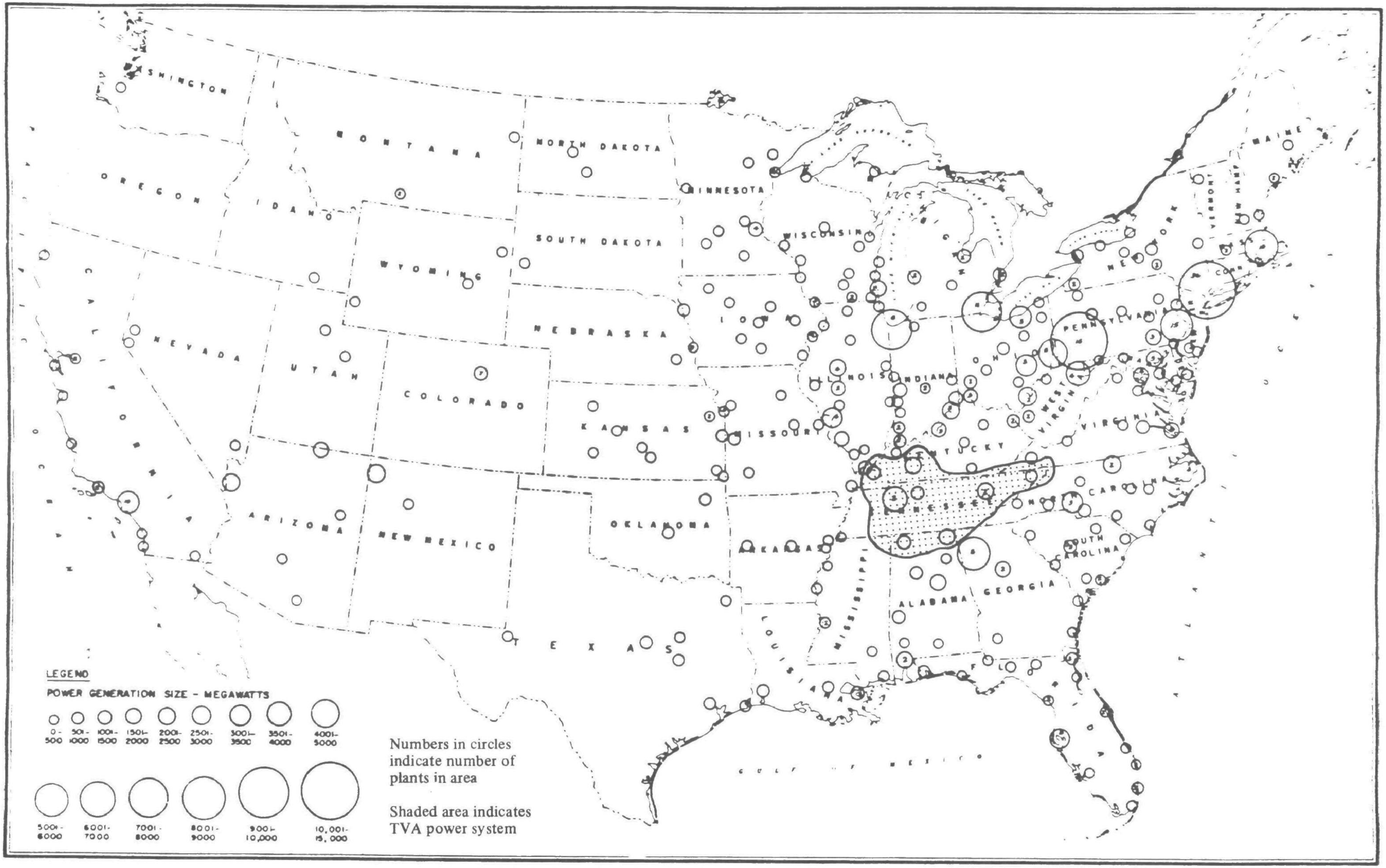

Figure 2. LOCATION OF MAJOR COAL- AND OIL-FIRED POWER UNITS--1971[6]

The importance of transportation costs varies with the value of the material being transported. Because sulfur has a low unit value (e.g., in $/long ton) transportation costs represent a significant part of the delivered price ranging from as little as 10 to 15% to as much as 70%.

Unit trains are feasible only for high-volume movements between fixed points.

Elemental S can be stored until a sufficient quantity is available for economic shipment by barge or bulk carrier. (This consideration does not apply to unit trains which must be kept in constant operation.)

Sulfuric acid cannot be stored, except at significant cost and as limited by available storage capacity. This would seem to favor (or even mandate) the establishment of local markets for abatement acid that could be served by owned transport. A transportation strike of any kind could force the shutdown of abatement acid plant--with serious consequences for an electric utility (and also the consumer).

Little or no value can be projected for abatement S recovered by a poorly located plant. This point has pertinence on a local as well as a macro-geographical basis. It is rather obvious that sulfur recovery in Arizona in unfavorably located. It may be less obvious that recovery of abatement S from mine mouth power plants in Eastern States could also be poorly located with respect to marketing of S values.

In general, recovery of abatement S at plants directly on the Mississippi River system, or with direct access to marine transportation, may be considered as favorable from the standpoint of marketing S values.

Prices at locations some distance from main terminals will be higher than at the terminals (to take account of local delivery costs). Hence, there may be specific locations where abatement S can enjoy a good netback. This is possible if local industry could absorb all of the abatement supply.

Handling Considerations

The storage, handling, and transportation of sulfuric acid require diligent care because the acid is a hazardous and toxic liquid, but the industry has over the years developed safe methods for handling and storing the acid. Sulfuric acid can be stored in mild steel vessels with an expected life of about 25 years. The acid forms a protective sulfate film on steel surfaces which inhibits corrosion. This film, however, is rapidly deteriorated where flow velocities of any appreciable extent exist and in such circumstances mild steel will corrode rapidly. Therefore, for tank nozzles, valves, and pumps, stainless steel must be used. Sulfuric acid has a high density. The specific gravity of 98% H_2SO_4 is 1.844 at 60°F or a density of about 15.4 pounds per gallon at 60°F. This high density must be taken into account in the selection of storage tanks, pumps, and barges.

Sulfuric acid exhibits an unusual freezing point curve. Such a curve is shown in Figure 3. The freezing point of 93% acid is -30°F and the freezing point of 98% acid is 35°F. Although shipment of acid in cold weather has been satisfactorily accomplished without freezing, the possibility should be recognized and steps taken to avoid it.

THE EXPECTED IMPACT OF ABATEMENT SULFUR AND SULFURIC ACID

Sulfur, its source and its cost, has been the main factor in the economics of sulfuric acid in recent years. Until recently, the primary source of elemental sulfur has been through mining with the Frasch process. In 1970, for the first time, the amount of recovered sulfur from sour gas and other sources surpassed Frasch sulfur production in the western world. This non-Frasch sulfur is produced regardless of the market value of sulfur. M. C. Manderson of Arthur D. Little, Inc., wrote in September 1970[7] that the pricing philosophy used by the byproduct producers--who must recover sulfur irrespective of prevailing price--"will influence the level of world sulfur prices over the next decade."

The Frasch sulfur industry's problems with sulfur from sour gas and smelters will be magnified with the production of abatement sulfur or sulfuric acid from utilities. This point is covered in the principal conclusions in Farmer's report,[8] portions of which are as follows:

> Smelters in Arizona are expected to have a continuing excess of S value potential over the quantity that can be marketed unless an economical way of recovering elemental S is developed.
>
> Large quantities of S are also expected to be recovered from coal gasification or liquefaction. The location of such operations will determine the way in which the recovered S is utilized (or whether it can be utilized at all). However, it is likely that the Chicago region . . . will be the most important center for coal conversion, with plants located on the Illinois Waterway and Ohio River.
>
> There will not be a market for all the abatement S that might conceivably be recovered in useful form. Attainment of a reasonable sales value for abatement S will depend either on stockpiling elemental S until it is needed or on avoiding the production of more abatement S in useful form than can be absorbed by the market at a given time. The quantity will increase with time.
>
> The domestic market is now essentially an 'elemental S market,' i.e., the merchanting of acid is less important than the marketing of elemental S. However, the market for merchant acid is expected to expand progressively during the 1980's and 1990's; i.e., industry structure will change.

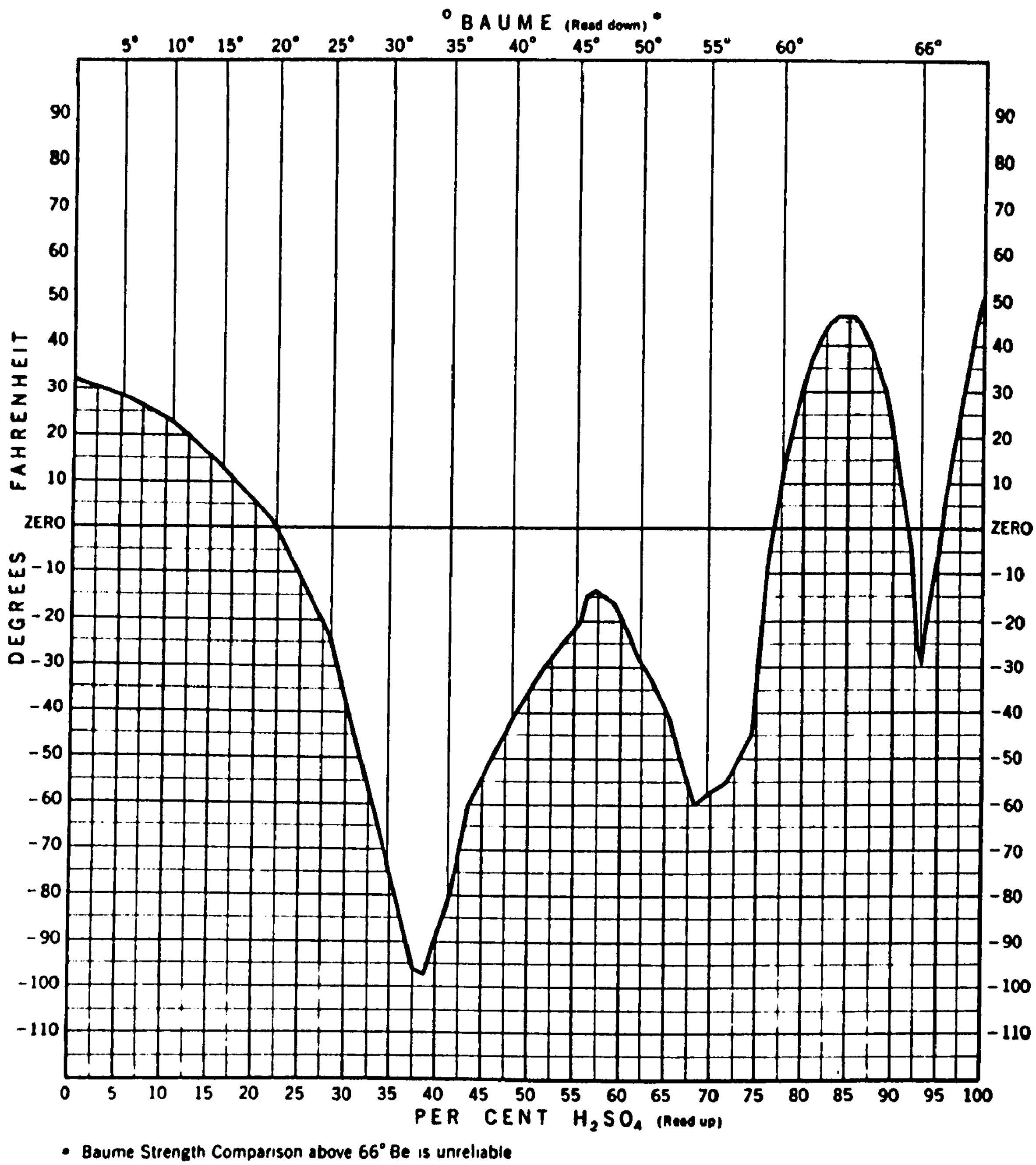

Figure 3. FREEZING POINTS OF SULFURIC ACID

> The production of elemental S from W. Canadian sour natural gas is expected to peak soon after 1980. However, a surplus of production over domestic demand will continue for some years and export potential will be maintained by a stockpile of elemental S that is not expected to peak until around 1985-86. Once this peaking occurs, the world balance on a current basis, and excluding U.S. abatement S, is expected to swing from oversupply to net demand (on a current basis). Conceptually, U.S. abatement S can incrementally fill this supply gap.
>
> By 1990, it will be important for the U.S. to be able to recover abatement S in useful form. This would help the U.S. to recapture its position as the world's leading exporter of elemental S. If the sulfur is not recovered in useful form, a reemergence of [chemical fertilizer] processes that do not use S and also of relatively high cost processes for manufacturing acid and/or elemental S from gypsum would be expected.

Furthermore Farmer observed that U.S. Frasch sulfur producers would defend the Tampa and Gulf Coast markets. He writes:

> Conceptually, in decreasing order of importance, markets for U.S. Frasch sulfur are as follows:
>
> a. The Tampa-Bartow area.
>
> b. Gulf Coast markets (almost as important as _a_, but somewhat more fragmented.
>
> c. Markets adjacent to owned terminals on the Mississippi River system and the East Coast.
>
> d. Markets adjacent to owned terminals in northern Europe.
>
> e. Other U.S. markets.
>
> f. Other foreign markets (e.g., in Asia, Latin America).
>
> Under conditions of world oversupply, it is probable that _e_ and _f_ would be relinquished if the alternative would be to invite greater competition and price erosion in the other areas. In the case of _c_ and _d_ the U.S. Frasch producers may be content to keep a reasonable volume moving through their own terminals without aggressive marketing that would invite competition to seek alternative outlet in _a_ or _b_.
>
> Thus U.S. Frasch producers may be expected to defend _a_ and _b_ strenuously and to maintain sales to _c_ and _d_ long enough for growth in _a_ and _b_ to be sufficient to support total production at economic levels.

Difficulty in sulfur market pricing was further summarized by J. M. Winton in 1971[9] when he stated that there are three sulfur price structures in the United States, (1) Canadian based on f.o.b. Alberta plus rail freight to the U.S. Midwest, which is about $20 to $27 per long ton, (2) Frasch sulfur which is $31 per long ton in Tampa, and (3) recovered sulfur with limited quantities at about $14 to $25 per long ton f.o.b. Southwest refinery. These sulfur price structures have a direct bearing on sulfuric acid production costs and price.

In regard to market penetration by abatement sulfuric acid, Farmer's 1971 report had these remarks:

> The total potential for abatement acid systems until 1980 may be equivalent to the acid recoverable from twenty 800-MW power stations operating at 60% load factor on 3 wt % S coal. Thus, development of outlet for acid recoverable from power plant SO_x is expected to be slow. It follows that alternatives to acid recovery will be essential for the near term.
>
> The structures and geography of the elemental sulfur and acid industries will make it difficult for abatement acid to enter the market. The willingness of existing acid marketers and captive users to offtake abatement acid is necessary if a significant outlet is to be developed. The incentives for such offtake have not been established yet. Currently the acid manufacturers, particularly those who merchant industrial acid, stand to benefit if abatement S were to enter the market in elemental form but to lose if entry were to be as acid. On the other hand, a significant amount of old acid plant capacity will soon need replacement. The shutdown of such capacity may provide the opportunity for some abatement acid to enter the market.
>
> The willingness of existing acid marketers and users to offtake abatement acid is necessary if a significant outlet is to be developed. However, this will require the offtakers to make radical changes in their business operations. The changes will involve difficulty and risk, and will not be undertaken without adequate incentives.
>
> Currently, the incentives for offtaking abatement acid are not clearly defined. In fact, the abatement acid potential may be regarded more as a threat than as an opportunity. The potential threats are erosion of acid prices, loss of market position by individual acid merchanters, and premature obsolescence of existing investments in manufacturing plants and other facilities. Nevertheless, many existing acid plants are old, and some will be shut down by 1975 because economic compliance with pollution control regulations will not be possible. The latter will supply an incentive for arranging to offtake abatement acid instead of building a new captive acid plant.

It must be considered that many acid manufacturers are benefitting from today's low prices for elemental sulfur. If recovery of abatement sulfur were to be in elemental form, such manufacturers would continue to enjoy this advantage. In fact, the delivered price of sulfur might well drop further in some locations. In contrast, if recovery occurs in acid form, this will tend to put pressure on acid prices in local markets.

Matching the size of an abatement acid plant to the outlet available to an existing acid marketer or consumer may be difficult even if the latter shuts down an existing plant. A single 800-MW plant, burning 3 wt % S coal and operating at an average 60% load factor, could produce about 140,000 ST/yr of 100% acid.

The recent literature, however, indicates that there may be more optimistic views within the industry as to the extent and timing of the impact of abatement acid. An article in the June 18, 1973, issue of Chemical and Engineering News notes that a second sulfur price increase in 1973 putting the price at $31 per long ton in Florida is a "sharp turnaround from the prospect, voiced in recent years, of unending glut." The article goes on to describe recent announcements of large new sulfuric acid plants which would not be consistent with fears of cheap abatement acid coming on the market in the foreseeable future. These new acid facilities, however, may be considered necessary to meet demands between now and the time that abatement acid would be available in significant quantities.

L. B. Gettinger of Freeport Minerals pointed out in March 1973[10] that even though sulfur was in surplus in 1972, logistically, supplies were tight. The logistics involve the high transportation cost of moving stockpiled Canadian sulfur into U.S. and worldwide markets. Availability also enters the picture. Buyers of large quantities of sulfur are reluctant to take advantage of cutrate prices of sulfur if the supplier cannot meet the buyer's total need. The recovered sulfur from sour gas and the refineries are of limited quantities at each source and the sources are scattered geographically. Buyers are concerned that the brimstone mines would be closed down if the price structure would be seriously weakened and without the mines operating a dependable source of sulfur would not be assured.

It thus appears one inference which can be drawn from the literature reviewed is that although a profitable market for a new source of abatement sulfuric acid may not be readily available, potential markets for some amount of acid probably could be developed. New production, transportation, and consumption patterns would have to be developed to accommodate the abatement acid. The pricing structure would be similar to that of sulfur recovered from sour gas in that the abatement acid would be sold, not on the basis of production costs, but on the basis of the maximum price the market will allow. With substantial quantities of abatement acid becoming available, the price would not be very stable.

A final note of caution is worth mentioning. In cases where local market competition is expected to be heavy, a potential abatement acid producer needs to consider necessary measures to protect his share of the market and to evaluate his alternatives if his outlet is lost. Long-term contracts, neutralization or storage facilities, and emission variances are some of the means which should be explored before committing to an acid-producing FGD process.

SULFURIC ACID PRODUCTION CAPACITY OF TVA

TVA is a corporate agency of the United States created by the Tennessee Valley Authority Act of 1933. In addition to various other programs, TVA operates a system supplying the power requirements for an area of approximately 80,000 square miles containing about 6 million people. Except for direct service by TVA to certain industrial customers and Federal installations with large or unusual power requirements, TVA power is supplied to the ultimate consumer by 160 municipalities and rural electric cooperatives which purchase their power requirements from TVA. TVA is interconnected at 26 points with neighboring utility systems.

As of July 1972, the TVA generating system consisted of 29 hydrogenerating plants with a capacity of 3,185 MW, 11 coal-fired steam-generating plants in operation with a capacity of 15,509 MW, and a small amount of gas- or oil-fired generating capacity. In addition, power from Corps of Engineers dams on the Cumberland River and dams owned by the Aluminum Company of America on Tennessee River tributaries is made available to TVA under long-term contracts. Figure 4 shows the location of TVA's present generating facilities and those under construction, as well as the location of the above Corps of Engineers and Alcoa dams. The approximate area served by municipal and cooperative distributors of TVA power is also shown.

Power loads on the TVA system have doubled in the past 10 years and are expected to continue to increase in the future. In order to keep pace with the growing demand it has been necessary to add substantial capacity to the generating and transmission system on a regular basis. Current plans are based on meeting future additional requirements with nuclear power stations. The TVA steam plants are listed in Table 5.

The categories of the various TVA plants are shown in Table 6.

Table 6. TVA POWER GENERATION CAPACITY (1972)

Plant type	Capacity in service June 30, 1972		Under construction or scheduled	
	No. of plants	MW	No. of plants	MW
Coal-fired steam plants	11	15,509	1	2,600
Hydroelectric plants	29	3,185		
Nuclear plants			4	11,101
Gas- or oil-fired turbines	2			

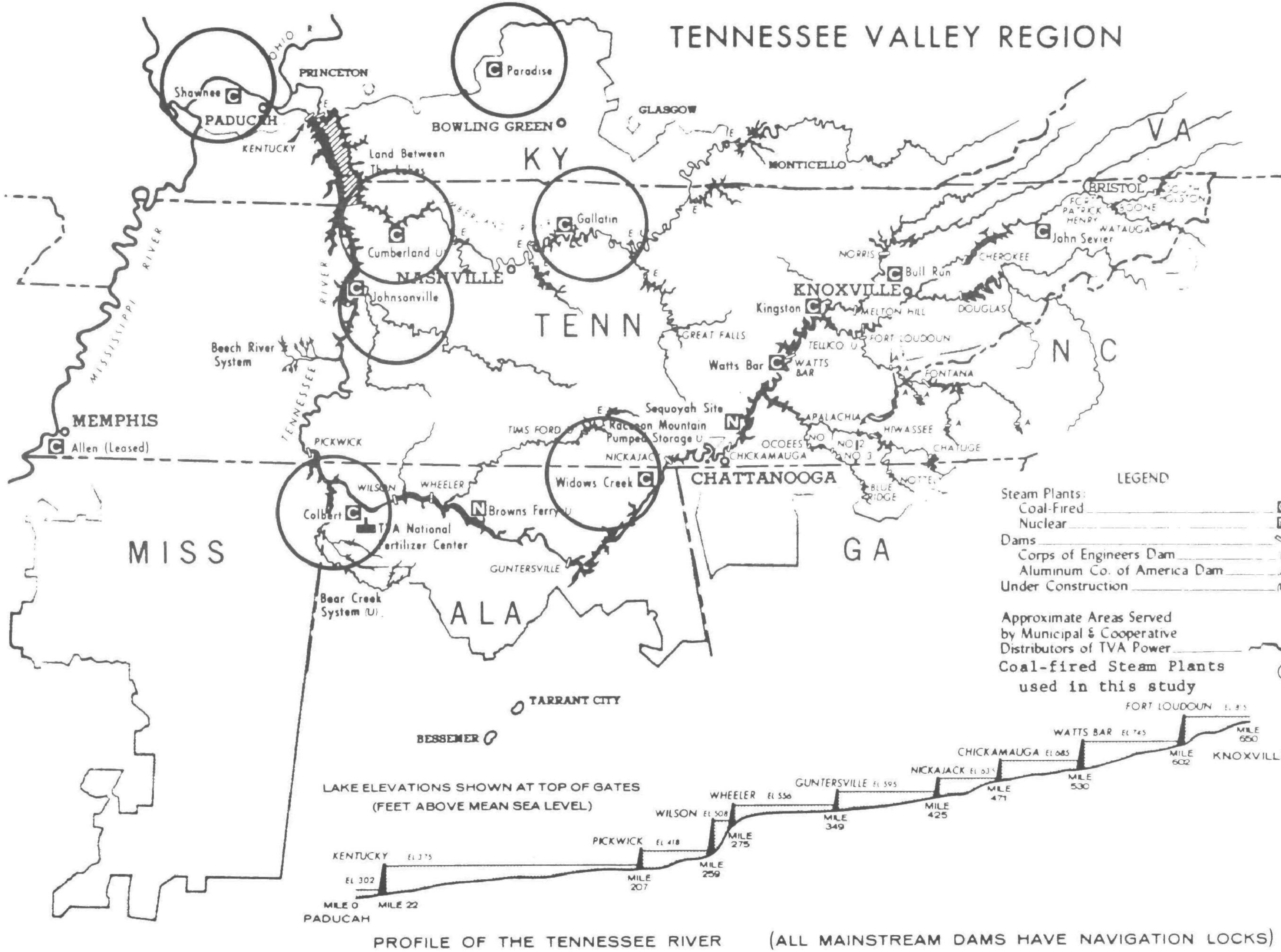

Figure 4. LOCATION OF TVA POWER PLANTS

Table 5. TVA STEAM PLANTS

Steam plant	Unit	Construction started	Units placed in service	Capacity, kW[a] Each unit	Capacity, kW[a] Total	Capacity in service, June 30, 1972	Fuel	24-hr coal use (tons) at full load	Location
Watts Bar (coal-fired)	1-4	1940	1942-45	60,000	240,000	240,000	Coal	3,040	Rhea County, TN
Johnsonville[b]	1-6	1949	1951-53	125,000-147,000	1,485,200	1,485,200	Coal	13,266	Humphreys County, TN
	7-10[b]	1956	1958-59	172,800					
Widows Creek[b]	1-6	1950	1952-54	140,625-149,850	1,977,985	1,977,985	Coal	16,230	Jackson County, AL
	7[b]	1958	1961	575,010					
	8	1960	1965	550,000					
Shawnee[b]	1-10[b]	1951	1953-57	175,000	1,750,000	1,750,000	Coal	14,040	McCracken County, KY
Kingston	1-9	1951	1954-55	175,000-200,000	1,700,000	1,700,000	Coal	14,256	Roane County, TN
Colbert[b]	1-4	1951	1955	200,000-223,250	1,396,500	1,396,500	Coal	11,832	Colbert County, AL
	5[b]	1960	1965	550,000					
John Sevier	1-4	1952	1955-57	200,000-223,250	823,250	823,250	Coal	7,392	Hawkins County, TN
Gallatin[b]	1-2[b]	1953	1956-57	300,000	1,255,200	1,255,200	Coal	9,636	Sumner County, TN
	3-4[b]	1956	1959	327,600					
Thomas H. Allen[c]	1-3	1956	1959	330,000	990,000	990,000	Coal, gas	7,200	Shelby County, TN
Paradise[b]	1-2[b]	1959	1963	704,000	2,558,200	2,558,200	Coal	21,016	Muhlenburg County, TN
	3[b]	1965	1970	1,150,200					
Bull Run	1	1962	1967	950,000	950,000	950,000	Coal	7,560	Anderson County, TN
Browns Ferry Nuclear	1-3[d]	1967	1973-74	1,152,000	3,456,000		Nuclear		Limestone County, AL
Cumberland[b]	1-2[b,d]	1968	1972-73	1,300,000	2,600,000		Coal	22,500	Stewart County, TN
Sequoyah Nuclear	1-2[d]	1970	1975	1,220,580	2,441,160		Nuclear		Hamilton County, TN
Watts Bar Nuclear	1-2[d]	1972	1977-78	1,269,900	2,539,800		Nuclear		Rhea County, TN
Future nuclear plant	1-2[d]	1974	1979-80	1,332,000	2,664,000		Nuclear		Undetermined
SUPPLEMENTAL GAS TURBINES									
Thomas H. Allen	1-16	1970	1971	23,900	382,400	382,400	Gas, oil		
	17-20	1971	1972	59,600	238,400		Gas, oil		
Colbert	1-8	1971	1972	59,500	476,000		Gas, oil		

[a] Capacity expressed as maximum generator nameplate rating.
[b] Plants and units used in this study.
[c] Allen Plant built by Memphis Light, Gas, and Water Division, leased by TVA in 1965.
[d] Under construction or scheduled.

The total of 15,509 and 2,600 or 18,109 MW of coal-fired capacity is of interest in this study because this capacity represents the potential for sulfuric acid production. Of this potential only a portion of this capacity is used as "base load"; that is, the plants are operated continuously except for maintenance. These are the newer, larger and more efficient plants. The other portion is used as "swing load," that is intermittently, or at times of peak demand. These are the older, smaller and less efficient plants.

The TVA plants which would have the greatest potential for the installation of sulfuric acid production facilities would be the base load coal-fired plants (except Bull Run which burns low-sulfur content coal, 1.5%). This is based on the indication that sulfur dioxide recovery and sulfuric acid-producing facilities would be less competitive in intermittent service for TVA than limestone scrubbing or "throwaway processes" facilities. Also, sulfur dioxide recovery and acid-producing facilities operate more efficiently under continuous duty with steady-state conditions.

One of the relatively new and large units is being equipped with a limestone scrubbing sulfur dioxide removal system. This plant is the Widows Creek Unit No. 8 and is not considered a potential sulfuric acid producer. The swing load plants--Colbert Units 1-4, John Sevier, Johnsonville 1-6, and Kingston--generally would have limited potential for acid production.

Therefore, of the total 18,109 MW of coal-fired capacity, 9,979 MW could be considered for sulfuric acid production. This analysis, however, is for study purposes and does not take into account process reliability, costs available alternatives, or other environmental factors.

Using fiscal year 1972 (which started July 1, 1971, and ended June 30, 1972) data from TVA power plant operation, estimates of possible acid production from the 9,979 MW is shown in Table 7.

Table 7. ESTIMATE OF ACID PRODUCTION CAPABILITY (1972)

Steam plant and unit	Capacity, total MW	Capacity factor, %	% sulfur-coal	Millions of tons coal burned	Thousands of tons sulfuric acid produced[a]
Colbert (5)	550	31.5[b]	4.2	0.64	59.9
Cumberland (1-2)	2600	12.0[c]	3.8	0.13[c]	10.7
Gallatin (1-4)	1255	55.9	2.8	2.51	138.3
Johnsonville (7-10)	691	54.3	3.7	1.36	108.7
Paradise (1-3)	2558	66.4	4.0	6.61	582.5
Shawnee (1-10)	1750	67.6	2.8	4.64	255.6
Widows Creek (7)	575	46.1	3.2	1.08	71.4
					1227.1

[a] Sulfuric acid tonnage in tabulation and elsewhere in report is on 100% H_2SO_4 basis unless otherwise noted.
[b] Low factor due to unusual outage.
[c] Was put in operation during later part of year.

The above acid production was calculated on the basis that about 90% of the sulfur in the coal is found as sulfur dioxide in the stack gas. The remaining sulfur is rejected in the coal mills as pyrites, leaves in the ash, or is unaccounted for. For every pound of sulfur oxidized, 2 pounds of sulfur dioxide are produced and for every pound of sulfur dioxide that is recovered, 1.53 pounds of sulfuric acid can be produced. The figures in the table are based on the foregoing and on the EPA emission standard for new coal-fired steam plants--1.2 pounds of sulfur dioxide per million Btu heat input. Such emission control would require the sulfur dioxide removal efficiencies shown in Table 8.

Table 8. ESTIMATED SO_2 REMOVAL EFFICIENCY

Steam plant and unit	SO_2 removal efficiency
Colbert (5)	81
Cumberland (1-2)	79
Gallatin (1-4)	71
Johnsonville (7-10)	78
Paradise (1-3)	80
Shawnee (1-10)	71
Widows Creek (7)	75

It is thus determined that if TVA had installed acid facilities on its potential sulfuric acid-producing plants, TVA would have produced about 1,200,000 tons of sulfuric acid in fiscal year 1972. The entire production of sulfuric acid in the United States in 1972 was about 31 million tons; therefore, the TVA production of sulfuric acid would have represented less than 4% of the national production.

Based on tentative operating projections supplied by TVA's Division of Power Resource Planning, an estimate of potential sulfuric acid production from TVA's plants through the year 1985 was made. In this forecast, consideration was given to the oncoming new plants--coal-fired and nuclear--and the effect of time, age, and maintenance on operating schedules for existing plants. Coal analyses were based on 1972 data. The years 1973 and 1974 were not included because sufficient lead time is not available for the installation of acid production facilities during those years and probably not until several years later. The changes from 1972 to 1975 reflect the anticipated higher load factors at some of the plants. The forecast of theoretical TVA production is shown in Table 9.

Table 9. FORECAST OF POSSIBLE TVA ACID PRODUCTION

Steam plant and unit	Estimated production of sulfuric acid (thousands of tons)										
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Colbert (5)	121.9	112.4	121.9	112.4	103.3	121.9	112.4	103.3	84.4	65.5	84.4
Cumberland (1-2)	578.7	578.7	578.7	578.7	578.7	578.7	570.5	562.2	520.8	487.8	471.2
Gallatin (1-4)	165.3	159.8	159.8	148.8	143.3	137.8	126.8	115.7	99.2	77.1	71.6
Johnsonville (7-10)	135.9	135.9	135.9	120.0	111.9	111.9	95.9	71.9	55.9	48.0	40.0
Paradise (1-3)	617.3	617.3	617.3	608.4	608.4	608.4	608.4	600.0	573.2	555.6	546.7
Shawnee (1-10)	270.0	187.4	253.5	253.5	253.5	253.5	215.0	187.4	137.8	115.7	99.2
Widows Creek (7)	92.6	86.0	92.6	86.0	86.0	86.0	79.4	72.8	66.1	59.5	52.9
Total	1981.7	1877.5	1959.7	1907.8	1884.8	1898.2	1808.4	1713.0	1537.4	1401.6	1366.0

With sulfuric acid production between about 300 and 2000 tons of acid per day, depending on the size of the plant; sufficient sulfuric acid storage capacity should be provided at each power plant to provide for upsets in shipping schedules. Such upsets could be caused by delays in barge movements due to strikes, floods, or breakdowns, or an inability of the acid purchasers to receive scheduled shipments due to a variety of reasons. A rough determination indicates that storage for 90 days of production should be provided at each generating station. This 90-day storage capability matches that for coal supply, permits shipping in barge quantities, allows for reasonable transportation tie-ups and covers the normal seasonal demand of acid for fertilizer. Storage would also be required at the acid consumer's location; to be prudent, this would probably be on the order of thirty times the daily consumption rate. The anticipated maximum tonnages of acid shipped monthly and plant storage facilities are estimated in Table 10.

Table 10. ESTIMATED PRODUCTION AND STORAGE VOLUMES

Steam plant and unit	Maximum monthly production 1000 tons	3-month storage at maximum production rates	
		1000 tons	(98% acid) 1000 gallons
Colbert (5)	11.6	34.8	4,530
Cumberland (1-2)	55.1	165.3	21,520
Gallatin (1-4)	15.7	47.1	6,130
Johnsonville (7-10)	12.9	38.7	5,039
Paradise (1-3)	58.8	176.4	22,970
Shawnee (1-10)	25.7	77.1	10,040
Widows Creek (7)	8.8	26.4	3,437

MARKET APPROACH

In order to determine the relationship between volume and revenue for sale of recovered acid, a model was developed based on the hypothetical production potential of the TVA power system. The response criterion of the model is net sales revenue (or loss if costs for distribution exceed price) after freight, handling, and marketing costs are deducted from total income. For the purpose of this evaluation, a zero dollar value for the acid has been assumed at the TVA steam plant point of production to determine net sales revenue. However, since actual production cost will vary with the process used, the size of the generating unit, and other factors, the net sales revenue would be reduced by the production cost in order to determine profitability.

Sulfuric acid may be consumed at the point of production, shipped either across the fence or for longer distances to the final consumer, or used in one application and after it becomes contaminated (spent) consumed in another application. The manufacturing-marketing schemes are quite complex, but several different situations can be identified.

1. Production of acid near the point of use from purchased sulfur.

2. Production of acid near the source of sulfur by the basic sulfur producer.

3. Marketing of spent or regenerated acid.

4. Marketing of acid recovered from pollution abatement processes (smelters, refineries, power plants).

The first of these situations--production from purchased sulfur--is the most vulnerable because the producer is dependent on an external source of sulfur. The acid producer who owns his source of sulfur would consider the investment in mining facilities as "sunk" and would take into account only his "out-of-pocket" costs when meeting market price pressures. The arrangements for utilization of spent acid are specialized and it would be difficult to place abatement acid in this market.

A large incremental volume of merchant acid would result in serious price erosion. The most orderly way to incorporate the abatement acid into the market would be to replace the capacity of sulfur-burning sulfuric acid plants which purchase sulfur from external sources. Therefore, the strategy assumed for this study is to substitute recovered acid for purchased sulfur.

MARKET POTENTIAL

At TVA's National Fertilizer Development Center, a computerized file of worldwide manufacturers of fertilizers and related products is maintained; a list of sulfur-burning acid plants currently in production or planned through 1975 was developed from this file. The study was limited to a 10-state area on the inland waterway system in the central United States. The TVA power plants are located with access to this waterway. The states selected were Alabama, Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, Ohio, Tennessee, and Texas. Also, Florida was included as an alternate marketing area, if required.

Information from the TVA file provided the following data for sulfuric acid plants: company, location, annual capacity, and process type. Dates of construction and major capital improvements were obtained from other sources.[3,11] A total of 61 sulfuric acid plants (see Appendix H1 and H2) were identified as potential points for acid sales. These points can be roughly grouped into seven market areas: Memphis, Houston, Chicago, New Orleans, Cincinnati, Columbus, and Tampa.

The production from the 61 plants represents the market potential for recovered acid--the market demand is dependent on incentive. Experience has shown that price, quality, and convenience are the major factors that influence product or process substitution. The primary incentive to purchase acid will be cost reduction compared with manufacture from purchased sulfur. In order to estimate the value of acid from sulfur-burning plants, it was necessary to determine the basic (avoidable) costs of acid production. Recovered acid could be expected to enter the market at a price no higher than the costs which could be avoided by shutting down the most inefficient plant. In order to move the total production, some of the more efficient plants would have to be shut down; therefore the price will be influenced by the volume.

AVOIDABLE COSTS

Estimates of avoidable costs for existing sulfur-burning acid plants are essential in this study. Simply stated, these costs are those which a producer would not incur if he discontinued operation of the plant. They can be delineated as follows:

Raw material	Sulfur
Utilities	Electric power, cooling water, process water, boiler feed water
Operating expenses	Labor, supervision, payroll overhead
Capital costs	Amortized costs for maintenance of existing facilities plus amortized cost of new capital investment at end of useful plant life

An adjustment for loss of steam generation in the acid plant is required.

SULFURIC ACID PRODUCTION--DISTRIBUTION MODEL

In the derivation of a model to maximize the net sales revenue from sale of abatement acid, the following factors were taken into consideration:

1. Trade-off between avoidable costs at 61 acid plants and shipping distances from 7 power plants.

2. Effect of sulfur price.

3. Effect of volume on net sales revenue.

The combinations of these factors contribute to the complexity of the evaluation and use of a computer is almost essential to establish maximum revenues. A production-distribution model (similar to a transportation linear program model) was developed to handle the several variables. The objective of the model is to minimize acid costs to the existing sulfuric acid plant locations while maximizing net sales revenue to TVA.

The program, which is explained in detail in Appendix A, was designed so that key technical and economic parameters can be varied. Table 11 lists the major parameters and shows typical values. The following description of the parameters illustrates the logic incorporated into the model.

The first three parameters in Table 11 relate to sulfur conversion efficiency as a function of plant design; the data are based on a report by the Chemical Construction Corporation.[11] Plants built prior to 1960 average 95.5% conversion and later ones are more efficient, 97%. Other technical variables could be included with minor programming effort. Parameters 4 through 9 are used to calculate the manufacturing cost of sulfuric acid; an example is shown in Table 12. The investment requirement is based on information from the Sulphur Institute Bulletin No. 8[12] and operating costs based on the Chemico report.[11] The values for the investment parameters (4-6) in Table 11 are estimates based on the initial capital estimates shown in Table 12. A regression analysis indicated that a seven-tenths scale factor would be appropriate for either single or multiple plant estimates. The utility costs (parameter 7) are fixed per ton of sulfuric acid and the operating expenses (parameter 8) are annualized; taxes and insurance (parameter 9) are proportional to initial capital investment.

In this model, the annual costs are summed and amortized, or averaged, over all years in the firm's planning horizon. The model is constructed in terms of constant dollars. Cost streams are composed of (1) constant annual expenditures for sulfur, utilities, labor, and maintenance; (2) periodic expenditures for new plants; and (3) maintenance of existing facilities which is assumed to grow at a compound rate. Constant annual expenditures are treated in the usual static manner since inflation is ignored and their first-year value is the same as their average value. Maintenance and capital outlays are treated as a percent of capital cost.

Table 11. MAJOR PARAMETERS IN MODEL

No.	Description of variable	Example value	Fortran name
1	Tons of sulfur per ton H_2SO_4 (before YEAR60)	.3053	PRE60
2	Tons of sulfur per ton H_2SO_4 (after YEAR60)	.3006	POST60
3	Year of technology change	60.	YEAR60
4	Sulfuric acid plant investment ($/ton-year)	27.285	EXPENDO
5	Capacity for this plant (M tons/year)	247.5	SIZEO
6	Scale factor for determining investment for other sized plants	.734054	FACTOR
7	Fixed conversion cost per ton ($/ton)	.47	AVC
8	Fixed annual conversion cost ($/year)	116.620	AFC
9	Taxes and insurance rate	.015	TIR
10	Time preference rate for money	.08	RATEI
11	Compound maintenance rate	.04	RATEM
12	Economic useful life	34.	USELIFE
13	Percent H_2SO_4 concentration	98.	ACDCON
14	Port Sulphur price ($/short ton)	22.32	PS
15	TVA H_2SO_4 price ($/ton H_2SO_4)	0.	PA
16	Proportion of 330 TPD capacity estimate	1.	DEMAND
17	Number of steam plants	7.	NPLANTS
18	Number of acid plants	61.	JNUM
19	Number of years considered	1.	NYEARS
20	Years considered	75.	YEAR(I)

Table 12. PRODUCTION COST ESTIMATES FOR SULFURIC ACID

Acid plant	Capacity			
Tons per day	50	250	750	1,500
Tons per year, at 330 days/yr	16,500	82,500	247,500	495,000
Initial capital, $	909,000	3,090,000	6,907,000	10,905,000
Unit capital, $/ton-yr	55.09	37.45	27.91	22.03
Operating costs, $				
Utility costs				
Electric power	11,570	57,800	172,700	346,600
Cooling water	6,040	30,200	90,300	181,200
Process water	70	350	1,020	2,100
Boiler feed water	980	4,910	14,730	29,440
Steam (credit)	-10,870	-54,400	-163,000	-326,000
Labor				
Operating	47,500	47,500	47,500	47,500
Supervision	21,100	21,100	21,100	21,100
Overhead at 70% above	48,020	48,020	48,020	48,020
Capital costs, $				
Amortized value of maintenance plus capital outlays at optimal useful life (29-41 yr), 14.9%	135,441	460,410	1,029,143	1,624,845
Taxes and insurance, 1-1/2%	13,635	46,350	103,605	163,575
Annual operating cost, $ (excluding sulfur)	273,486	662,240	1,365,118	2,138,380
Unit cost, $/ton (excluding sulfur)	16.57	8.03	5.52	4.32

The average values of these two components are plotted in Figure 5, as a function of useful life. It can be seen that average capital costs decline rather rapidly as useful life increases. On the other hand, average maintenance cost increases with the age of the plant. Optimal useful life is reached when the added capital cost savings from increasing useful life by one year just equals the added maintenance savings from shortening useful life by one year. In Figure 5 this point corresponds to 34 years and is based on the minimum point on the average total cost curve. Note that the average total cost curve in Figure 5 is very flat over a wide range of years. For example, average capital charge of 14.9% used in Table 12 covers a range of 29 to 41 years. However, random effects such as: abrupt physical, economic, technological, or environmental changes probably have the dominant influence on timing of plant replacement.

In the present study, existing rather than new plants are of primary concern. Initial capital expenditures for existing plants are "sunk" cost and do not directly enter a firm's decision to discontinue present production in favor of buying pollution abatement sulfuric acid. Only avoidable costs within the firm's planning horizon would be considered.

As explained in detail in Appendix A, the amortized cost of an existing plant can be expressed as a function of remaining useful life. The amortized values of maintenance and capital outlays for a 1-year-old plant are shown in Figure 6. The average cost of the existing plant only reflects maintenance, which increases with age and this is shown in Figure 6 as "old costs." It is assumed that the level of maintenance for a plant of given age is constant, regardless of the year built. The added savings from postponing the building of a new plant is just offset by added maintenance costs in the 34th year, which is the same optimal useful life as for a new plant. The main difference is that the level of costs decreases from 14.9% in Figure 5 to 7.1% in Figure 6. Figure 7 illustrates the same sets of curves but for a 30-year-old plant. Note that optimal useful life is still 34 years, but that the level of cost has risen to 14.6% of initial capital expenditure. Note also that in Figure 6 for a 1-year-old plant, new cost is only about 1% at 34 years, while new cost climbs to about 11% in Figure 7 for a 30-year-old plant. Management of a new plant is not very concerned with replacement alternatives while management of an old plant is faced with imminent replacement alternatives. This latter group should be receptive to exploring the alternative of purchasing pollution abatement acid because maintenance costs are high and within a few years a decision concerning plant modernization will have to be reached. The computer program calculates the above-mentioned costs based on interest rate (8% of total investment), maintenance rate (4% of initial investment compounded annually at a rate of 4%), and plant age. The user is given the freedom of selecting useful life, although the program could be modified to calculate and use the optimum value.

The last eight parameters in Table 11 relate primarily to the logistical portion of the model. It is assumed that the competitive pricing structure for sulfur in the United States is based on a Gulf Coast price plus transportation cost to a given sulfur-burning sulfuric acid plant. It is recognized that Canadian and other sources of sulfur are factors but it is assumed that these sources compete on world price basis. This assumption seems reasonable, since firms buying imported sulfur continually bargain against Gulf Coast sources.

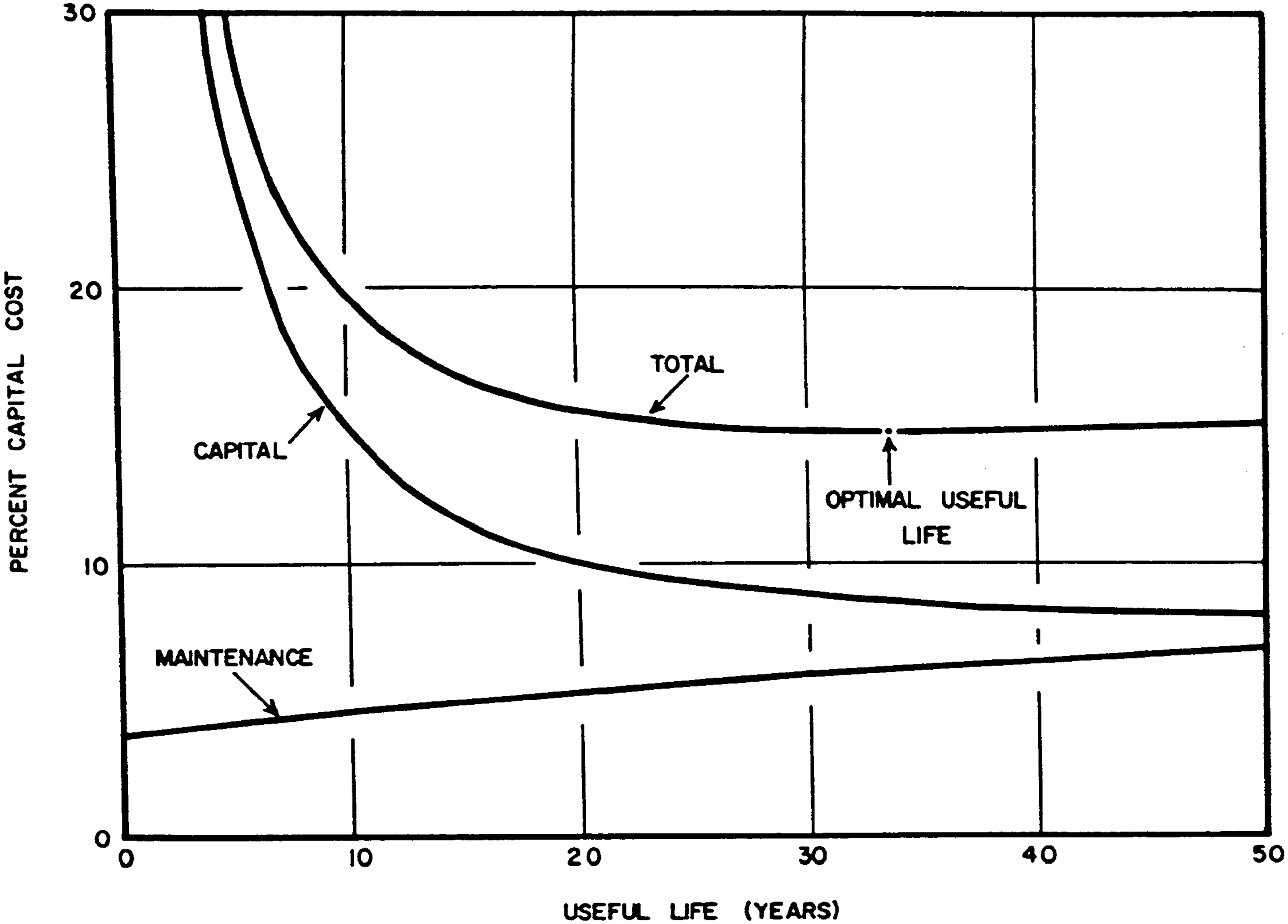

Figure 5. AMORTIZED VALUE OF MAINTENANCE AND CAPITAL OUTLAYS FOR NEW PLANTS (Assuming 8% Interest and 4% Compound Maintenance)

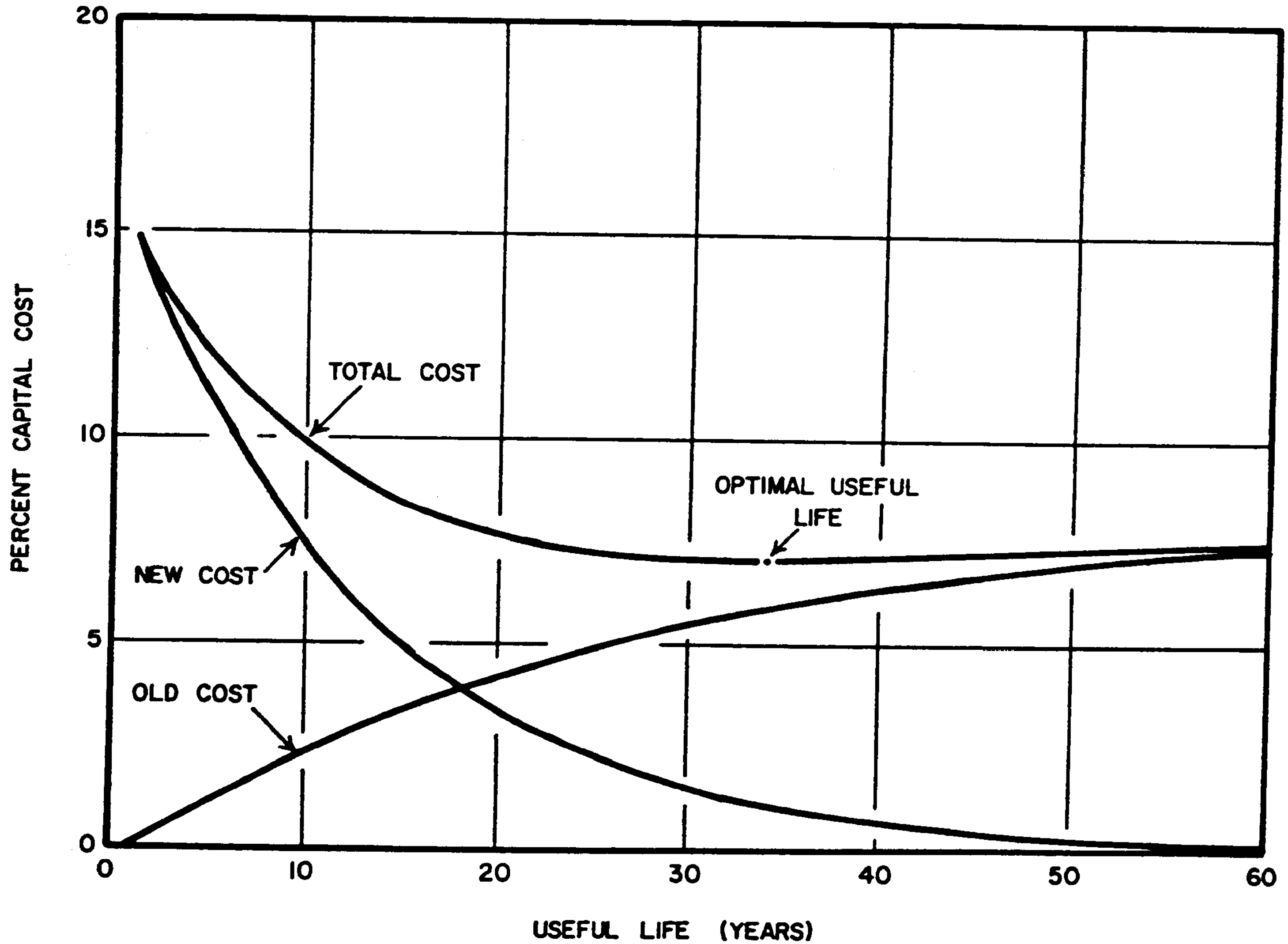

Figure 6. AMORTIZED VALUE OF MAINTENANCE AND CAPITAL OUTLAYS FOR ONE-YEAR-OLD PLANTS
(Assuming 8% Interest and 4% Compound Maintenance)

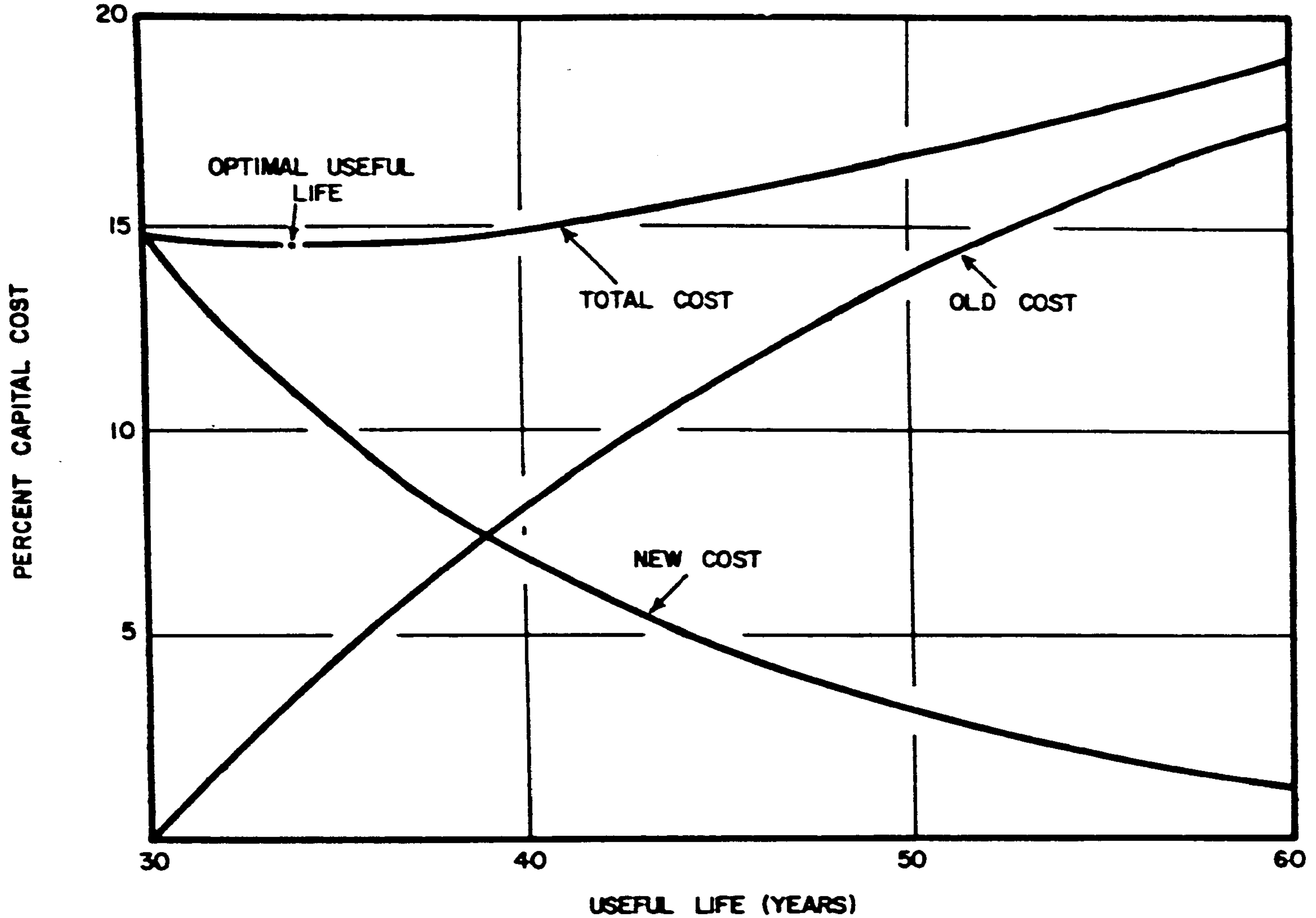

Figure 7. AMORTIZED VALUE OF MAINTENANCE AND CAPITAL OUTLAYS FOR THIRTY-YEAR-OLD PLANTS
(Assuming 8% Interest and 4% Compound Maintenance)

The model thus estimates a delivered sulfur cost to each acid plant considered and adds the appropriate sulfur to sulfuric acid conversion costs. These costs not only depend on a plant's age but also on its production capacity. This requires the assumption that obsolete plants will be replaced by new plants of the same capacity. The highest cost plants are the small, old ones farthest away from the Gulf Coast.

The model calculates transportation costs from each steam plant location to every potential sulfuric acid market point considered. While only TVA steam plants are now presently in the program, competitive utilities could also be included. The model allows a proportional selection of up to three modes of transportation to each acid producer and rates are based on 100% H_2SO_4.

Estimated handling costs (fixed cost per ton) associated with each steam plant, and a TVA f.o.b. acid price are added to the transportation cost, which results in a delivered price to each acid plant. Maximum net sales revenue is derived by adjusting the f.o.b. price of acid until the total volume is sold.

Another important economic factor is the cost of pollution abatement facilities that must be added to existing sulfur-burning acid plants. This cost could be expected to vary considerably from one plant to another due to age of plant and process used. The study[11] of several processes prepared by the Chemical Construction Corporation shows that costs vary from $1 to $7 per ton of sulfuric acid. We have estimated that the average would be about $3 per ton. This factor is not included in the program and in many cases net revenue results shown later in the report could be increased by this amount.

The program is written so that one or more years can be considered simultaneously. For a given year the model examines each acid plant to determine if that firm would be better off continuing production or buying abatement acid. It also determines the optimum distribution pattern from each steam plant to each acid plant. This optimization is done in such a manner as to result in the lowest possible industry cost. The model can determine the quantity of acid sold at a given price or the highest price which will just move the required amount from each steam plant.

The model is written for Control Data Corporation Kronos timesharing and can be run from most any location through a standard telephone. Furthermore, the program can be made available to anyone interested in its use. Appendix B summarizes the operating procedure. The heart of the model is a conversational linear programming package called APEX. The present program calculates costs for each acid plant - steam plant combination (presently over 400) and then generates the required input data file. APEX is run to optimize the model and a second program interprets solutions as printed reports. An interactive system is also available which can display any or all of the standard linear programming solution values.

A significant part of the present project is considered to be a demonstration of this highly useful, modern approach to computer service. Transferring results from one research group to another, either within the same organization or to another organization, is often difficult. It is possible that timesharing could prove an extremely valuable tool in improving this transferability.

FREIGHT RATES AND HANDLING CHARGES

Freight rates used in the model were obtained from TVA's Navigation Economics Branch located in Knoxville, Tennessee. These rates can be divided into two categories:

1. Those used for shipping sulfur from Port Sulphur, Louisiana, to various plant locations. These rates are used as a factor in determining the cost of sulfuric acid production at each plant location.

2. Those rates for shipping sulfuric acid from the seven TVA steam plants to each of the various sulfuric acid production locations. These rates are a factor in determining the netback to TVA.

The freight rates for sulfur, both rail and barge, are shown in Appendix C. The rail rates shown are for crude sulfur with the exception of Fort Madison, Iowa, where liquid (molten) sulfur has an established lower rate. Barge rates, which are negotiable, have been estimated for liquid sulfur per net ton (short ton). At some locations truck rates have been used because they are lower than rail rates. It will be noted that the tables contain a column for "percent barge." This was provided so that the cost of alternate transportation could be included when factors affecting the availability of barges such as river freezing or lack of supply prevent water transportation. This will be discussed in the various market "cases" later in the report.

Sulfuric acid freight rates are shown in Appendixes D, E, and F. Appendixes D and E are based on barge shipments. As mentioned before, since barge rates are negotiable, all of these rates have been estimated. It should be noted that the barge rates to the phosphate mining locations in Florida have been deleted in the appendix tables; only rail rates will be used because they are less than the barge rates. All barge rates used in the study are complete rates including equipment costs and towing charges.

In addition to acid and sulfur freight charges, there will be charges for handling or moving the materials at each plant location. These costs have not been delineated in this study due to the time that would be required to obtain the data. Handling charges can be expected to vary considerably from one location to another. For example, at Fort Madison the sulfur-burning plant is located on the waterway and has its own docking facilities. On the other hand, the plant located at North Little Rock, Arkansas, is located approximately 15 miles from the nearest docking facility. Plants included in this study are now incurring handling charges for movement of sulfur for their existing operation. Should they cease production, these charges would no longer be incurred. It is felt that, even though the tonnage of sulfuric acid would be about three times that of sulfur, the lowered cost for handling sulfuric acid would approximate the handling charges now being experienced by these plants so that, in effect, the costs are generally equivalent.

An estimated cost of $0.20 per ton has been programmed into the model to cover acid storage at the existing acid plants. This would provide 30-day storage at the existing sulfuric acid plants. (Storage required at the steam plants is assumed to be included in the steam plant's acid production costs.) The unit cost is based on estimated capital costs for the tanks and auxiliary facilities of $20 per ton. The investment requirement was determined from information obtained in personal communication with an acid producer and estimates of tank costs provided by General American Transportation Corporation.

RESULTS OF ANALYSIS

BASE CASE

Table 13 shows the market pattern for the abatement sulfuric acid for the base situation. Tables showing variations from the base situation are contained in Appendix G and will be discussed later in the report. The base situation shows the market pattern and maximum net sales revenue for the acid under the following conditions: All acid is sold externally; acid concentration is set at 98% H_2SO_4; demand, or market potential, is assumed to be 100% of annual capacity of sulfur-burning plants considered, using 330 working days per year; sulfur is priced at $25 per long ton f.o.b. Port Sulphur, Louisiana; transportation costs for sulfur from Port Sulphur to each acid plant location is assumed to equal barge rates shown in Appendix C with the exception of Texas locations where no transportation costs other than handling costs would be expected to occur. Sulfuric acid produced at each steam plant is shipped entirely by barge.

The base case market pattern shown in Table 13 is the most economical market pattern under these conditions and would allow TVA to obtain maximum net sales revenue for its acid. In this case, maximum net sales revenue is $8.76 per ton. It should be noted that this is the lowest of the marginal costs shown for each of the seven steam plants. If the unit price were increased without a change in other variables such as sulfur price, then TVA would not be able to sell all of its acid. Furthermore, if net sales revenue per ton were to be increased and acid sales were reduced, the production from the Widows Creek plant (which has the lowest net sales revenue) would be the most economical place to cut acid production. However, if operation of the power plant were dependent on continued operation of the abatement facility, acid would be produced and sold at a lower return or neutralized for disposal.

The list of plant locations shown is the most economical number of customers where TVA acid could be marketed. If acid is sold at these locations, then cost of sulfuric acid in the 11-state area is minimized and TVA maximizes its net sales revenue.

Table 13 lists production capacity and actual production for each of the sulfuric acid plant locations selected by the model. These two columns are used to identify the sulfuric acid plant's marginal capacity versus its actual use. The plant which continues to produce a portion of its own acid is identified as the "swing" or marginal plant. In this case the swing plant is No. 37 located at East Chicago, Indiana, and would be the first plant to discontinue purchase of TVA acid should delivered acid price increase or delivered sulfur costs decrease. Appendix I shows the cost of sulfuric acid production for each plant location used in the model.

The column headed "sulfur reduction, $" shows the change in the marginal cost of sulfur at any given plant that would be required before it would become more economical for it to produce its own acid. For instance, if the plant at Joliet, Illinois (No. 35) could reduce its sulfur costs by $1.24 per short ton while sulfur costs to all other plants remained the the same, then it would not receive TVA acid.

Table 13. BASE CASE MARKET PATTERN FOR TVA H_2SO_4

(M TONS)

SULFUR PRICE = $22.32 ACID CONCENTRATION = 98% CAPACITY = 100% BARGE = 100%

MAXIMUM TVA ACID PRICE WOULD BE $ 8.76

PLANT LOCATION	PRODUCTION CAPACITY	ACTUAL PROD'N	YEAR BUILT	SULFUR REDUC'N ($)	STEAM PLANT SALES COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
2. N.LITTLE ROCK,AR	86	0	46	7.25	0	0	0	0	0	86	0
28. E.ST.LOUIS,ILL.	153	0	37	7.38	92	0	0	55	0	7	0
29. MONSANTO,ILL	139	0	67	1.40	0	0	0	139	0	0	0
30. E.ST.LOUIS,ILL.	239	0	54	2.50	0	0	0	239	0	0	0
32. CALUMET CITY,ILL	111	0	56	3.87	0	35	0	76	0	0	0
33. JOLIET,ILLINOIS	36	0	54	17.06	0	0	36	0	0	0	0
35. JOLIET,ILLINOIS	256	0	45	1.24	0	127	129	0	0	0	0
36. STREATOR,ILL.	35	0	51	13.91	0	35	0	0	0	0	0
37. E.CHICAGO,IND.	334	72	37	0.	0	18	0	0	108	0	136
38. LASALLE,ILLINOIS	35	0	37	21.89	0	35	0	0	0	0	0
40. JOLIET,ILLINOIS	299	0	42	.68	0	299	0	0	0	0	0
41. CALUMET CITY,ILL	30	0	47	22.90	30	0	0	0	0	0	0
42. CHICAGO HTS,ILL	30	0	60	17.39	0	30	0	0	0	0	0
46. BATON ROUGE,LA.	90	0	53	0.	0	0	0	0	90	0	0
47. NEW ORLEANS,LA.	30	0	65	8.56	0	0	0	0	30	0	0
54. HAMILTON,OHIO	63	0	48	11.35	0	0	0	63	0	0	0
55. CINCINNATI,OHIO	30	0	46	28.03	0	0	0	30	0	0	0
56. CINCINNATI,OHIO	16	0	38	44.54	0	0	0	16	0	0	0
60. COLUMBUS,OHIO.	18	0	37	22.54	0	0	0	0	18	0	0
61. COLUMBUS,OHIO	24	0	37	15.07	0	0	0	0	24	0	0
PLANT CAPACITY					122	579	165	617	270	93	136
PLANT PRODUCTION					122	579	165	617	270	93	136
MARGINAL ACID COST ($)					9.27	9.78	9.27	9.27	10.19	8.76	9.78

TOTAL PRODUCTION = 1982

TOTAL NET SALES REVENUE = $ 17351886

Acid shipments from each steam plant to the various locations are also shown in Table 13. This is the most economical distribution pattern for TVA acid. Should some other distribution pattern be used, then TVA would have a reduced net sales revenue or sell less acid. For instance, by examining a complete listing of the program we can determine the amount of freight TVA would have to absorb in order to sell acid in the large sulfuric acid-producing area of Florida. TVA's net sales revenue would vary from a minus $0.28 per ton for acid shipped from the Widows Creek Steam Plant to a minus $2.21 per ton for acid shipped from the Shawnee Steam Plant to plant location No. 10 at Pierce, Florida.

Plant capacity refers to sulfuric acid production capabilities for each steam plant as listed earlier in this report. Plant production shows the amount produced from the seven steam plants--in this case, 1.98 million tons.

INFLUENCE OF FREIGHT COSTS

Acid freight costs have the greatest effect on TVA's net sales revenue. The base case assumes that TVA would be able to ship all of its acid by barge. In all likelihood, weather and other external forces would make it necessary for TVA to occasionally rely on rail shipment to maintain an even supply to its customers. A variation of the base case calculated on the basis that 80% of the acid produced by TVA would be shipped by barge and 20% by rail is shown in Appendix G1. Total net sales revenue in this variation would be $12.9 million, a decrease in total net sales revenue of $4.4 million or a reduction of 25% from the base case. This decrease reflects the increased cost of rail rates and emphasizes the advantage that TVA would have due to the location of its plants on or near the inland waterway system. Tables A and B in Appendix K show transportation costs for sulfuric acid from each steam plant. The costs shown in these tables can also be used to calculate the delivered price of acid for each location. For example, the delivered price to acid plant No. 37 in the base case would be $8.76 plus $3.08, the weighted average barge rate for the acid shipped from the three steam plants involved, or $11.84 per ton.

INFLUENCE OF SULFUR PRICE

In order to determine the effect that sulfur prices would have on TVA's net sales revenue, variations of the base case have been calculated for two additional levels in sulfur price, $20 and $30 per long ton, f.o.b. Port Sulphur, Louisiana. (The effect of sulfur price on TVA net sales revenue is shown in Figure 8.) A reduction in the price of sulfur from $25 to $20 results in a decrease of $2.7 million in TVA's net sales revenue. An increase of $5 per ton in the cost of sulfur to $30 per ton would result in an additional $2.7 million in net sales revenue to TVA.

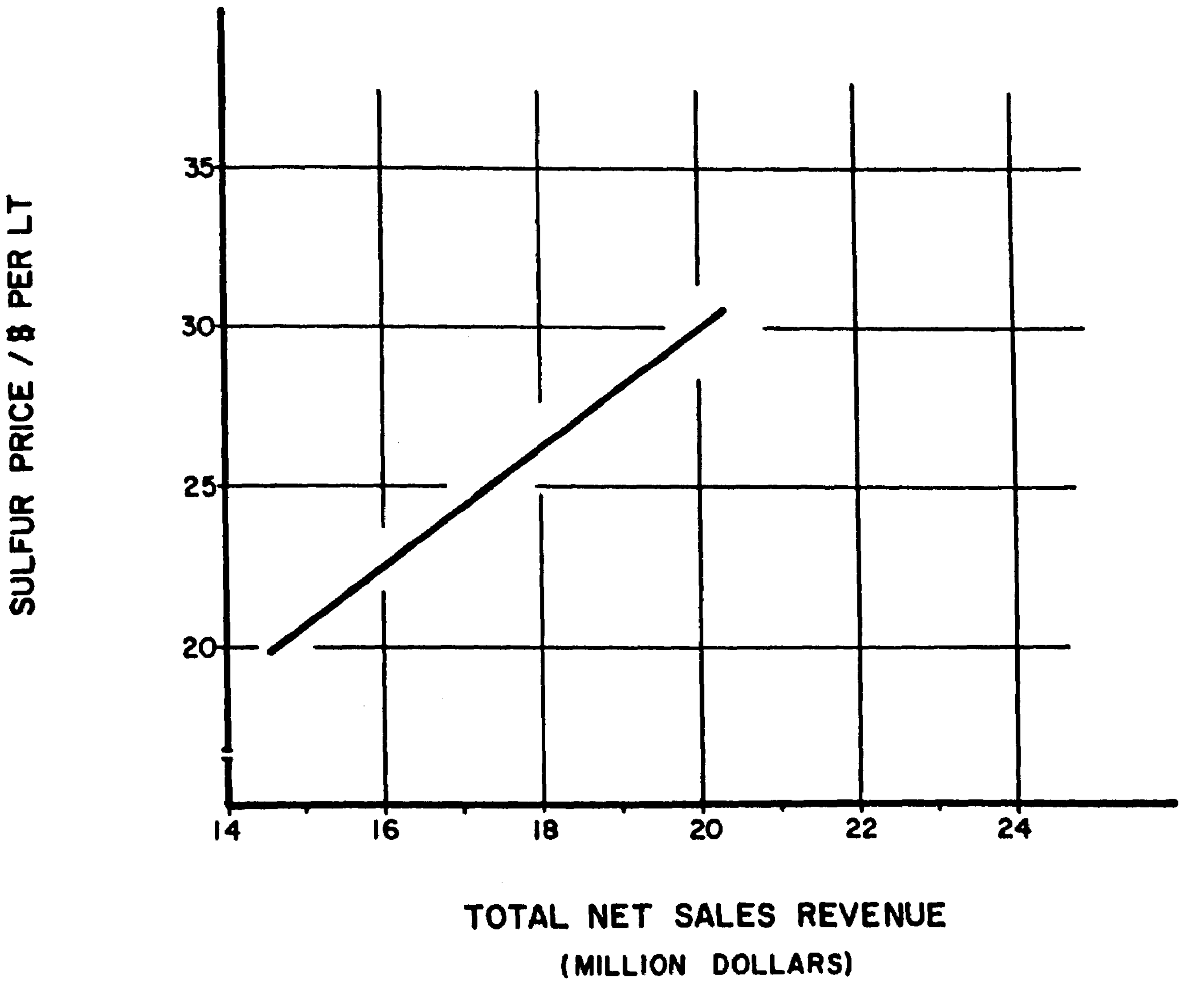

Figure 8. EFFECT OF SULFUR PRICE ON TVA NET SALES REVENUE

INFLUENCE OF ACID CONCENTRATION

As pointed out earlier in the report, one of the sulfur dioxide recovery processes, Monsanto Cat-Ox, produces 80% sulfuric acid. Appendix G4 shows the market distribution pattern for 80% acid. It has been assumed that this acid could be marketed to the fertilizer industry at the same price (100% basis) that the 98% acid could be marketed. This may be an oversimplification because the potential market volume for the lower strength acid is less than for the total sulfuric acid market. Even at the equivalent price, net sales revenue per ton of sulfuric acid would decline about $1 from $8.76 to $7.75, as compared to the base case. This reduction in net sales revenue is a result of increased transportation cost for the more dilute acid.

EFFECT OF CHANGE IN NET SALES REVENUE

The effect that a change in TVA's net sales revenue or "price" has on acid sales is shown in Figure 9 for the base case. As expected, acid movement declines as the "price" of TVA acid increases. In order to move all of its acid, TVA could charge no more than $8.76 per ton plus freight. It could expect to move only about one-half of its production for $10. At $20 per ton of acid no acid could be sold externally.

EFFECT OF CHANGE IN DEMAND

As used in this report, market demand is assumed to equal annual capacity based on a 330-day work year. It is recognized that in actuality this would not be true. Older plants would tend to operate at less than rated capacity, while newer plants would tend to operate at or above rated capacity. Thus, costs of older plants that are operating below capacity would be higher and cost for new plants somewhat lower than those shown in the report. In order to obtain an accurate estimate of demand, a more detailed survey of potential users of abatement acid would be required. As a means of approach to this problem, a comparison was made between the total acid plant capacity on the TVA list for the United States versus production estimated for the United States by the Department of Commerce for 1971 (latest data available).

The Department of Commerce estimate of 29.3 million tons is 74.4% of the TVA estimated capacity of 39.4 million tons. In order to illustrate the effect of changes in demand, one variation of the base case was run at 75%, or an annual capacity based on about 250 days. Appendix G5 shows the distribution pattern for this variation of the base case. Note that TVA acid must be shipped to 26 locations as compared with 20 in the base case. Net sales revenue is reduced by slightly over $2 million due to the necessity of moving TVA acid for longer distances to customers who will have lower acid production costs.

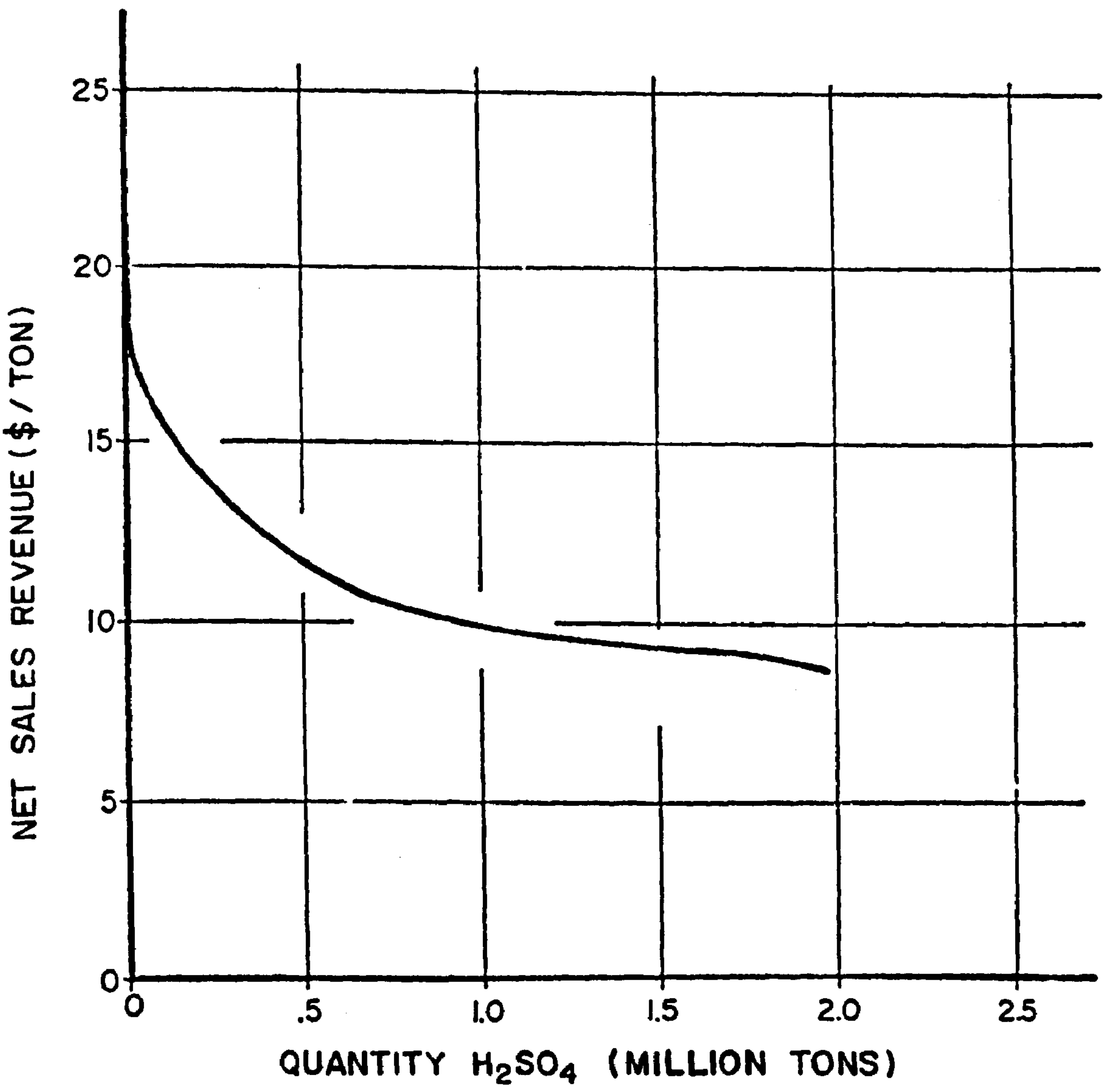

Figure 9. DEMAND FOR TVA SULFURIC ACID

REALISTIC 1975 CASE

From an industry overview, the variations from the base case which appear the most realistic have been combined and a 1975 solution shown in Table 14. The production-distribution transportation pattern is shown for a total external marketing situation where demand is set at 75%, acid concentration at 98%, and transportation costs for sulfuric acid based on 20% rail and 80% barge rates. Under these conditions maximum TVA sales revenue would be $5.99 per ton of acid. Total net sales revenue would be $11.9 million.

INTERNAL USE OF SULFURIC ACID

As an alternative to total external marketing of sulfuric acid, TVA might use a portion of the sulfuric acid at its National Fertilizer Development Center at Muscle Shoals, Alabama. The abatement sulfuric acid would be used in the production of phosphoric acid for fertilizer manufacture. Current TVA plans indicate the need for purchasing merchant-grade phosphoric acid in the amount of approximately 74,000 tons of P_2O_5 in 1975. The cost to TVA for this phosphoric acid is estimated to be $1.25 per unit of P_2O_5 in 1975 and $1.30 per unit of P_2O_5 in 1976 (a unit is 20 pounds of P_2O5; merchant-grade phosphoric acid contains 54% P_2O_5).

The amount of sulfuric acid that would be produced from Colbert No. 5 (550 MW) and Widows Creek No. 7 (575 MW) would be about 221,000 tons in 1975. A phosphoric acid plant sized to use this amount of sulfuric acid would produce about 74,250 tons per year of P_2O_5, or about 225 tons per day. The capital cost of such a plant would be about $8 million. The production costs in dollars per ton of P_2O_5 are shown in Table 15.

In addition to the savings incurred by producing its own P_2O_5, TVA would receive an increased net sales revenue from its remaining external acid sales as shown earlier. Assuming a situation where sulfur is priced at $25 per long ton, f.o.b. Port Sulphur, Louisiana, and acid concentration is 98%, net sales revenue would climb from $8.76 per ton where all acid (1.98 million tons) is sold externally to $9.27 per ton when only 1.78 million tons has to be marketed. This is due to (1) increased freight savings when TVA acid could be shipped from closer steam plant locations, and (2) to the fact that less acid would have to be sold to the marginal (low conversion cost) sulfur-burning acid plant.

At the market price of $1.25 per unit for P_2O_5, the marginal value of sulfuric acid used in phosphoric acid production is $8.36 per ton after an adjustment is made for the loss of revenue from reduced external acid sales. This unit acid value represents the increased return from use of the acid as compared with marketing the total volume. Thus, the total net sales revenue to TVA under these conditions could be estimated as follows:

Savings to TVA for P_2O_5 (74,250 tons/yr)	$ 2,524,000
Net sales revenue from external sales	16,500,000
Total net sales revenue	$19,024,000

Table 14. REALISTIC MARKET PATTERN FOR TVA H_2SO_4

(M TONS)

SULFUR PRICE = $22.32 ACID CONCENTRATION = 98% CAPACITY = 75% BARGE = 80%

MAXIMUM TVA ACID PRICE WOULD BE $ 5.99

PLANT LOCATION	PRODUCTION CAPACITY	ACTUAL PROD'N	YEAR BUILT	SULFUR REDUC'N ($)	STEAM PLANT SALES COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
1. HELENA,ARK.	101	0	67	7.52	101	0	0	0	0	0	0
2. N.LITTLE ROCK,AR	64	0	46	15.19	0	0	0	0	0	0	64
28. E.ST.LOUIS,ILL.	115	0	37	14.64	0	0	10	35	0	70	0
29. MONSANTO,ILL	104	0	67	8.37	0	0	0	104	0	0	0
30. E.ST.LOUIS,ILL.	179	0	54	9.13	0	0	0	179	0	0	0
31. MARSEILLES,ILL.	157	0	62	1.62	0	0	0	0	157	0	0
32. CALUMET CITY,ILL	83	0	56	7.91	0	0	0	83	0	0	0
33. JOLIET,ILLINOIS	27	0	54	23.92	0	0	0	27	0	0	0
35. JOLIET,ILLINOIS	192	0	45	4.53	0	192	0	0	0	0	0
36. STREATOR,ILL.	26	0	51	22.74	0	0	0	0	26	0	0
37. E.CHICAGO,IND.	250	0	37	0.	0	190	0	0	60	0	0
38. LASALLE,ILLINOIS	26	0	37	29.41	0	0	0	0	26	0	0
40. JOLIET,ILLINOIS	224	0	42	3.88	0	117	0	107	0	0	0
41. CALUMET CITY,ILL	22	0	47	30.81	0	22	0	0	0	0	0
42. CHICAGO HTS,ILL	22	0	60	24.91	0	22	0	0	0	0	0
46. BATON ROUGE,LA.	67	0	53	7.79	21	34	0	0	0	0	13
47. NEW ORLEANS,LA.	22	0	65	19.49	0	0	0	0	0	22	0
52. GEISMAR,LA.	58	0	68	3.42	0	0	0	0	0	0	58
54. HAMILTON,OHIO	47	0	48	21.22	0	0	0	47	0	0	0
55. CINCINNATI,OHIO	22	0	46	39.16	0	0	0	22	0	0	0
56. CINCINNATI,OHIO	12	0	38	59.82	0	0	0	12	0	0	0
57. COLUMBUS,OHIO	48	4	65	0.	0	0	44	0	0	0	0
58. COLUMBUS,OHIO	40	0	49	9.35	0	0	40	0	0	0	0
59. COLUMBUS,OHIO	40	0	55	0.	0	0	40	0	0	0	0
60. COLUMBUS,OHIO	13	0	37	37.49	0	0	13	0	0	0	0
61. COLUMBUS,OHIO	18	0	37	28.09	0	0	18	0	0	0	0
PLANT CAPACITY					122	579	165	617	270	93	136
PLANT PRODUCTION					122	579	165	617	270	93	136
MARGINAL ACID COST ($)					6.65	6.97	6.62	6.84	7.57	5.99	7.01

TOTAL PRODUCTION = 1982

TOTAL NET SALES REVENUE = $ 11872170

Table 15. PRODUCTION COSTS FOR PHOSPHORIC ACID PLANT (225 tons/day)

Annual operating costs	\$/ton P_2O_5
Direct cost	
Phosphate rock, 31.1% P_2O_5 (68% BPL) 3.58 tons at \$14.25/ton	51.00
Sulfuric acid, transportation cost from Colbert and Widows Creek, 2.7 tons at \$1/ton (truck rate)	2.70
Labor, 0.83 man-hr at \$6.50	5.40
Maintenance, 6% of plant cost	7.20
Electricity, 330 kWh, \$0.006/kWh	1.98
Cooling water, 5.5 M gal at \$0.02/M gal	0.11
Supplies, analysis, and handling	2.20
Total direct cost	70.59
Indirect cost	
Insurance and taxes, 2% of plant cost	2.40
Depreciation, 12 yr	10.00
Overhead, 100% labor	5.40
Interest, 7-1/2%	4.50
Total indirect cost	20.22
Total production cost	90.81[a]

[a] This is equivalent to \$0.91/unit of P_2O_5 (unit = 20 lb). The net savings would be about \$1.25 minus \$0.91 equals \$0.34/unit of P_2O_5 or

\$34 per ton of P_2O_5
\$2,524,000 per year

This can be compared to the same situation for the base case where total net sales revenue amounted to $17,351,886 or a difference of $1,672,000 per year.

If TVA were to enter into an agreement with a commercial fertilizer company or some other organization that has P_2O_5 requirements and jointly build a phosphoric acid plant, further savings could be realized due to economics of scale. With completion of the Tennessee-Tombigbee canal expected in 1981, barge shipment of phosphate rock to Muscle Shoals at low rates will make such an arrangement even more attractive.

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APPENDIX A

SULFURIC ACID PRODUCTION--DISTRIBUTION MODEL

The sulfuric acid production-distribution model can be defined using the following:

AC(J) = sulfuric acid production cost for the J^{th} acid plant ($/ton)

P(J) = quantity of acid produced by the J^{th} acid plant (thousand tons)

DAP(I,J) = price of sulfuric acid delivered to acid plant J from steam plant I ($/ton)

B(I,J) = quantity of acid purchased by acid plant J from steam plant I (thousand tons)

D(J) = sulfuric acid demand for acid plant J (thousand tons)

K(I) = sulfuric acid production capacity for steam plant I (thousand tons)

The objective of the model is to determine the quantities of acid production P(J) and acid purchases B(I,J) which minimize sulfuric acid cost to all sulfur-burning sulfuric acid producers. In the model each acid producer is given the option of continuing production at AC(J) $/ton or purchasing acid from each TVA steam plant at DAP(I,J) $/ton. The model selects the production-purchase pattern which minimizes total sulfuric acid cost for the industry, subject to the constraints that steam plant acid capacities are not exceeded and sulfuric acid producer demands are met. The model can be summarized mathematically as follows, assuming 61 acid plants and 7 steam plants.

$$\underset{[P(J),B(I,J)]}{\text{MINIMIZE}} \sum_{J=1}^{61} \left\{AC(J) + \sum_{I=1}^{7}[DAP(I,J)*B(I,J)]\right\}$$

subject to:

$$P(J) + \sum_{I=1}^{7} B(I,J) = D(J) \quad (J=1,2,\ldots,61)$$

$$\sum_{J=1}^{61} B(I,J) \le K(I) \qquad (I=1,2,\ldots,7)$$

$$P(J) \ge 0 \qquad (J=1,2,\ldots,61)$$

$$B(I,J) \ge 0 \qquad (I=1,2,\ldots,7)$$

$$(J=1,2,\ldots,61).$$

Solutions to the model are obtained using linear programming optimization techniques.

While a certain amount of price discrimination may be possible, the model assumes an f.o.b. steam plant pricing policy. Delivered acid price is thus defined as

$$DAP(I,J) = PA + T(I,J)$$

where

PA = TVA f.o.b. base price of sulfuric acid

T(I,J) = transportation cost from steam plant I to acid producer J.

Sulfuric acid production cost is defined as

$$AC(J) = [PS + S(J)]*F(J) + C(J)$$

where

PS = Gulf Coast f.o.b. price of sulfur

S(J) = sulfur transportation cost to acid producer J

F(J) = tons of sulfur required per ton of acid by producer J

C(J) = other production costs for producer J.

The model assumes that the competitive pricing pattern for sulfur is dominated by Gulf Coast Sulfur which has a relatively elastic long-run world demand curve. While sulfur is actually purchased from Canadian and other sources, it is assumed that Gulf Coast price plus freight determines delivered sulfur costs. The sulfur conversion rates F(J) are a function of technology advancements and depend on the year a particular plant was built.

Other production costs are defined as

$$C(J) = AVC + [AFC/D(J)] + [TIR*EXPEND(J)] + AVCE(J)$$

where

AVC = fixed conversion cost per ton

AFC = fixed annual cost

TIR = taxes and insurance rate

EXPEND(J) = capital expenditure per ton for sulfuric acid plant J

AVCE(J) = amortized value of annual capital expenditures by producer J.

The predominate reason for defining these cost categories is to conform with previous engineering cost studies.

Capital expenditure for a sulfuric acid plant reflects economies to scale. An accepted statistical model for estimating capital expenditure curves is

$$\ln(EXPEND_i) = \ln(B) + A\ln D_i$$

which is a log linear model whose coefficients (A,B) can be estimated by least squares, given observations on $(EXPEND_i, D_i)$. The model can then be expressed as

$$EXPEND = BD^A.$$

An alternative procedure used in engineering cost studies is called the six-tenth factor rule of thumb. It can be expressed mathematically as

$$\frac{EXPEND(J)*D(J)}{EXPENDO*DO} = \left(\frac{D(J)}{DO}\right)^{.6},$$

where (EXPENDO,DO) are the known expenditure and capacity of a given plant; and it is desirable to scale to plant size D(J) and estimate its expenditure, EXPEND(J), according to a .6 factor. This procedure results in the following estimators:

$$A = -.4$$

$$B = EXPENDO(DO)^{.4}.$$

Hence, in the model the only expenditure estimates required are:

EXPENDO,DO,FACTOR.

The model was constructed using the factor rule-of-thumb concept, but FACTOR and EXPENDO were estimated with a log-linear regression.

As is the case with most engineering cost studies, the present model assumes constant dollars overtime. However, the model does deal with cash-flow patterns in a more realistic manner, and thus could be readily modified to account for expected rates of inflation. The fundamental problem in dealing with alternative cash-flow patterns is expressing multivariable flows as unique, comparable values. This is done by introducing a time preference rate for money, i, and discounting cash-flow streams to a common equivalent point in time. If TCF_k is the total cash flow for year k, the present value of this cash-flow pattern (PVCF) is:

$$PVCF = \sum_{k=1}^{H} \frac{TCF_k}{(1+i)^k},$$

where H is the firm's planning horizon in years. The model assumes an infinite planning horizon, although the accuracy of cash-flow estimates beyond about 40 years is not critical since their added discounted value is essentially zero. Since persons are more accustomed to dealing with annual rather than lump-sum present values, an amortization or equal annual mortgage representation of cash-flow patterns is desirable. This can be stated mathematically as

$$\sum_{k=1}^{H} \frac{AMCOST}{(1+i)^k} = PVCF$$

where AMCOST is a constant annual cash flow which is precisely equal to the present value of cash flow (PVCF). For very long planning horizons it can be shown that

$$AMCOST = i\ PVCF$$

or

$$AMCOST = \sum_{k=1}^{\infty} \frac{i\ TCF_k}{(1+i)^k}.$$

All costs referenced to this point have been assumed constant per year and their sum is now defined as ACF, while time-dependent expenditures are defined as CF_k, hence

$$TCF_k = ACF + CF_k,$$

and it can be shown that,*

$$\text{AMCOST} = \text{ACF} + \sum_{k=1}^{\infty} \frac{i\ \text{CF}_k}{(1+i)^k}.$$

A more formal presentation of the model could include constant-per-year costs in the cash flow; since without inflation, the dynamic and static statement of the model yields identical results.

Suppose the cash-flow stream can be represented as equal lump-sum expenditures which occur every T years. This might represent the useful life of a piece of equipment or of an entire plant. The above cash-flow equation assumes that costs are incurred at the end of the k^{th} period. Let these periodic expenditures occur at the beginning of the period so that the amortized value of these expenditures, AMEXPEND, is

$$\text{AMEXPEND} = \sum_{k=0}^{\infty} \frac{i\ \text{EXPEND}}{(1+i)^{kT}},$$

and it can be shown that

$$\text{AMEXPEND} = \text{AMORT*EXPEND}$$

where

$$\text{AMORT} = \frac{i(1+i)^T}{(1+i)^T-1},$$

which is the standard amortization formula, often referred to as periodic rent of an annuity whose present value is one. It might be noted that a standard approximation used in mathematical analysis is+

$$(1+i)^T \doteq 1 + Ti.$$

Using the approximation

$$\text{AMORT} \doteq \frac{1}{T} + i,$$

---

* "Geometrical Progression," Handbook of Chemistry and Physics, (36th edition) 1954-1955, p. 294.

\+ "Approximations," Handbook of Chemistry and Physics, (36th edition) 1954-1955, p. 296.

one gets the approximation used in most engineering cost studies. The first term is called depreciation, and the second term is called interest on investment. The exact amortization expression is used in the model.

When equipment is new, plant maintenance is at a relatively low level, but as plants age maintenance and replacement costs increase. At some point in time it becomes more profitable to stop rebuilding old plants and build a new one. It seems reasonable to estimate maintenance patterns with an expotential growth function, which is equivalent to compound interest. Since historical maintenance data on sulfuric acid plants were not available, the standard engineering cost assumption that maintenance is proportional to initial capital expenditure was used. As a result, annual maintenance expenditure in year k, MA_k, is estimated as

$$MA_k = M(1+M)^{k-1} * EXPEND,$$

where M is the compound maintenance rate. As a result, the present value of maintenance over T years, PVMA(T), is

$$PVMA(T) = EXPEND * \sum_{k=1}^{T} \frac{M(1+M)^{k-1}}{(1+i)^k}.$$

It can be shown that

$$PVMA(T) = \frac{EXPEND*M}{(i-M)} \left\{ 1 - \left(\frac{1+M}{1+i}\right)^T \right\}.$$

Define the useful life of a plant as USELIFE, so that the present value of maintenance for a new plant, PVMANEW, is

$$PVMANEW = PVMA(USELIFE).$$

The present value of maintenance is equivalent to a lump-sum expenditure like initial capital investment, so they may be added and amortized to get the capital and maintenance cost for a new plant:

$$COSTNEW = AMORT(EXPEND + PVMANEW).$$

In addition to dealing with the cost of new plants, a requirement of the model is that it handle the cost of existing plants. Since the capital expenditure on an existing plant is a sunk cost, it does not enter the cash flow. Only avoidable costs are considered. The amortized cost for an existing plant, AMCOST, can be defined as

$$AMCOST = COSTOLD + \frac{COSTNEW}{(1+i)^{USELIFE-AGE}}$$

where COSTOLD is the amortized or average maintenance and replacement cost for an existing plant which is AGE years old. As the managers of this existing plant look at their cash flow in perpetuity, they expect annual costs to increase. When it becomes profitable to stop rebuilding the old plant and replace it with a new one, they will. Hence, the useful life, USELIFE, is an economic rather than a physically determined variable. It is definitely not an income tax related variable to be confused with IRS accepted depreciation rates. The AMCOST formula reflects not only the average annual costs of the existing plant but also the amortized cost of replacing this plant after (USELIFE-AGE) more years. However, since COSTNEW can be avoided for sometime, it must be discounted to the present. If an existing plant has just been built, COSTNEW will be discounted to virtually zero and will not materially affect the estimate of AMCOST. However, the managers of a very old plant may be seriously considering such a replacement decision within the next year or so, and the discounted value of the new plant will greatly affect their decision. The important thing to keep in mind is that AMCOST is an avoidable cost. One opportunity for avoiding it in the present study is to buy pollution abatement sulfuric acid.

Since data on maintenance costs of existing sulfuric acid plants of various ages were not available, it was decided to assume that maintenance on an existing plant would be approximately the same as that of a new plant of equivalent AGE. As a result, the present value of maintenance on the existing plant, PVMAOLD, is

$$\text{PVMAOLD} = \sum_{k=1}^{\text{USELIFE-AGE}} \frac{M(1+M)^{\text{AGE}+k-1}}{(1+I)^{k}}$$

$$= \text{PVMA(USELIFE-AGE)}*(1+M)^{\text{AGE}},$$

and the amortized cost of this present value is

$$\text{COSTOLD} = i*\text{PVMAOLD}.$$

APPENDIX B

DATA SETUP AND OPERATING PROCEDURES FOR PROGRAM EXECUTION

DATA SETUP

An ASCII sequential data file was developed for the TVA sulfuric acid distribution model. These data include major parameters used in the model (Table 5); data for TVA steam plants (Appendix J); capacity data for sulfuric acid plants (Appendix H); and barge and rail rates (Appendices D, E, and F). Each line in the data file begins with a specific 5-digit line number followed by the standard delimiter (one space). On pages 59 through 63 is a listing of this data file which has been named SDAT714.

Major Parameters in Model

The major parameters for this model are given in lines 00001 through 00020 of the data file. A value must be specified for each of the 20 parameters. One or more spaces separate the value from the line number. The major parameter data setup is as follows:

Line No.	Value of Parameter
Columns	
1-5	7-18
00001	.3053
00002	.3006
00003	60.
00004	27.285
00005	247.5
00006	.734054
00007	.47
00008	116.620
00009	.015
00010	.08

Line No.	Value of Parameter
Columns	
1-5	7-18
00011	.04
00012	34.
00013	98.
00014	22.32
00015	0.
00016	1.00
00017	7
00018	61
00019	1
00020	75

Data for Steam Plants--Fixed Format

Data for this section of the file are supplied in the order of line number, steam plant name, report name, steam plant costs in dollars per ton, and sulfuric acid production capacity in thousand tons per year for a maximum of 10 years. Line numbers for these data are from 10001 to 100** in increments of one, where ** represents the number of steam plants. A maximum of 10 steam plants may be used in this model. A description of these data are as follows:

Line No.	Steam Plant Name	Report Name	Steam Plant Costs	Sulfuric Acid - Prod. Capacity Year 1	Year 2	Year 3	Year 4	Year 5-9	Year 10
Columns									
1-5	7-18	20-23	24-29	30-35	36-41	42-47	48-53	...	84-89
10001	Colbert	COLB	.20	121.9					
10002	Cumberland	CUMB	.20	578.7					
10003	Gallatin	GALL	.20	165.3					
10004	Paradise	PARA	.20	617.3					

Data for Sulfuric Acid Plants--Fixed Format

Sulfuric acid plant data are supplied in the order of line number, plant name, plant location, year built, annual sulfuric acid production capacity in thousand tons, rail freight rate for sulfur from Gulf Coast to acid plants in cents per ton, barge freight rate for sulfur from Gulf Coast to acid plant in cents per ton, and the percent barge assumed in the model. Line numbers will extend from 20001 to 200** in increments of one, where ** represents the total number of acid plants. A maximum of 99 acid plants can be used in this model. The following example shows the data layout for sulfuric acid plants:

Line No.	Sulfuric Acid Plant Name	Plant Location	Year Built	Ann. Cap.	Rail Rate	Barge Rate	% Barge
Columns							
1-5	7-26	28-43	45-46	48-51	53-56	58-61	63-65
20001	Arkla Chemical Corp	Helena, AR	67	135	1580	260	100
20002	Olin Corporation	N Little Rock, AR	46	86	1343	280	100
20003	American Plant Food	Houston, TX	65	116	1740	0	100
20004	Borden Chemical	Texas City, TX	53	128	1740	0	100

Barge and Rail Rates--Fixed Format

The last section of the data file provides the barge and rail rates for shipments of sulfuric acid from TVA steam plants to each of the sulfuric acid plants. There are three data lines for each sulfuric acid plant: (first line) 1,500-ton barge rates from each TVA steam plant, (second line) 3,000-ton barge rates from each TVA steam plant, and (third line) rail rates from each TVA steam plant. The line numbers extend from 30101 to 3**03 where the second and third digits represent the particular acid plant number and ** represents the total number of acid plants. The second and third digits represent acid plant numbers. The fifth digit represents the type rates as described above. The first figure in each line following the line number is the percentage of that type freight used in the model. An example of these data are shown below:

	Line No.	% Used	FROM STEAM PLANT 1	2	3	4	5	6	7	8	9	10
	Columns											
	1-5	7-9	11-14	16-19	21-24	26-29	31-34	36-39	41-44	46-49	51-54	56-59
To acid Plant 1	30101	100	285	245	285	285	195	345	245			
	30102	0	265	210	265	265	185	325	210			
	30103	0	619	675	782	782	675	805	675			
To acid Plant 2	30201	100	370	315	370	370	275	400	315			
	30202	0	350	300	350	350	260	370	300			
	30203	0	828	904	997	997	904	1021	852			

PROGRAM EXECUTION

Program--GENS714

The Fortran program GENS714 will print eight different data Tables and/or generate the required APEX input data file after calculating costs for each acid plant, steam plant combination. (See complete listing of this program on pages 64 through 71.)

Program execution begins with a RUN, MA = 56000 command. In response to the "ENTER DATA FILE NAME?" command, the present data file name, SDAT714, is entered. The program then responds "IS SPECIAL REPORT DESIRED?" A "NO" answer to this query causes the program to skip to the question "DO YOU WISH TO RUN THIS PROBLEM (YES OR NO)?" which is discussed below. A "YES" answer initiates the program response "ENTER SPECIAL REPORT DESIRED #(1-8, 9=ALL, 0=REPORT NAMES)?" One or all of the data reports (Tables 1-8) may be printed at this point. A "0" may be entered to print the eight report names (shown below). The nine choices for printing the tables are:

1. Sulfuric Acid Plants Considered in Model
2. Steam Plants Considered
3. Sulfur Freight Rates
4. 1,500-Ton Barge Rates
5. 3,000-Ton Barge Rates
6. Rail Rates
7. Transportation Costs Used in Model
8. Sulfuric Acid Production Costs
9. All of the Above

After the final table is printed, the program responds "DO YOU WISH TO RUN THIS PROBLEM (YES OR NO)?" A "NO" answer terminates execution, whereas a "YES" answer causes the program to generate the APEX input data file called TAPE3. This file is to be saved under a permanent file named LUCK714.

Program--GOG714

After the APEX input data file has been saved as a permanent file (LUCK714), the linear programming formulation is ready to be initiated. (See complete listing of this program on page 72.)

The actual linear programming formulation of the model takes a slightly different form from that described earlier. The activities of the model are defined as:

XO = Aggregate quantity of sulfur purchased by the sulfur-burning sulfuric acid plants considered

X1(J) = Quantity of sulfur shipped from Port Sulphur to acid producer J

X2(J) = Quantity of sulfuric acid produced by acid plant J

X3(I,J) = Quantity of sulfuric acid purchased from steam plant I by acid producer J

X4 = Total quantity of TVA acid sold.

The objective of the model is to determine values of the above quantities which minimize the functional

$$\sum_{J=1}^{61}\left[S(J) \times 1(J) + C(J)\ X2(J) + \sum_{I=1}^{7} T(I,J)\ X3(I,J) + PA\ X4 + PS\ XO\right],$$

which is constructed for 61 acid plants and 7 steam plants. Each cost term is defined earlier. This minimization is subject to the following constraints:

$$(0)\quad X0 - \sum_{J=1}^{61} X1(J) = 0$$

$$(1)\quad X(J) - F(J)\ X2(J) = 0 \qquad (J=1,2,\ldots,61)$$

$$(2)\quad X2(J) + \sum_{I=1}^{7} X3(I,J) = D(J) \qquad (J=1,2,\ldots,61)$$

$$(3)\quad \sum_{J=1}^{61} X3(I,J) \le K(I) \qquad (I=1,2,\ldots,7)$$

$$(4)\quad X4 - \sum_{J=1}^{61} \sum_{I=1}^{7} X3(I,J) = 0.$$

The linear programming model is solved with Control Data Corporation's APEX optimizer, which uses a modified MPS input-output format. The main difference in standard MPS and APEX format is that 10-character names, which may begin with numbers, are acceptable by APEX. The naming scheme for both rows and columns is the 5-digit format

L JJII,

where L is the node level corresponding to the above five constraint sets or the five XL activity definitions

L = 0,1,2,3,4.

The formula for a given name is

(10000*L) + (100*J) + I,

where J=0 or I=0 where ranges of these indicies are not implied. A primary purpose of the program GENS is to generate this MPS format on TAPE3 for input to APEX.

A unique feature of interactive APEX is the option that solutions may be placed in very compact Fortran files. This feature is used in generating the special report for the model. This APEX operation is triggered by typing "-GOG714" or, if the APEX input data file name is other than LUCK714, operation is begun by typing "-GOG714 (LUCK714=input data file name)."

The results of this run are saved by the program in a direct access solution file called SOL714. After the solution file has been generated by APEX, a second program can be used to list the entire MPS report, or to selectively list various parts of the total solution, using masking options.

Program--REPT714

A special report (Appendix G1) on the Market Pattern for H25Ø4 can be printed by using the program REPT714. This Fortran program is a report writer that reads the results from the solution file SOL714 and prints the special report. (See a complete listing of this program on pages 73 through 75.)

```
00001 .3053
00002 .3006
00003 60.
00004 27.285
00005 247.5
00006 .734054
00007 .47
00008 116.620
00009 .015
00010 .08
00011 .04
00012 34.
00013 98.
00014 22.32
00015 0.
00016 1.00
00017 7
00018 61
00019 1
00020 75
10001 CØLBERT       CØLB   .20 121.9
10002 CUMBERLAND    CUMB   .20 578.7
10003 GALLATIN      GALL   .20 165.3
10004 PARADISE      PARA   .20 617.3
10005 SHAWNEE       SHAW   .20 270.0
10006 WIDØWS CREEK  WIDC   .20  92.6
10007 JØHNSØNVILLE  JØHN   .20 135.9
20001 ARKLA CHEMICAL CØPR. HELENA,ARK.         67  135 1580  260 100
20002 OLIN CORPØRATIØN     N.LITTLE RØCK,AR    46   86 1343  280 100
20003 AMERICAN PLANT FØØD  HØUSTØN,TEXAS       65  116 1740    0 100
20004 BØRDEN CHEMICAL IND. TEXAS CITY,TEXAS    53  128 1740    0 100
20005 E.I.DUPØNT DE NEM    HØUSTØN,TEXAS       61  300 1740    0 100
20006 E.I.DUPØNT DE NEM    LAPØRTE,TEXAS       60  350 1740    0 100
20007 OLIN CORPORATIØN     BEAUMØNT,TX         57  180 1740    0 100
20008 OLIN CØRPØRATIØN     PASADENA,TEXAS      65  222 1740    0 100
20009 OLIN CØRPØRATIØN     PASADENA,TEXAS      65  150 1740    0 100
20010 AGRICØ CHEM-WILLIAMS PIERCE,FLØRIDA      55  718 1129  490 100
20011 BØRDEN CHEMICAL IND. PALMETTØ,FLØRIDA    66  450 1129  565 100
20012 CF INDUSTRIES,INC.   BØNNIE,FLA.         55 1486 1129  565 100
20013 CF INDUSTRIES,INC.   PLANT CITY,FLA.     55  419 1129  410 100
20014 CF INDUSTRIES,INC.   PLANT CITY,FLA.     55  660 1129  410 100
20015 CF INDUSTRIES,INC.   PIERCE,FLØRIDA      55  428 1129  490 100
20016 CITIES SERVICE CØ    TAMPA,FLØRIDA       59  928 1129  185 100
20017 CØNSERVE,INC.        NICHØLS,FLØRIDA     73  400 1129  490 100
20018 FARMLAND INDUSTRIES  PIERCE,FLØRIDA      61  478 1129  490 100
20019 FARMLAND INDUSTRIES  GREENBAY,FLA.       66  748 1129  565 100
20020 W.R.GRACE & CØ.      BARTØW,FLA.         65  330 1129  565 100
20021 W.R.GRACE & CØ.      BARTØW,FLA.         60  700 1129  565 100
20022 CHEMICALS,INC.       BARTØW,FLØRIDA      65  980 1129  565 100
20023 CHEMICALS,INC.       BØNNIE,FLA.         63  594 1129  565 100
20024 RØYSTER CØMPANY      PIERCE,FLØRIDA      65  278 1129  490 100
20025 SWIFT & CØMPANY      BARTØW,FLA.         48  274 1129  565 100
20026 U.S.S.AGRI-CHEM.     BARTØW,FLA.         60  376 1129  565 100
20027 U.S.S.AGRI-CHEM.     FØRT MEADE,FLA.     62  492 1129  600 100
20028 ALLIED CHEMICAL CØRP E.ST.LØUIS,ILL.     37  153 1580  375 100
```

20029	AMER.ZINC,LEAD&SMELT	MONSANTO,ILL	67	139	1580	375	100
20030	MONSANTO COMPANY	E.ST.LOUIS,ILL.	54	239	1580	375	100
20031	AG PRODUCTS CO	MARSEILLES,ILL.	62	210	1640	475	100
20032	ALLIED CHEMICAL CORP	CALUMET CITY,ILL	56	111	1640	505	100
20033	AMERICAN CYANAMID	JOLIET,ILLINOIS	54	36	1640	485	100
20034	ARCO CHEMICAL	FORT MADISON,IA.	68	449	938	450	100
20035	ARMY AMMUNITION PLT	JOLIET,ILLINOIS	45	256	1640	485	100
20036	BORDEN CHEMICAL IND.	STREATOR,ILL.	51	35	1640	655	100
20037	E.I.DUPONT DE NEM	E.CHICAGO,IND.	37	334	1640	505	100
20038	MATTHIESSEN & HEGLER	LASALLE,ILLINOIS	37	35	1640	470	100
20039	MOBIL OIL COMPANY	DEPUE,ILLINOIS	67	359	1640	470	100
20040	OLIN CORPORATION	JOLIET,ILLINOIS	42	299	1640	485	100
20041	SWIFT AND COMPANY	CALUMET CITY,ILL	47	30	1640	505	100
20042	U.S.S.AGRI-CHEM.	CHICAGO HTS,ILL	60	30	1640	505	100
20043	AGRICO CHEM-WILLIAMS	DONALD'VLLE,LA.	70	1224	820	110	100
20044	AGRI PRODUCTS(BEKER)	TAFT,LA	65	429	820	110	100
20045	ALLIED CHEMICAL CORP	GEISMAR,LA.	67	450	820	110	100
20046	ALLIED CHEMICAL CORP	BATON ROUGE,LA.	53	90	820	120	100
20047	AMERICAN CYANAMID	NEW ORLEANS,LA.	65	30	820	100	100
20048	COASTAL CHEMICAL	PASCAGOULA,MI	58	210	1023	135	100
20049	COASTAL CHEMICAL	PASCAGOULA,MI	72	495	1023	135	100
20050	E.I.DUPONT DE NEM	BURNSIDE,LA.	67	450	820	110	100
20051	FREEPORT MINERALS	UNCLE SAM,LA.	68	1632	820	110	100
20052	RUBICON	GEISMAR,LA.	68	78	820	110	100
20053	STAUFFER CHEMICAL CO	BATON ROUGE,LA.	65	750	820	120	100
20054	AMERICAN CYANAMID	HAMILTON,OHIO	48	63	1700	670	100
20055	INTERNATIONAL MINER.	CINCINNATI,OHIO	46	30	1700	485	100
20056	MOBIL OIL COMPANY	CINCINNATI,OHIO	38	16	1700	485	100
20057	AMER.ZINC,LEAD&SMELT	COLUMBUS,OHIO	65	64	1700	1085	100
20058	AMERICAN ZINC OXIDE	COLUMBUS,OHIO	49	53	1700	1085	100
20059	AMERICAN ZINC OF ILL	COLUMBUS,OHIO	55	54	1700	1085	100
20060	BORDEN CHEMICAL IND.	COLUMBUS,OHIO	37	18	1700	1085	100
20061	FARMERS FERTILIZER	COLUMBUS,OHIO	37	24	1700	1085	100

30101	100	285	245	285	285	195	345	245
30102	0	265	210	265	265	185	325	210
30103	0	619	675	782	782	675	805	675
30201	100	370	315	370	370	275	400	315
30202	0	350	300	350	350	260	370	300
30203	0	828	904	997	997	904	1021	852
30301	100	590	530	590	590	490	655	530
30302	0	540	485	540	540	450	600	485
30303	0	1322	1344	1438	1438	1344	1462	1344
30401	100	590	530	590	590	490	655	530
30402	0	540	485	540	540	450	600	485
30403	0	1322	1344	1438	1438	1344	1462	1344
30501	100	590	530	590	590	490	655	530
30502	0	540	485	540	540	450	600	485
30503	0	1322	1344	1438	1438	1344	1462	1344
30601	100	590	530	590	590	490	655	530
30602	0	540	485	540	540	450	600	485
30603	0	1322	1344	1438	1438	1344	1462	1344
30701	100	550	490	550	550	450	615	490
30702	0	505	450	505	505	415	565	450
30703	0	1229	1275	1344	1368	1299	1368	1275
30801	100	590	530	590	590	490	655	530

30802	0	540	485	540	540	450	600	485
30803	0	1322	1344	1438	1438	1344	1462	1344
30901	100	590	530	590	590	490	655	530
30902	0	540	485	540	540	450	600	485
30903	0	1322	1344	1438	1438	1344	1462	1344
31003	100	1126	1210	1169	1210	1210	1106	1189
31103	100	1126	1210	1189	1231	1231	1106	1210
31203	100	1126	1189	1169	1210	1210	1082	1189
31303	100	1106	1189	1169	1189	1210	1082	1169
31403	100	1106	1189	1169	1189	1210	1082	1169
31503	100	1126	1210	1169	1210	1210	1106	1189
31601	100	1000	940	1000	1000	890	1050	940
31602	0	960	905	960	960	860	1005	905
31603	0	1106	1189	1169	1210	1210	1082	1182
31703	100	1126	1189	1169	1210	1210	1082	1189
31803	100	1126	1210	1169	1210	1210	1106	1189
31903	100	1126	1210	1169	1210	1210	1106	1189
32003	100	1126	1189	1169	1210	1210	1082	1189
32103	100	1126	1189	1169	1210	1210	1082	1189
32203	100	1126	1189	1169	1210	1210	1082	1189
32303	100	1126	1189	1169	1210	1210	1082	1189
32403	100	1126	1210	1169	1210	1210	1106	1189
32503	100	1126	1189	1169	1210	1210	1082	1189
32603	100	1126	1189	1169	1210	1210	1082	1189
32703	100	1126	1189	1169	1210	1210	1082	1189
32801	100	250	230	250	250	160	300	230
32802	0	230	210	230	230	155	280	210
32803	0	805	719	782	675	713	890	719
32901	100	250	230	250	250	160	300	230
32902	0	230	210	230	230	155	280	210
32903	0	805	719	782	675	713	890	719
33001	100	250	250	250	250	160	300	230
33002	0	230	210	230	230	155	280	210
33003	0	805	719	782	675	713	890	719
33101	100	350	290	350	350	250	400	290
33102	0	325	270	325	325	240	370	270
33103	0	1576	1441	1467	1304	1304	1603	1467
33201	100	370	320	370	370	285	445	320
33202	0	340	300	340	340	265	410	300
33203	0	1603	1441	1467	1304	1304	1603	1494
33301	100	365	315	365	365	275	435	315
33302	0	335	290	335	335	260	405	290
33303	0	1603	1441	1467	1304	1304	1603	1494
33401	100	320	260	320	320	220	390	260
33402	0	295	245	295	295	210	340	245
33403	0	1547	1441	1494	1359	1276	1683	1441
33501	100	365	315	365	365	275	435	315
33502	0	335	290	335	335	260	405	290
33503	0	1603	1441	1467	1304	1304	1603	1494
33601	100	560	510	560	560	470	620	510
33602	0	535	490	535	535	455	590	490
33603	0	1520	1412	1441	1276	1235	1576	1441
33701	100	385	325	385	385	285	450	325
33702	0	355	300	355	355	270	415	300
33703	0	1603	1441	1467	1304	1304	1603	1494

33801	100	335	285	335	335	245	395	285
33802	0	310	265	310	310	230	365	265
33803	0	1547	1441	1441	1304	1235	1603	1441
33901	100	330	280	330	330	240	390	280
33902	0	305	265	305	305	230	365	265
33903	0	1547	1441	1441	1304	1235	1603	1441
34001	100	365	315	365	365	275	435	315
34002	0	335	290	335	335	260	405	290
34003	0	1603	1441	1467	1304	1304	1603	1494
34101	100	370	320	370	370	285	445	320
34102	0	340	300	340	340	265	410	300
34103	0	1603	1441	1467	1304	1304	1603	1494
34201	100	385	325	385	385	285	450	325
34202	0	355	300	355	355	270	415	300
34203	0	1603	1441	1467	1304	1304	1603	1494
34301	100	465	405	465	465	355	515	405
34302	0	425	370	425	425	325	470	370
34303	0	1112	1183	1275	1229	1205	1205	1159
34401	100	465	405	465	465	355	515	405
34402	0	425	370	425	425	325	470	370
34403	0	1043	1136	1205	1253	1159	1136	1136
34501	100	465	405	465	465	355	515	405
34502	0	425	370	425	425	325	470	370
34503	0	912	996	1061	1082	996	1061	977
34601	100	465	405	465	465	355	515	405
346C2	0	425	370	425	425	325	470	370
34603	0	912	996	1061	1082	996	1061	977
34701	100	465	405	465	465	355	515	405
34702	0	425	370	425	425	325	470	370
34703	0	890	996	1061	1082	1018	996	996
34801	100	545	485	545	545	445	600	485
34802	0	500	445	500	500	415	550	445
34803	0	869	977	996	1061	996	935	977
34901	100	545	485	545	545	445	600	485
34902	0	500	445	500	500	415	550	445
34903	0	869	977	996	1061	996	935	977
35001	100	465	405	465	465	355	515	405
35002	0	425	370	425	425	325	470	370
35003	0	935	1039	1061	1106	1039	1018	1018
35101	100	465	405	465	465	355	515	405
35102	0	425	370	425	425	325	470	370
35103	0	935	1039	1061	1106	1039	1018	1018
35201	100	465	405	465	465	355	515	405
35202	0	425	370	425	425	325	470	370
35203	0	912	996	1061	1082	996	1061	977
35301	100	465	405	465	465	355	515	405
35302	0	425	370	425	425	325	470	370
35303	0	912	996	1061	1082	996	1061	977
35401	100	536	486	531	426	451	596	486
35402	0	511	466	506	416	436	566	466
35403	0	912	761	719	675	1276	826	826
35501	100	330	280	325	220	245	390	280
35502	0	305	260	300	210	230	360	260
35503	0	912	761	719	675	1276	826	826
35601	100	330	280	325	220	245	390	280

SDAT714 -- PAGE 5 12.31.23 73/08/29

35602	0	305	260	300	210	230	360	260
35603	0	912	761	719	675	1276	826	826
35701	100	965	910	965	965	860	1030	910
35702	0	930	885	930	930	830	1000	885
35703	0	1603	1439	1358	1304	1467	1520	1494
35801	100	965	910	965	965	860	1030	910
35802	0	930	885	930	930	830	1000	885
35803	0	1603	1439	1358	1304	1467	1520	1494
35901	100	965	910	965	965	860	1030	910
35902	0	930	885	930	930	830	1000	885
35903	0	1603	1439	1358	1304	1467	1520	1494
36001	100	965	910	965	965	860	1030	910
36002	0	930	885	930	930	830	1000	885
36003	0	1603	1439	1358	1304	1467	1520	1494
36101	100	965	910	965	965	860	1030	910
36102	0	930	885	930	930	830	1000	885
36103	0	1603	1439	1358	1304	1467	1520	1494

LENGTH = 237 LINES

```
*** THIS FØRTRAN PRØGRAM PRINTS DATA REPØRTS AND GENERATES MPS FILE
***
*** DIMENSIØN AND DATA STATEMENTS
      PRØGRAM GENS(INPUT,ØUTPUT,TAPE1,TAPE3)
      DIMENSIØN D(100),S(100),T(10,100),STMCAP(10,10),C(100,10)
      DIMENSIØN F(100),ILØC(2,100),RAIL(10,100)
      DIMENSIØN YEARBLT(100),YEAR(10),INØ(100),INAM(2,100)
      DIMENSIØN YEAR19(10),NNØ(10),NNAM(2,10),NRPTNAM(10)
      DIMENSIØN BARG(100),BAR2(10,100),CØST(10),PERBARS(100)
      DIMENSIØN PERFSTM(3,100),TEMRATE(10),BAR1(10,100)
      DIMENSIØN SULTCST(100),TØTCØST(100,10)
      DATA INAME/6HH2S04A/
      J=1 $ NALL=1
      PRINT 55
   55 FØRMAT(20HENTER DATA FILE NAME)
      READ 56,DATFILE
   56 FØRMAT(A7)
      CALL GET(5HTAPE1,DATFILE,0,0)
      REWIND 1
***
*** READ DATA FILE
***
*** MØDEL DESCRIPTIØNS AND FACTØRS
      READ(1,)LC,PRE60
      READ(1,)LC,PØST60
      READ(1,)LC,YEAR60
      READ(1,)LC,EXPENDO
      READ(1,)LC,SIZEO
      READ(1,)LC,FACTØR
      READ(1,)LC,AVC
      READ(1,)LC,AFC
      READ(1,)LC,TIR
      READ(1,)LC,RATEI
      READ(1,)LC,RATEM
      READ(1,)LC,USELIFE
      READ(1,)LC,ACDCON
      READ(1,)LC,PS
      READ(1,)LC,PA
      READ(1,)LC,DEMAND
      READ(1,)LC,NPLANTS
      READ(1,)LC,JNUM
      READ(1,)LC,NYEARS
      READ(1,)LC,(YEAR(I),I=1,NYEARS)
      DØ 2 L=1,NYEARS
    2 YEAR19(L)=YEAR(L)+1900.
***
*** STEAM PLANT DATA
      DØ 36 I=1,NPLANTS
   36 READ(1,35)NNØ(I),NNAM(1,I),NNAM(2,I),NRPTNAM(I),CØST(I),
+     (STMCAP(I,J),J=1,NPLANTS)
   35 FØRMAT(3X,I2,1X,A10,A2,1X,A4,F6.2,10F6.1)
***
*** SULFURIC ACID PLANTS DATA
      DØ 31 J=1,JNUM
   10 READ(1,800)INØ(J),INAM(1,J),INAM(2,J),ILØC(1,J),ILØC(2,J),
```

```
+       YEARBLT(J),D(J),S(J),BARG(J),PERBARS(J)
  800 FORMAT(3X,I2,1X,2A10,1X,A10,A6,1X,F2.0,3(1X,F4.0),1X,F3.0)
      D(J)=D(J)*DEMAND
     SULTCST(J)=(((100.-PERBARS(J))*S(J))+(PERBARS(J)*BARG(J)))/10000
    9 IF(YEARBLT(J).GT.YEAR60)GØ TØ 96
      F(J)=PRE60
      GO TO 31
   96 F(J)=PØST60
   31 CØNTINUE
      EXP=FACTØR-1.
      ALPHA=EXPENDO/(SIZEO**EXP)
      DØ 103 J=1,JNUM
      EXPEND=ALPHA*(D(J)**EXP)
      DO 102 I=1,NYEARS
      AGE=YEAR(I)-YEARBLT(J)
      IF(AGE.GT.USELIFE)AGE=USELIFE
      C(J,I)=AMCOST(RATEI,RATEM,AGE,USELIFE,EXPEND)
+     +AVC+(AFC/D(J))+(TIR*EXPEND)
  102 TØTCØST(J,I)=C(J,I)+F(J)*(SULTCST(J)+PS)
  103 CONTINUE
***
*** BARGE AND RAIL RATES
   48 READ(1,47)J,L,PERCENT,(TEMRATE(I),I=1,NPLANTS)
   47 FØRMAT(1X,I2,I2,1X,F3.0,10(1X,F4.0))
      IF(EØF,1)554,810
  810 PERFSTM(L,J)=PERCENT
      GØ TØ (801,802,803),L
  801 DØ 901 I=1,NPLANTS
  901 BAR1(I,J)=TEMRATE(I)
      GØ TØ 48
  802 DØ 902 I=1,NPLANTS
  902 BAR2(I,J)=TEMRATE(I)
      GØ TØ 48
  803 DØ 903 I=1,NPLANTS
  903 RAIL(I,J)=TEMRATE(I)
      GØ TØ 48
  554 DØ 556 J=1,JNUM
      DØ 555 I=1,NPLANTS
  555 T(I,J)=(PERFSTM(1,J)*BAR1(I,J)+PERFSTM(2,J)*BAR2(I,J)+
+     PERFSTM(3,J)*RAIL(I,J))/100.
  556 CONTINUE
***
*** PRINT SPECIAL REPØRTS
***
   50 PRINT 550
  550 FØRMAT(//37HIS SPECIAL REPØRT DESIRED (YES ØR NØ))
      READ,ANSW
      IF(ANSW.EQ.2HNØ)GØ TØ 199
  116 PRINT 105
  105 FØRMAT(48HENTER SPECIAL REPØRT #(1-8,9=ALL,0=REPØRT NAMES))
      READ,NØREPT
      IF(NØREPT.EQ.0)GØ TØ 106
      GØ TØ (107,3,6,12,14,170,521,180,114),NØREPT
***
*** REPØRT NAMES
```

```
106 PRINT 115
115 FØRMAT(/1H#,2X,11HREPØRT NAME/2H1.,1X,
+   40HSULFURIC ACID PLANTS CØNSIDERED IN MØDEL/2H2.,1X,
+   23HSTEAM PLANTS CONSIDERED/2H3.,1X,20HSULFUR FREIGHT RATES/
+   2H4.,1X,20H1500 TØN BARGE RATES/2H5.,1X,
+   20H3000 TØN BARGE RATES/2H6.,1X,10HRAIL RATES/2H7.,
+   1X,34HTRANSPØRTATIØN CØSTS USED IN MØDEL/2H8.,
+   1X,30HSULFURIC ACID PRØDUCTIØN CØSTS/2H9.,1X,
+   16HALL ØF THE ABØVE//)
    GØ TO 116
114 NALL=0
***
*** REPØRT #1
107 J=1
137 PRINT 131
131 FØRMAT(///8X,40HSULFURIC ACID PLANTS CØNSIDERED IN MØDEL//
+   45X,4HYEAR,3X,6HANNUAL/1X,1H#,2X,4HNAME,18X,8HLØCATIØN,
+   10X,5HBUILT,2X,8HCAPACITY/)
    K=7
132 PRINT 134,INØ(J),INAM(1,J),INAM(2,J),ILØC(1,J),ILØC(2,J),
+   YEARBLT(J),D(J)
134 FØRMAT(I2,2H. ,2A10,2X,A10,A6,3X,2H19,F2.0,3X,F4.0)
    K=K+1
    IF(J.EQ.JNUM)GØ TØ 333
    J=J+1
    IF(K.EQ.61)GØ TØ 139
    GØ TØ 132
139 PRINT 136 $ GØ TØ 137
136 FØRMAT(///)
333 J=65-K
    DØ 233 I=1,J
233 PRINT 60
 60 FØRMAT(1H )
    IF(NALL.EQ.0)GØ TØ 3
    GØ TØ 50
***
*** REPØRT #2
  3 J=1
  7 PRINT 11,(YEAR19(I),I=1,NYEARS)
 11 FØRMAT(///11X,23HSTEAM PLANTS CØNSIDERED//19X,6HREPØRT,
+   9X,8HCAPACITY/1X,1H#,2X,4HNAME,12X,4HNAME,4X,4HCØST,
+   10(4X,F4.0)//)
    PRINT 60
    K=7
  5 PRINT 80,NNØ(J),NNAM(1,J),NNAM(2,J),NRPTNAM(J),CØST(J),
+   (STMCAP(J,I),I=1,NYEARS)
 80 FØRMAT(I2,2H. ,A10,A2,4X,A4,F8.2,10F8.1)
    K=K+1
    IF(J.EQ.NPLANTS)GØ TØ 130
    J=J+1
    IF(K.EQ.61)GØ TØ 120
    GØ TØ 5
120 PRINT 136 $ GØ TØ 7
130 J=65-K
    DØ 140 I=1,J
```

```
 140 PRINT 60
     IF(NALL.EQ.0)GØ TØ 6
     GØ TØ 50
***
*** REPØRT #3
   6 J=1
   8 PRINT 45
  45 FØRMAT(///13X,20HSULFUR FREIGHT RATES//21X,
+    17HPØRT SULFUR RATES,3X,7HPERCENT/1X,1H#,2X,8HLØCATIØN,12X,
+    4HRAIL,3X,5HBARGE,6X,5HBARGE/)
     K=7
  53 PRINT 49,INØ(J),ILØC(1,J),ILØC(2,J),S(J),BARG(J),PERBARS(J)
  49 FØRMAT(I2,2H. ,A10,A6,2(4X,F4.0)7X,F3.0)
     K=K+1
     IF(J.EQ.JNUM)GØ TØ 51
     J=J+1
     IF(K.EQ.61)GØ TØ 52
     GØ TØ 53
  52 PRINT 136 $ GØ TØ 8
  51 J=65-K
     DØ 54 I=1,J
  54 PRINT 60
     IF(NALL.EQ.0)GØ TØ 12
     GØ TØ 50
***
*** REPØRT #4
  12 J=1
  13 PRINT 160,(NRPTNAM(M),M=1,NPLANTS)
 160 FØRMAT(///21X,20H1500 TØN BARGE RATES//22X,3HPER,15X,
+    12HSTEAM PLANTS/1X,1H#,2X,8HLØCATIØN,9X,4HUSED,1X,10(2X,A4)//)
     PRINT 60
     K=7
  72 SUM=0.0
     DØ 440 I=1,NPLANTS
 440 SUM=SUM+BAR1(I,J)
     IF(SUM.EQ.0.0)GØ TØ 442
     PRINT 64,INØ(J),ILØC(1,J),ILØC(2,J),PERFSTM(1,J),
+    (BAR1(I,J),I=1,NPLANTS)
  64 FØRMAT(I2,2H. ,A10,A6,1X,F4.0,1X,10F6.0)
     K=K+1
     IF(J.EQ.JNUM)GØ TØ 75
 442 J=J+1
     IF(K.EQ.61)GØ TØ 71
     GØ TØ 72
  71 PRINT 136 $ GØ TØ 13
  75 J=65-K
     DØ 78 I=1,J
  78 PRINT 60
     IF(NALL.EQ.0)GØ TØ 14
     GØ TØ 50
***
*** REPØRT #5
  14 J=1
  15 PRINT 150,(NRPTNAM(M),M=1,NPLANTS)
 150 FØRMAT(///21X,20H3000 TØN BARGE RATES//22X,3HPER,15X,
```

```
     12HSTEAM PLANTS/1X,1H#,2X,8HLØCATIØN,9X,4HUSED,1X,10(2X,A4)//)
     PRINT 60
     K=7
124  SUM=0.0
     DØ 43 I=1,NPLANTS
443  SUM=SUM+BAR2(I,J)
     IF(SUM.EQ.0.0)GØ TØ 444
     PRINT 64,INØ(J),ILØC(1,J),ILØC(2,J),PERFSTM(2,J),
     (BAR2(I,J),I=1,NPLANTS)
     K=K+1
     IF(J.EQ.JNUM)GØ TØ 121
444  J=J+1
     IF(K.EQ.61)GØ TØ 122
     GØ TØ 124
122  PRINT 136 $ GØ TØ 15
121  J=65-K
     DØ 123 I=1,J
123  PRINT 60
     IF(NALL.EQ.0)GØ TØ 170
     GØ TØ 50
***
*** REPØRT #6
170  J=1
172  PRINT 171,(NRPTNAM(M),M=1,NPLANTS)
171  FØRMAT(///26X,10HRAIL RATES//22X,3HPER,15X,12HSTEAM PLANTS/
     1X,1H#,2X,8HLØCATIØN,9X,4HUSED,1X,10(2X,A4)//)
     PRINT 60
     K=7
173  SUM=0.0
     DØ 445 I=1,NPLANTS
445  SUM=SUM+RAIL(I,J)
     IF(SUM.EQ.0.0)GØ TØ 446
     PRINT 64,INØ(J),ILØC(1,J),ILØC(2,J),PERFSTM(3,J),
     (RAIL(I,J),I=1,NPLANTS)
     K=K+1
     IF(J.EQ.JNUM)GØ TØ 174
446  J=J+1
     IF(K.EQ.61)GØ TØ 175
     GØ TØ 173
175  PRINT 136 $ GØ TØ 172
174  J=65-K
     DØ 176 I=1,J
176  PRINT 60
     IF(NALL.EQ.0)GØ TØ 521
     GØ TØ 50
***
*** REPØRT #7
521  J=1
522  PRINT 523,(NRPTNAM(M),M=1,NPLANTS)
523  FØRMAT(///15X,34HTRANSPØRTATIØN CØSTS USED IN MØDEL//39X,
     12HSTEAM PLANTS/1X,1H#,2X,8HLØCATIØN,10X,10(2X,A4)//)
     PRINT 60
     K=7
524  SUM=0.0
     DØ 525 I=1,NPLANTS
```

```
 525 SUM=SUM+T(I,J)
     IF(SUM.EQ.0.0)GØ TØ 526
     PRINT 564,INØ(J),ILØC(1,J),ILØC(2,J),(T(I,J),I=1,NPLANTS)
 564 FØRMAT(I2,2H. ,A10,A6,2X,10F6.0)
     K=K+1
     IF(J.EQ.JNUM)GØ TØ 527
 526 J=J+1
     IF(K.EQ.61)GØ TØ 528
     GØ TØ 524
 528 PRINT 136 $ GØ TØ 522
 527 J=65-K
     DØ 529 I=1,J
 529 PRINT 60
     IF(NALL.EQ.0)GØ TØ 180
     GØ TØ 50
***
*** REPØRT #8
 180 J=1
 190 PRINT 81,(YEAR19(L),L=1,NYEARS)
  81 FØRMAT(///8X,30HSULFURIC ACID PRODUCTIØN CØSTS//22X,
+    6HSULFUR,2X,24HCØNVERSIØN & TØTAL CØSTS/1X,1H#,2X,8HLØCATIØN,
+    10X,6HFACTØR,10(10X,F4.0)//)
     PRINT 60
     K=7
  84 PRINT 83,INØ(J),ILØC(1,J),ILØC(2,J),F(J),
+    (C(J,I),TØTCØST(J,I),I=1,NYEARS)
  83 FØRMAT(I2,2H. ,A10,A6,3X,F5.4,4X,10(F6.2,2X,F6.2))
     K=K+1
     IF(J.EQ.JNUM)GØ TØ 210
     J=J+1
     IF(K.EQ.61)GØ TØ 89
     GØ TØ 84
  89 PRINT 136 $ GØ TØ 190
 210 J=65-K
     DØ 133 I=1,J
 133 PRINT 60
***
*** GENERATE MPS FILE
***
 199 PRINT 4
   4 FØRMAT(/43HDØ YØU WISH TØ RUN THIS PRØBLEM (YES ØR NØ))
     READ,ANSWRUN
     IF(ANSWRUN.EQ.2HNØ)GØ TØ 299
     REWIND 3
     WRITE(3,900)INAME
 900 FØRMAT(4HNAME,10X,A10,/,4HRØWS)
 910 FØRMAT(1X,1HE,2X,I5)
 920 FØRMAT(1X,1HL,2X,I5)
 930 FØRMAT(1X,1HN,2X,4HCØST,F2.0)
     DØ 30 I=1,NYEARS
  30 WRITE(3,930)YEAR(I)
     DØ 90 J=1,JNUM
     IRØW=10000+100*J
  90 WRITE(3,910)IRØW
     DØ 92 J=1,JNUM
```

```
      IRØW=20000+100*J
   92 WRITE(3,910)IRØW
      DØ 94 I=1,NPLANTS
      IRØW=30000+I
   94 WRITE(3,920)IRØW
      IRØW=10000
      WRITE(3,910)IRØW
      IRØW=40000
      WRITE(3,910)IRØW
      WRITE(3,990)
  990 FØRMAT(7HCØLUMNS)
      DØ 100 J=1,JNUM
      ICØL=10000+100*J
      WRITE(3,1000)ICØL,ICØL
      S(J)=S(J)/100.
      DØ 41 I=1,NYEARS
   41 WRITE(3,1010)ICØL,YEAR(I),SULTCST(J)
  100 CONTINUE
 1000 FØRMAT(4X,I5,5X,5H10000,5X,3H-1.,12X,I5,5X,3H-1.)
 1010 FØRMAT(4X,I5,5X,4HCØST,F2.0,4X,F6.2)
      DØ 200 J=1,JNUM
      ICØL=20000+100*J
      IRØW=10000+100*J
      WRITE(3,1020)ICØL,IRØW,F(J),ICØL
 1020 FØRMAT(4X,I5,5X,I5,5X,F6.4,9X,I5,5X,2H1.)
      DØ 40 I=1,NYEARS
   40 WRITE(3,1010)ICØL,YEAR(I),C(J,I)
  200 CØNTINUE
      DØ 300 J=1,JNUM
      DØ 300 I=1,NPLANTS
      IF(T(I,J).EQ.0.)GØ TØ 300
      ICØL=30000+100*J+I
      IRØW1=20000+100*J
      IRØW2=30000+I
      WRITE(3,1030)ICØL,IRØW1,IRØW2
 1030 FØRMAT(4X,I5,5X,I5,5X,2H1.,13X,I5,5X,2H1.)
      T(I,J)=(T(I,J)/ACDCØN)+CØST(I)
      WRITE(3,1040)ICØL
 1040 FØRMAT(4X,I5,5X,5H40000,5X,3H-1.)
      DØ 42 K=1,NYEARS
   42 WRITE(3,1041)ICØL,YEAR(K),T(I,J)
 1041 FØRMAT(4X,I5,5X,4HCØST,F2.0,4X,F6.2)
  300 CØNTINUE
      WRITE(3,1050)
 1050 FØRMAT(4X,5H40000,5X,5H40000,5X,2H1.)
      DØ 43 I=1,NYEARS
   43 WRITE(3,1051)YEAR(I),PA
 1051 FØRMAT(4X,5H40000,5X,4HCØST,F2.0,3X,F6.2)
      WRITE(3,1060)
 1060 FØRMAT(4X,5H10000,5X,5H10000,5X,2H1.)
      DØ 44 I=1,NYEARS
   44 WRITE(3,1061)YEAR(I),PS
 1061 FØRMAT(4X,5H10000,5X,4HCØST,F2.0,4X,F6.2)
      WRITE(3,1070)
 1070 FØRMAT(3HRHS)
```

```
      DO 46 K=1,NYEARS
      DO 400 J=1,JNUM
      IRØW=20000+100*J
  400 WRITE(3,1080)YEAR(K),IRØW,D(J)
 1080 FØRMAT(4X,3HRHS,F2.0,5X,I5,5X,F10.3)
      DO 500 I=1,NPLANTS
      IRØW=30000+I
  500 WRITE(3,1080)YEAR(K),IRØW,STMCAP(I,K)
   46 CONTINUE
      WRITE(3,1090)
 1090 FØRMAT(6HENDATA)
      REWIND 3
      PRINT 1100
 1100 FØRMAT(20HTAPE3 READY FØR APEX)
  299 STOP
      END
***
*** FUNCTIØNS
***
*** FUNCTIØN #1
      FUNCTION PVMA(TM,RATEI,RATEM)
      R=(1.+RATEM)/(1.+RATEI)
      PVMA=(1.-(R**TM))*RATEM/(RATEI-RATEM)
      RETURN
      END
***
*** FUNCTIØN #2
      FUNCTIØN AMØRT(TM,RATEI)
      AMØRT=(RATEI*(1.+RATEI)**TM)/(((1.+RATEI)**TM)-1.)
      RETURN
      END
***
*** FUNCTIØN #3
      FUNCTIØN AMCØST(RATEI,RATEM,AGE,USELIFE,EXPEND)
      PVMANEW=PVMA(USELIFE,RATEI,RATEM)*EXPEND
      REMYRS=USELIFE-AGE
      PVMAØLD=PVMA(REMYRS,RATEI,RATEM)*EXPEND
      CØSTØLD=PVMAØLD*RATEI*((1.+RATEM)**AGE)
      CØSTNEW=AMØRT(USELIFE,RATEI)*(EXPEND+PVMANEW)
      AMCØST=CØSTØLD+CØSTNEW/((1.+RATEI)**(USELIFE-AGE))
      RETURN
      END

LENGTH =  427 LINES
```

```
GOG714  -- PAGE  1     13.35.23     73/08/29

110,ATTACH,APEX/UN=LIBRARY.
120,$GET,TAPE1=LUCK714.
130,$REWIND,TAPE1.
140,$GET,TAPE3=INB714.
150,$REWIND,TAPE3.
160,$ATTACH,SØL714/M=W.
170,$ATTACH,ØUT714/M=W.
180,RFL,40000.
190,APEX(SØLVE,MIN,Ø=SOL714,SØF=ØUT714,RL=25,SP,BCD,INB)
200,$REWIND,SØL714.
210,$RETURN,SØL714.
220,$REWIND,ØUT714.
230,$RETURN,ØUT714.

LENGTH =    13 LINES
```

```
*** THIS FORTRAN PROGRAM PRINTS REPØRT ØN MARKET PATTERN FØR H2SØ4
***
      PROGRAM SULRPT(INPUT,ØUTPUT,TAPE1,TAPE2)
      DIMENSION LOC(100,2),DEM(100),PCØST(100),PRØD(100),BUY(103,10)
      DIMENSION ACAP(10),ACØST(10),A(16),B(8),APRØ(10),YEAR(10)
      DIMENSION STM(10),NRPTNAM(10),YEARBLT(100)
      EQUIVALENCE (KNPRØB,A(2)),(RDØBJFN,A(8)),(LJRØWS,A(15))
      EQUIVALENCE (LJCØLS,A(16)),(ACT,B(3)),(UP,B(6)),(VAL,B(7))
      PRINT 1000
 1000 FØRMAT(24HENTER SØLUTIØN FILE NAME)
      READ 1010,SØLFILE
 1010 FØRMAT(A7)
      CALL ATTACH(5HTAPE1,SØLFILE,0,0,0)
      REWIND 1
      CALL ØPENMS(1,0,0,-0)
      CALL READMS(1,A,16,-0)
      INDEX=17
      CALL SETSCT(1,INDEX)
      PRINT 1020
 1020 FØRMAT(23HENTER PRØBLEM FILE NAME)
      READ 1010,PRØFILE
      CALL GET(5HTAPE2,PRØFILE,0,0)
      REWIND 2
***
*** READ DATA FILE
***
      DØ 300 I=1,12
  300 READ(2,)LC,ARN
      READ(2,)LC,ACDCØN
      READ(2,)LC,SULPRIC
      READ(2,)LC,ARN
      READ(2,)LC,DEMAND
      DEMAND=DEMAND*100.
      READ(2,)LC,JNUM
      READ(2,)LC,INUM
      READ(2,)LC,NYEARS
      READ(2,)LC,(YEAR(I),I=1,NYEARS)
      DØ 301 I=1,JNUM
  301 READ(2,303)NNØ,NNAM1,NNAM2,NRPTNAM(I),CØST,(STM(I),I=1,NYEARS)
  303 FØRMAT(3X,I2,1X,A10,A2,1X,A4,F6.2,10F6.1)
      I=1
  100 READ(2,1030)LØC(I,1),LØC(I,2),YEARBLT(I)
 1030 FØRMAT(27X,A10,A6,1X,F2.0)
      IF(I.EQ.INUM)GØ TØ 110
  105 I=I+1
      GØ TØ 100
***
*** READ SØLUTIØN FILE
***
  110 INDEX=INDEX+INUM*8+(8*NYEARS)
      DØ 120 I=1,INUM
      CALL SETSCT(1,INDEX)
      CALL READMS(1,B,8,-0)
      INDEX=INDEX+8
  120 DEM(I)=UP
```

```
REPT714 -- PAGE  2     13.38.14     73/08/29
      DO 130 J=1,JNUM
      CALL SETSCT(1,INDEX)
      CALL READMS(1,B,8,-0)
      INDEX=INDEX+8
      ACAP(J)=UP
      ACOST(J)=VAL
 130  APRO(J)=ACT
      CALL SETSCT(1,INDEX)
      CALL READMS(1,B,8,-0)
      SULVAL=VAL*(-1.)
      INDEX=INDEX+8
      CALL SETSCT(1,INDEX)
      CALL READMS(1,B,8,-0)
      ACDVAL=VAL*(-1.)
      DO 220 J=1,INUM
      INDEX=INDEX+8
      CALL SETSCT(1,INDEX)
      CALL READMS(1,B,8,-0)
      PCOST(J)=VAL
 220  CONTINUE
      INDEX=INDEX+8
      DO 140 I=1,INUM
      CALL SETSCT(1,INDEX)
      CALL READMS(1,B,8,-0)
      INDEX=INDEX+8
      PROD(I)=ACT
 140  CONTINUE
      DO 155 I=1,INUM
      DO 150 J=1,JNUM
      CALL SETSCT(1,INDEX)
      CALL READMS(1,B,8,-0)
      INDEX=INDEX+8
 150  BUY(I,J)=ACT
 155  CONTINUE
      SUMAPRO=0.0
      DO 361 J=1,JNUM
 361  SUMAPRO=SUMAPRO+APRO(J)
      AMACLOW=100.0
      DO 362 J=1,JNUM
      IF(ACOST(J).EQ.0.)GO TO 362
      IF(ACOST(J).LT.AMACLOW)GO TO 363
      GO TO 362
 363  AMACLOW=ACOST(J)
 362  CONTINUE
      TNB=SUMAPRO*AMACLOW*1000.
***
*** PRINT REPORT
***
      PRINT 170,SULVAL,ACDCON,DEMAND,AMACLOW
      PRINT 171
      PRINT 172,(NRPTNAM(I),I=1,JNUM)
 170  FORMAT(///33X,28HMARKET PATTERN FOR TVA H2S04/43X,8H(M TONS)/
+ 6X,16HSULFUR PRICE = $,F5.2,4X,29HPERCENT ACID CONCENTRATION = ,
+     F3.0,4X,19HPERCENT CAPACITY = ,F3.0/29X,12HMAXIMUM TVA ,
+     21HACID PRICE WOULD BE $,F5.2)
```

```
REPT714 -- PAGE  3     13.38.14     73/08/29

 171 FØRMAT(/8X,5HPLANT,8X,10HPRØDUCTIØN,1X,6HACTUAL,2X,4HYEAR,2X,
     6HSULFUR,14X,17HSTEAM PLANT SALES)
 172 FØRMAT(7X,8HLØCATIØN,7X,8HCAPACITY,2X,6HPRØD'N,2X,5HBUILT,1X,
     7HREDUC'N,10(2X,A4))
     PRINT 173
 173 FØRMAT(48X,3H($))
     DØ 160 I=1,INUM
     TBUY=0.
     DØ 240 J=1,JNUM
     TBUY=TBUY+BUY(I,J)
 240 CØNTINUE
     IF(TBUY.EQ.0.)GØ TØ 160
     PRINT 2000,I,LØC(I,1),LØC(I,2),DEM(I),PRØD(I),YEARBLT(I),
     PCØST(I),(BUY(I,J),J=1,JNUM)
2000 FØRMAT(I2,2H. ,A10,A6,3X,2(F6.0,2X),2X,F2.0,2X,F7.2,1X,
     10F6.0)
 160 CØNTINUE
     PRINT 180,(ACAP(J),J=1,JNUM)
     PRINT 190,(APRØ(J),J=1,JNUM)
     PRINT 200,(ACØST(J),J=1,JNUM)
     PRINT 270,SUMAPRØ,TNB
 180 FØRMAT(/14HPLANT CAPACITY,39X,10F6.0)
 190 FØRMAT(/16HPLANT PRØDUCTIØN,37X,10F6.0)
 200 FØRMAT(/22HMARGINAL ACID CØST ($),31X,10F6.2)
 270 FØRMAT(/19HTØTAL PRØDUCTIØN = ,F6.0,20X,
     27HTØTAL NET SALES REVENUE = $,F9.0/////)
     STØP
     END

LENGTH =  138 LINES
```

APPENDIX C

SULFUR FREIGHT RATES

#	LOCATION	PORT SULFUR RATES RAIL[a]	BARGE[b]	PERCENT BARGE
1.	HELENA,ARK.	1580	260	0
2.	N.LITTLE ROCK,AR	1343	280	0
3.	HOUSTON,TEXAS	1740	245	0
4.	TEXAS CITY,TEXAS	1740	245	0
5.	HOUSTON,TEXAS	1740	245	0
6.	LAPORTE,TEXAS	1740	245	0
7.	BEAUMONT,TX	1740	210	0
8.	PASADENA,TEXAS	1740	245	0
9.	PASADENA,TEXAS	1740	245	0
10.	PIERCE,FLORIDA	1129	490[c]	0
11.	PALMETTO,FLORIDA	1129	565[c]	0
12.	BONNIE,FLA.	1129	565[c]	0
13.	PLANT CITY,FLA.	1129	410[c]	0
14.	PLANT CITY,FLA.	1129	410[c]	0
15.	PIERCE,FLORIDA	1129	490[c]	0
16.	TAMPA,FLORIDA	1129	185[c]	0
17.	NICHOLS,FLORIDA	1129	490[c]	0
18.	PIERCE,FLORIDA	1129	490[c]	0
19.	GREENBAY,FLA.	1129	565[c]	0
20.	BARTOW,FLA.	1129	565[c]	0
21.	BARTOW,FLA.	1129	565[c]	0
22.	BARTOW,FLORIDA	1129	565[c]	0
23.	BONNIE,FLA.	1129	565[c]	0
24.	PIERCE,FLORIDA	1129	490[c]	0
25.	BARTOW,FLA.	1129	565[c]	0
26.	BARTOW,FLA.	1129	565[c]	0
27.	FORT MEADE,FLA.	1129	600	0
28.	E.ST.LOUIS,ILL.	1580	375	0
29.	MONSANTO,ILL	1580	375	0
30.	E.ST.LOUIS,ILL.	1580	375	0
31.	MARSEILLES,ILL.	1640	475	0
32.	CALUMET CITY,ILL	1640	505	0
33.	JOLIET,ILLINOIS	1640	485	0
34.	FORT MADISON,IA.	938[d]	450	0
35.	JOLIET,ILLINOIS	1640	485	0
36.	STREATOR,ILL.	1640	655[e]	0
37.	E.CHICAGO,IND.	1640	505	0
38.	LASALLE,ILLINOIS	1640	470	0
39.	DEPUE,ILLINOIS	1640	470	0
40.	JOLIET,ILLINOIS	1640	485	0
41.	CALUMET CITY,ILL	1640	505	0
42.	CHICAGO HTS,ILL	1640	505	0
43.	DONALD'VLLE,LA.	820	110	0
44.	TAFT,LA	820	110	0
45.	GEISMAR,LA.	820	110	0
46.	BATON ROUGE,LA.	820	120	0
47.	NEW ORLEANS,LA.	820	100	0
48.	PASCAGOULA,MI	1023	135	0
49.	PASCAGOULA,MI	1023	135	0
50.	BURNSIDE,LA.	820	110	0
51.	UNCLE SAM,LA.	820	110	0
52.	GEISMAR,LA.	820	110	0
53.	BATON ROUGE,LA.	820	120	0
54.	HAMILTON,OHIO	1700	670[f]	0

APPENDIX C (Cont'd)

SULFUR FREIGHT RATES

#	LOCATION	PORT SULFUR RATES RAIL[a]	BARGE[b]	PERCENT BARGE
55.	CINCINNATI,OHIO	1700	485	0
56.	CINCINNATI,OHIO	1700	485	0
57.	COLUMBUS,OHIO	1700	1085[f]	0
58.	COLUMBUS,OHIO	1700	1085[f]	0
59.	COLUMBUS,OHIO	1700	1085[f]	0
60.	COLUMBUS,OHIO	1700	1085[f]	0
61.	COLUMBUS,OHIO	1700	1085[f]	0

[a] Rates in cents/net ton (short ton) for crude sulfur, single-car minimum. Weight requirements vary between 40 to 50 tons.

[b] Barge rates in cents/net ton (short ton) of liquid sulfur, single barge 3,200 tons.

[c] Seagoing barge rate used with minimum of 8,000 tons for all Florida locations. Barge-truck combinations used to interior plants.

[d] Special rate used for molten sulfur, minimum weight 190,000 pounds.

[e] Barge-truck rates used via LaSalle, Illinois.

[f] Barge-truck rates used via Cincinnati, Ohio.

APPENDIX D

1500 TON BARGE RATES[a]

#	LOCATION	PER USED	STEAM PLANTS COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
1.	HELENA,ARK.	100	285	245	285	285	195	345	245
2.	N.LITTLE ROCK,AR	100	370	315	370	370	275	400	315
3.	HOUSTON,TEXAS	100	590	530	590	590	490	655	530
4.	TEXAS CITY,TEXAS	100	590	530	590	590	490	655	530
5.	HOUSTON,TEXAS	100	590	530	590	590	490	655	530
6.	LAPORTE,TEXAS	100	590	530	590	590	490	655	530
7.	BEAUMONT,TX	100	550	490	550	550	450	615	490
8.	PASADENA,TEXAS	100	590	530	590	590	490	655	530
9.	PASADENA,TEXAS	100	590	530	590	590	490	655	530
16.	TAMPA,FLORIDA[b]	100	1000	940	1000	1000	890	1050	940
28.	E.ST.LOUIS,ILL.	100	250	230	250	250	160	300	230
29.	MONSANTO,ILL	100	250	230	250	250	160	300	230
30.	E.ST.LOUIS,ILL.	100	250	250	250	250	160	300	230
31.	MARSEILLES,ILL.	100	350	290	350	350	250	400	290
32.	CALUMET CITY,ILL	100	370	320	370	370	285	445	320
33.	JOLIET,ILLINOIS	100	365	315	365	365	275	435	315
34.	FORT MADISON,IA.	100	320	260	320	320	220	390	260
35.	JOLIET,ILLINOIS	100	365	315	365	365	275	435	315
36.	STREATOR,ILL.[c]	100	560	510	560	560	470	620	510
37.	E.CHICAGO,IND.	100	385	325	385	385	285	450	325
38.	LASALLE,ILLINOIS	100	335	285	335	335	245	395	285
39.	DEPUE,ILLINOIS	100	330	280	330	330	240	390	280
40.	JOLIET,ILLINOIS	100	365	315	365	365	275	435	315
41.	CALUMET CITY,ILL	100	370	320	370	370	285	445	320
42.	CHICAGO HTS,ILL	100	385	325	385	385	285	450	325
43.	DONALD'VLLE,LA.	100	465	405	465	465	355	515	405
44.	TAFT,LA	100	465	405	465	465	355	515	405
45.	GEISMAR,LA.	100	465	405	465	465	355	515	405
46.	BATON ROUGE,LA.	100	465	405	465	465	355	515	405
47.	NEW ORLEANS,LA.	100	465	405	465	465	355	515	405
48.	PASCAGOULA,MI	100	545	485	545	545	445	600	485
49.	PASCAGOULA,MI	100	545	485	545	545	445	600	485
50.	BURNSIDE,LA.	100	465	405	465	465	355	515	405
51.	UNCLE SAM,LA.	100	465	405	465	465	355	515	405
52.	GEISMAR,LA.	100	465	405	465	465	355	515	405
53.	BATON ROUGE,LA.	100	465	405	465	465	355	515	405
54.	HAMILTON,OHIO[d]	100	536	486	531	426	451	596	486
55.	CINCINNATI,OHIO	100	330	280	325	220	245	390	280
56.	CINCINNATI,OHIO	100	330	280	325	220	245	390	280
57.	COLUMBUS,OHIO[d]	100	965	910	965	965	860	1030	910
58.	COLUMBUS,OHIO[d]	100	965	910	965	965	860	1030	910
59.	COLUMBUS,OHIO[d]	100	965	910	965	965	860	1030	910
60.	COLUMBUS,OHIO[d]	100	965	910	965	965	860	1030	910
61.	COLUMBUS,OHIO[d]	100	965	910	965	965	860	1030	910

[a] Rates in cents/net ton of sulfuric acid.

[b] Tampa rates shown allow for transfer from inland waterway barges to seagoing barge. Barge rates to all other Florida locations are not shown since rail rates are cheaper.

[c] Barge-truck rates used via LaSalle, Illinois.

[d] Barge-truck rates used via Cincinnati, Ohio.

APPENDIX E

3000 TON BARGE RATES[a]

#	LOCATION	PER USED	COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
			STEAM PLANTS						
1.	HELENA,ARK.	0	265	210	265	265	185	325	210
2.	N.LITTLE ROCK,AR	0	350	300	350	350	260	370	300
3.	HOUSTON,TEXAS	0	540	485	540	540	450	600	485
4.	TEXAS CITY,TEXAS	0	540	485	540	540	450	600	485
5.	HOUSTON,TEXAS	0	540	485	540	540	450	600	485
6.	LAPORTE,TEXAS	0	540	485	540	540	450	600	485
7.	BEAUMONT,TX	0	505	450	505	505	415	565	450
8.	PASADENA,TEXAS	0	540	485	540	540	450	600	485
9.	PASADENA,TEXAS	0	540	485	540	540	450	600	485
16.	TAMPA,FLORIDA[b]	0	960	905	960	960	860	1005	905
28.	E.ST.LOUIS,ILL.	0	230	210	230	230	155	280	210
29.	MONSANTO,ILL	0	230	210	230	230	155	280	210
30.	E.ST.LOUIS,ILL.	0	230	210	230	230	155	280	210
31.	MARSEILLES,ILL.	0	325	270	325	325	240	370	270
32.	CALUMET CITY,ILL	0	340	300	340	340	265	410	300
33.	JOLIET,ILLINOIS	0	335	290	335	335	260	405	290
34.	FORT MADISON,IA.	0	295	245	295	295	210	340	245
35.	JOLIET,ILLINOIS	0	335	290	335	335	260	405	290
36.	STREATOR,ILL.[c]	0	535	490	535	535	455	590	490
37.	E.CHICAGO,IND.	0	355	300	355	355	270	415	300
38.	LASALLE,ILLINOIS	0	310	265	310	310	230	365	265
39.	DEPUE,ILLINOIS	0	305	265	305	305	230	365	265
40.	JOLIET,ILLINOIS	0	335	290	335	335	260	405	290
41.	CALUMET CITY,ILL	0	340	300	340	340	265	410	300
42.	CHICAGO HTS,ILL	0	355	300	355	355	270	415	300
43.	DONALD'VLLE,LA.	0	425	370	425	425	325	470	370
44.	TAFT,LA	0	425	370	425	425	325	470	370
45.	GEISMAR,LA.	0	425	370	425	425	325	470	370
46.	BATON ROUGE,LA.	0	425	370	425	425	325	470	370
47.	NEW ORLEANS,LA.	0	425	370	425	425	325	470	370
48.	PASCAGOULA,MI	0	500	445	500	500	415	550	445
49.	PASCAGOULA,MI	0	500	445	500	500	415	550	445
50.	BURNSIDE,LA.	0	425	370	425	425	325	470	370
51.	UNCLE SAM,LA.	0	425	370	425	425	325	470	370
52.	GEISMAR,LA.	0	425	370	425	425	325	470	370
53.	BATON ROUGE,LA.	0	425	370	425	425	325	470	370
54.	HAMILTON,OHIO[d]	0	511	466	506	416	436	566	466
55.	CINCINNATI,OHIO	0	305	260	300	210	230	360	260
56.	CINCINNATI,OHIO	0	305	260	300	210	230	360	260
57.	COLUMBUS,OHIO[d]	0	930	885	930	930	830	1000	885
58.	COLUMBUS,OHIO[d]	0	930	885	930	930	830	1000	885
59.	COLUMBUS,OHIO[d]	0	930	885	930	930	830	1000	885
60.	COLUMBUS,OHIO[d]	0	930	885	930	930	830	1000	885
61.	COLUMBUS,OHIO[d]	0	930	885	930	930	830	1000	885

[a] Rates in cents/net ton of sulfuric acid.

[b] Tampa rates shown allow for transfer from inland waterway barges to seagoing barge. Barge rates to all other Florida locations are not shown since rail rates are cheaper.

[c] Barge-truck rates used via LaSalle, Illinois.

[d] Barge-truck rates used via Cincinnati, Ohio.

APPENDIX F

RAIL RATES[a]

#	LOCATION	PER USED	COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
			STEAM PLANTS						
1.	HELENA,ARK.	0	619	675	782	782	675	805	675
2.	N.LITTLE ROCK,AR	0	828	904	997	997	904	1021	852
3.	HOUSTON,TEXAS	0	1322	1344	1438	1438	1344	1462	1344
4.	TEXAS CITY,TEXAS	0	1322	1344	1438	1438	1344	1462	1344
5.	HOUSTON,TEXAS	0	1322	1344	1438	1438	1344	1462	1344
6.	LAPORTE,TEXAS	0	1322	1344	1438	1438	1344	1462	1344
7.	BEAUMONT,TX	0	1229	1275	1344	1368	1299	1368	1275
8.	PASADENA,TEXAS	0	1322	1344	1438	1438	1344	1462	1344
9.	PASADENA,TEXAS	0	1322	1344	1438	1438	1344	1462	1344
10.	PIERCE,FLORIDA	100	1126	1210	1169	1210	1210	1106	1189
11.	PALMETTO,FLORIDA	100	1126	1210	1189	1231	1231	1106	1210
12.	BONNIE,FLA.	100	1126	1189	1169	1210	1210	1082	1189
13.	PLANT CITY,FLA.	100	1106	1189	1169	1210	1210	1082	1189
14.	PLANT CITY,FLA.	100	1106	1189	1169	1189	1210	1082	1169
15.	PIERCE,FLORIDA	100	1126	1210	1169	1189	1210	1082	1169
16.	TAMPA,FLORIDA	0	1106	1189	1169	1210	1210	1106	1189
17.	NICHOLS,FLORIDA	100	1126	1189	1169	1210	1210	1082	1182
18.	PIERCE,FLORIDA	100	1126	1189	1169	1210	1210	1082	1189
19.	GREENBAY,FLA.	100	1126	1210	1169	1210	1210	1106	1189
20.	BARTOW,FLA.	100	1126	1189	1169	1210	1210	1082	1189
21.	BARTOW,FLA.	100	1126	1189	1169	1210	1210	1082	1189
22.	BARTOW,FLORIDA	100	1126	1189	1169	1210	1210	1082	1189
23.	BONNIE,FLA.	100	1126	1189	1169	1210	1210	1082	1189
24.	PIERCE,FLORIDA	100	1126	1210	1169	1210	1210	1106	1189
25.	BARTOW,FLA.	100	1126	1189	1169	1210	1210	1082	1189
26.	BARTOW,FLA.	100	1126	1189	1169	1210	1210	1082	1189
27.	FORT MEADE,FLA.	100	1126	1189	1169	1210	1210	1082	1189
28.	E.ST.LOUIS,ILL.	0	805	719	782	675	713	890	719
29.	MONSANTO,ILL	0	805	719	782	675	713	890	719
30.	E.ST.LOUIS,ILL.	0	805	719	782	675	713	890	719
31.	MARSEILLES,ILL.	0	1576	1441	1467	1304	1304	1603	1467
32.	CALUMET CITY,ILL	0	1603	1441	1467	1304	1304	1603	1467
33.	JOLIET,ILLINOIS	0	1603	1441	1467	1304	1304	1603	1494
34.	FORT MADISON,IA.	0	1547	1441	1494	1359	1276	1683	1441
35.	JOLIET,ILLINOIS	0	1603	1441	1467	1304	1304	1603	1494
36.	STREATOR,ILL.	0	1520	1412	1441	1276	1235	1576	1441
37.	E.CHICAGO,IND.	0	1603	1441	1467	1304	1304	1603	1494
38.	LASALLE,ILLINOIS	0	1547	1441	1441	1304	1235	1603	1441
39.	DEPUE,ILLINOIS	0	1547	1441	1441	1304	1235	1603	1441
40.	JOLIET,ILLINOIS	0	1603	1441	1467	1304	1304	1603	1494
41.	CALUMET CITY,ILL	0	1603	1441	1467	1304	1304	1603	1494
42.	CHICAGO HTS,ILL	0	1603	1441	1467	1304	1304	1603	1494
43.	DONALD'VLLE,LA.	0	1112	1183	1275	1229	1205	1205	1159
44.	TAFT,LA	0	1043	1136	1205	1253	1159	1136	1136
45.	GEISMAR,LA.	0	912	996	1061	1082	996	1061	977
46.	BATON ROUGE,LA.	0	912	996	1061	1082	996	1061	977
47.	NEW ORLEANS,LA.	0	890	996	1061	1082	1018	996	996
48.	PASCAGOULA,MI	0	869	977	996	1061	996	935	977
49.	PASCAGOULA,MI	0	869	977	996	1061	996	935	977
50.	BURNSIDE,LA.	0	935	1039	1061	1106	1039	1018	1018
51.	UNCLE SAM,LA.	0	935	1039	1061	1106	1039	1018	1018
52.	GEISMAR,LA.	0	912	996	1061	1082	996	1061	977
53.	BATON ROUGE,LA.	0	912	996	1061	1082	996	1061	977
54.	HAMILTON,OHIO	0	912	761	719	675	1276	826	826

APPENDIX F (Cont'd)

RAIL RATES[a]

# LOCATION	PER USED	STEAM PLANTS COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
55. CINCINNATI,OHIO	0	912	761	719	675	1276	826	826
56. CINCINNATI,OHIO	0	912	761	719	675	1276	826	826
57. COLUMBUS,OHIO	0	1603	1439	1358	1304	1467	1520	1494
58. COLUMBUS,OHIO	0	1603	1439	1358	1304	1467	1520	1494
59. COLUMBUS,OHIO	0	1603	1439	1358	1304	1467	1520	1494
60. COLUMBUS,OHIO	0	1603	1439	1358	1304	1467	1520	1494
61. COLUMBUS,OHIO	0	1603	1439	1358	1304	1467	1520	1494

[a] Rates expressed in cents/net ton of sulfuric acid.

APPENDIX G1

MARKET PATTERN FOR TVA H2SO4
(M TONS)

SULFUR PRICE = $22.32 ACID CONCENTRATION = 98% CAPACITY = 100% BARGE = 80%
MAXIMUM TVA ACID PRICE WOULD BE $ 6.53

PLANT LOCATION	PRODUCTION CAPACITY	ACTUAL PROD'N	YEAR BUILT	SULFUR REDUC'N ($)	STEAM PLANT SALES COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
1. HELENA,ARK.	135	0	67	3.51	122	13	0	0	0	0	0
2. N.LITTLE ROCK,AR	86	0	46	10.46	0	0	0	0	0	0	86
28. E.ST.LOUIS,ILL.	153	0	37	10.72	0	0	16	74	0	63	0
29. MONSANTO,ILL	139	0	67	4.79	0	0	0	139	0	0	0
30. E.ST.LOUIS,ILL.	239	0	54	5.84	0	0	0	239	0	0	0
32. CALUMET CITY,ILL	111	0	56	3.83	0	55	0	56	0	0	0
33. JOLIET,ILLINOIS	36	0	54	16.96	0	0	0	0	36	0	0
35. JOLIET,ILLINOIS	256	0	45	1.14	0	112	0	0	144	0	0
36. STREATOR,ILL.	35	0	51	15.58	0	0	0	0	35	0	0
37. E.CHICAGO,IND.	334	314	37	0.	0	0	0	0	20	0	0
38. LASALLE,ILLINOIS	35	0	37	22.09	0	0	0	0	35	0	0
40. JOLIET,ILLINOIS	299	0	42	.59	0	299	0	0	0	0	0
41. CALUMET CITY,ILL	30	0	47	22.86	0	30	0	0	0	0	0
42. CHICAGO HTS,ILL	30	0	60	17.39	0	30	0	0	0	0	0
46. BATON ROUGE,LA.	90	0	53	3.32	0	40	0	0	0	0	50
47. NEW ORLEANS,LA.	30	0	65	12.02	0	0	0	0	0	30	0
54. HAMILTON,OHIO	63	0	48	15.87	0	0	0	63	0	0	0
55. CINCINNATI,OHIO	30	0	46	31.18	0	0	0	30	0	0	0
56. CINCINNATI,OHIO	16	0	38	47.69	0	0	0	16	0	0	0
58. COLUMBUS,OHIO	53	0	49	3.57	0	0	53	0	0	0	0
59. COLUMBUS,OHIO	54	0	55	0.	0	0	54	0	0	0	0
60. COLUMBUS,OHIO	18	0	37	26.34	0	0	18	0	0	0	0
61. COLUMBUS,OHIO	24	0	37	18.87	0	0	24	0	0	0	0
PLANT CAPACITY					122	579	165	617	270	93	136
PLANT PRODUCTION					122	579	165	617	270	93	136
MARGINAL ACID COST ($)					7.30	7.51	7.16	7.38	8.11	6.53	7.55

TOTAL PRODUCTION = 1982 TOTAL NET SALES REVENUE = $ 12932695

APPENDIX G2

MARKET PATTERN FOR TVA H2SO4
(M TONS)

SULFUR PRICE = $17.86 ACID CONCENTRATION = 98% CAPACITY = 100% BARGE = 100%

MAXIMUM TVA ACID PRICE WOULD BE $ 7.39

PLANT LOCATION	PRODUCTION CAPACITY	ACTUAL PROD'N	YEAR BUILT	SULFUR REDUC'N ($)	STEAM PLANT SALES COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
2. N.LITTLE ROCK,AR	86	0	46	7.25	0	0	0	0	0	86	0
28. E.ST.LOUIS,ILL.	153	0	37	7.38	92	0	0	55	0	7	0
29. MONSANTO,ILL	139	0	67	1.47	0	0	0	139	0	0	0
30. E.ST.LOUIS,ILL.	239	0	54	2.50	0	0	0	239	0	0	0
32. CALUMET CITY,ILL	111	0	56	3.87	0	35	0	76	0	0	0
33. JOLIET,ILLINOIS	36	0	54	17.06	0	0	36	0	0	0	0
35. JOLIET,ILLINOIS	256	0	45	1.24	0	127	129	0	0	0	0
36. STREATOR,ILL.	35	0	51	13.91	0	35	0	0	0	0	0
37. E.CHICAGO,IND.	334	72	37	0.	0	18	0	0	108	0	136
38. LASALLE,ILLINOIS	35	0	37	21.89	0	35	0	0	0	0	0
40. JOLIET,ILLINOIS	299	0	42	.68	0	299	0	0	0	0	0
41. CALUMET CITY,ILL	30	0	47	22.90	30	0	0	0	0	0	0
42. CHICAGO HTS,ILL	30	0	60	17.39	0	30	0	0	0	0	0
46. BATON ROUGE,LA.	90	0	53	0.	0	0	0	0	90	0	0
47. NEW ORLEANS,LA.	30	0	65	8.63	0	0	0	0	30	0	0
54. HAMILTON,OHIO	63	0	48	11.35	0	0	0	63	0	0	0
55. CINCINNATI,OHIO	30	0	46	28.03	0	0	0	30	0	0	0
56. CINCINNATI,OHIO	16	0	38	44.54	0	0	0	16	0	0	0
60. COLUMBUS,OHIO	18	0	37	22.54	0	0	0	0	18	0	0
61. COLUMBUS,OHIO	24	0	37	15.07	0	0	0	0	24	0	0
PLANT CAPACITY					122	579	165	617	270	93	136
PLANT PRODUCTION					122	579	165	617	270	93	136
MARGINAL ACID COST ($)					7.90	8.41	7.90	7.90	8.82	7.39	8.41

TOTAL PRODUCTION = 1982 TOTAL NET SALES REVENUE = $ 14653528

APPENDIX G3

MARKET PATTERN FOR TVA H2SO4
(M TONS)

SULFUR PRICE = $26.79 ACID CONCENTRATION = 98% CAPACITY = 100% BARGE = 100%

MAXIMUM TVA ACID PRICE WOULD BE $10.12

PLANT LOCATION	PRODUCTION CAPACITY	ACTUAL PROD'N	YEAR BUILT	SULFUR REDUC'N ($)			STEAM PLANT SALES				
					COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
2. N.LITTLE ROCK,AR	86	0	46	7.25	0	0	0	0	0	86	0
28. E.ST.LOUIS,ILL.	153	0	37	7.38	92	0	0	55	0	7	0
29. MONSANTO,ILL	139	0	67	1.33	0	0	0	139	0	0	0
30. E.ST.LOUIS,ILL.	239	0	54	2.50	0	0	0	239	0	0	0
32. CALUMET CITY,ILL	111	0	56	3.87	0	35	0	76	0	0	0
33. JOLIET,ILLINOIS	36	0	54	17.06	0	0	36	0	0	0	0
35. JOLIET,ILLINOIS	256	0	45	1.24	0	127	129	0	0	0	0
36. STREATOR,ILL.	35	0	51	13.91	0	35	0	0	0	0	0
37. E.CHICAGO,IND.	334	72	37	0.	0	18	0	0	108	0	136
38. LASALLE,ILLINOIS	35	0	37	21.89	0	35	0	0	0	0	0
40. JOLIET,ILLINOIS	299	0	42	.68	0	299	0	0	0	0	0
41. CALUMET CITY,ILL	30	0	47	22.90	30	0	0	0	0	0	0
42. CHICAGO HTS,ILL	30	0	60	17.39	0	30	0	0	0	0	0
46. BATON ROUGE,LA.	90	0	53	0.	0	0	0	0	90	0	0
47. NEW ORLEANS,LA.	30	0	65	8.49	0	0	0	0	30	0	0
54. HAMILTON,OHIO	63	0	48	11.35	0	0	0	63	0	0	0
55. CINCINNATI,OHIO	30	0	46	28.03	0	0	0	30	0	0	0
56. CINCINNATI,OHIO	16	0	38	44.54	0	0	0	16	0	0	0
60. COLUMBUS,OHIO	18	0	37	22.54	0	0	0	0	18	0	0
61. COLUMBUS,OHIO	24	0	37	15.07	0	0	0	0	24	0	0
PLANT CAPACITY					122	579	165	617	270	93	136
PLANT PRODUCTION					122	579	165	617	270	93	136
MARGINAL ACID COST ($)					10.63	11.14	10.63	10.63	11.55	10.12	11.14

TOTAL PRODUCTION = 1982 TOTAL NET SALES REVENUE = $ 20056294

APPENDIX G4

MARKET PATTERN FOR TVA H2SO4
(M TONS)

SULFUR PRICE = $22.32   ACID CONCENTRATION = 80%   CAPACITY = 100%   BARGE = 100%

MAXIMUM TVA ACID PRICE WOULD BE $ 7.75

PLANT LOCATION	PRODUCTION CAPACITY	ACTUAL PROD'N	YEAR BUILT	SULFUR REDUC'N ($)	COLB	CUMB	STEAM PLANT SALES GALL	PARA	SHAW	WIDC	JOHN
1. HELENA, ARK.	135	117	67	0.	0	0	0	18	0	0	0
2. N.LITTLE ROCK, AR	86	0	46	7.53	0	0	0	0	0	86	0
28. E.ST.LOUIS, ILL.	153	0	37	8.41	92	0	0	55	0	7	0
29. MONSANTO, ILL	139	0	67	2.45	0	0	0	139	0	0	0
30. E.ST.LOUIS, ILL.	239	0	54	3.53	0	0	0	239	0	0	0
32. CALUMET CITY, ILL	111	0	56	4.01	0	53	0	58	0	0	0
33. JOLIET, ILLINOIS	36	0	54	17.21	0	0	36	0	0	0	0
35. JOLIET, ILLINOIS	256	0	45	1.39	0	127	129	0	0	0	0
36. STREATOR, ILL.	35	0	51	12.62	0	35	0	0	0	0	0
37. E.CHICAGO, IND.	334	0	37	0.	0	0	0	0	198	0	136
38. LASALLE, ILLINOIS	35	0	37	22.30	0	35	0	0	0	0	0
40. JOLIET, ILLINOIS	299	0	42	.83	0	299	0	0	0	0	0
41. CALUMET CITY, ILL	30	0	47	23.04	30	0	0	0	0	0	0
42. CHICAGO HTS, ILL	30	0	60	17.51	0	30	0	0	0	0	0
47. NEW ORLEANS, LA.	30	0	65	8.11	0	0	0	0	30	0	0
54. HAMILTON, OHIO	63	0	48	11.07	0	0	0	63	0	0	0
55. CINCINNATI, OHIO	30	0	46	29.26	0	0	0	30	0	0	0
56. CINCINNATI, OHIO	16	0	38	45.77	0	0	0	16	0	0	0
60. COLUMBUS, OHIO	18	0	37	18.33	0	0	0	0	18	0	0
61. COLUMBUS, OHIO	24	0	37	10.86	0	0	0	0	24	0	0
PLANT CAPACITY					122	579	165	617	270	93	136
PLANT PRODUCTION					122	579	165	617	270	93	136
MARGINAL ACID COST ($)					8.38	9.00	8.38	8.38	9.50	7.75	9.00

TOTAL PRODUCTION = 1982   TOTAL NET SALES REVENUE = $ 15360062

APPENDIX G5

MARKET PATTERN FOR TVA H2SO4
(M TONS)

SULFUR PRICE = $22.32 ACID CONCENTRATION = 98% CAPACITY = 75% BARGE = 100%

MAXIMUM TVA ACID PRICE WOULD BE $ 7.71

PLANT LOCATION	PRODUCTION CAPACITY	ACTUAL PROD'N	YEAR BUILT	SULFUR REDUC'N ($)	STEAM PLANT SALES COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
1. HELENA,ARK.	101	0	67	4.55	0	0	0	101	0	0	0
2. N.LITTLE ROCK,AR	64	0	46	13.65	0	0	0	0	0	64	0
28. E.ST.LOUIS,ILL.	115	0	37	12.96	0	0	0	87	0	28	0
29. MONSANTO,ILL	104	0	67	6.67	0	0	0	104	0	0	0
30. E.ST.LOUIS,ILL.	179	0	54	7.46	29	0	0	151	0	0	0
31. MARSEILLES,ILL.	157	0	62	0.	0	157	0	0	0	0	0
32. CALUMET CITY,ILL	83	0	56	9.61	0	0	0	83	0	0	0
33. JOLIET,ILLINOIS	27	0	54	25.69	27	0	0	0	0	0	0
35. JOLIET,ILLINOIS	192	0	45	6.30	0	17	165	10	0	0	0
36. STREATOR,ILL.	26	0	51	22.74	0	26	0	0	0	0	0
37. E.CHICAGO,IND.	250	0	37	0.	0	105	0	0	10	0	136
38. LASALLE,ILLINOIS	26	0	37	30.88	0	26	0	0	0	0	0
39. DEPUE,ILLINOIS	269	226	67	0.	44	0	0	0	0	0	0
40. JOLIET,ILLINOIS	224	0	42	5.64	0	224	0	0	0	0	0
41. CALUMET CITY,ILL	22	0	47	32.51	22	0	0	0	0	0	0
42. CHICAGO HTS,ILL	22	0	60	26.58	0	22	0	0	0	0	0
46. BATON ROUGE,LA.	67	0	53	6.32	0	0	0	0	67	0	0
47. NEW ORLEANS,LA.	22	0	65	17.72	0	0	0	0	22	0	0
52. GEISMAR,LA.	58	0	68	1.92	0	0	0	0	58	0	0
54. HAMILTON,OHIO	47	0	48	18.37	0	0	0	47	0	0	0
55. CINCINNATI,OHIO	22	0	46	37.68	0	0	0	22	0	0	0
56. CINCINNATI,OHIO	12	0	38	58.35	0	0	0	12	0	0	0
58. COLUMBUS,OHIO	40	0	49	7.22	0	0	0	0	40	0	0
59. COLUMBUS,OHIO	40	0	55	0.	0	0	0	0	40	0	0
60. COLUMBUS,OHIO	13	0	37	35.36	0	0	0	0	13	0	0
61. COLUMBUS,OHIO	18	0	37	25.96	0	0	0	0	18	0	0
PLANT CAPACITY					122	579	165	617	270	93	136
PLANT PRODUCTION					122	579	165	617	270	93	136
MARGINAL ACID COST ($)					8.22	8.73	8.22	8.22	9.14	7.71	8.73

TOTAL PRODUCTION = 1982 TOTAL NET SALES REVENUE = $ 15283291

APPENDIX H1

SULFURIC ACID PLANTS CONSIDERED IN MODEL

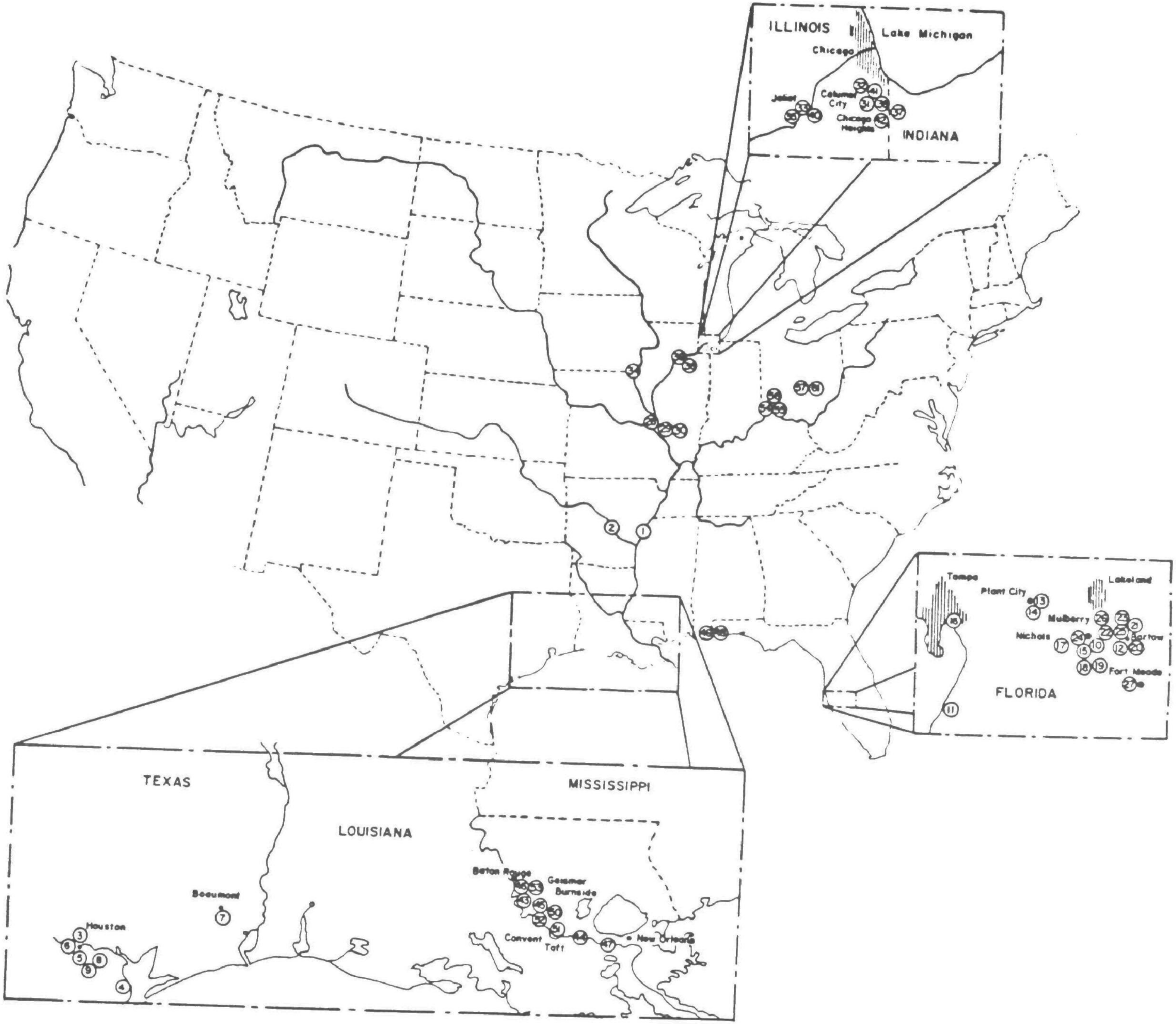
#	NAME	LOCATION	YEAR BUILT	ANNUAL CAPACITY
1.	ARKLA CHEMICAL COPR.	HELENA,ARK.	1967	135
2.	OLIN CORPORATION	N.LITTLE ROCK,AR	1946	86
3.	AMERICAN PLANT FOOD	HOUSTON,TEXAS	1965	116
4.	BORDEN CHEMICAL IND.	TEXAS CITY,TEXAS	1953	128
5.	E.I.DUPONT DE NEM	HOUSTON,TEXAS	1961	300
6.	E.I.DUPONT DE NEM	LAPORTE,TEXAS	1960	350
7.	OLIN CORPORATION	BEAUMONT,TX	1957	180
8.	OLIN CORPORATION	PASADENA,TEXAS	1965	222
9.	OLIN CORPORATION	PASADENA,TEXAS	1965	150
10.	AGRICO CHEM-WILLIAMS	PIERCE,FLORIDA	1955	718
11.	BORDEN CHEMICAL IND.	PALMETTO,FLORIDA	1966	450
12.	CF INDUSTRIES,INC.	BONNIE,FLA.	1955	1486
13.	CF INDUSTRIES,INC.	PLANT CITY,FLA.	1955	419
14.	CF INDUSTRIES,INC.	PLANT CITY,FLA.	1955	660
15.	CF INDUSTRIES,INC.	PIERCE,FLORIDA	1955	428
16.	CITIES SERVICE CO	TAMPA,FLORIDA	1959	928
17.	CONSERVE,INC.	NICHOLS,FLORIDA	1973	400
18.	FARMLAND INDUSTRIES	PIERCE,FLORIDA	1961	478
19.	FARMLAND INDUSTRIES	GREENBAY,FLA.	1966	748
20.	W.R.GRACE & CO.	BARTOW,FLA.	1965	330
21.	W.R.GRACE & CO.	BARTOW,FLA.	1960	700
22.	CHEMICALS,INC.	BARTOW,FLORIDA	1965	980
23.	CHEMICALS,INC.	BONNIE,FLA.	1963	594
24.	ROYSTER COMPANY	PIERCE,FLORIDA	1965	278
25.	SWIFT & COMPANY	BARTOW,FLA.	1948	274
26.	U.S.S.AGRI-CHEM.	BARTOW,FLA.	1960	376
27.	U.S.S.AGRI-CHEM.	FORT MEADE,FLA.	1962	492
28.	ALLIED CHEMICAL CORP	E.ST.LOUIS,ILL.	1937	153
29.	AMER.ZINC,LEAD&SMELT	MONSANTO,ILL	1967	139
30.	MONSANTO COMPANY	E.ST.LOUIS,ILL.	1954	239
31.	AG PRODUCTS CO	MARSEILLES,ILL.	1962	210
32.	ALLIED CHEMICAL CORP	CALUMET CITY,ILL	1956	111
33.	AMERICAN CYANAMID	JOLIET,ILLINOIS	1954	36
34.	ARCO CHEMICAL	FORT MADISON,IA.	1968	449
35.	ARMY AMMUNITION PLT	JOLIET,ILLINOIS	1945	256
36.	BORDEN CHEMICAL IND.	STREATOR,ILL.	1951	35
37.	E.I.DUPONT DE NEM	E.CHICAGO,IND.	1937	334
38.	MATTHIESSEN & HEGLER	LASALLE,ILLINOIS	1937	35
39.	MOBIL OIL COMPANY	DEPUE,ILLINOIS	1967	359
40.	OLIN CORPORATION	JOLIET,ILLINOIS	1942	299
41.	SWIFT AND COMPANY	CALUMET CITY,ILL	1947	30
42.	U.S.S.AGRI-CHEM.	CHICAGO HTS,ILL	1960	30
43.	AGRICO CHEM-WILLIAMS	DONALD'VLLE,LA.	1970	1224
44.	AGRI PRODUCTS(BEKER)	TAFT,LA	1965	429
45.	ALLIED CHEMICAL CORP	GEISMAR,LA.	1967	450
46.	ALLIED CHEMICAL CORP	BATON ROUGE,LA.	1953	90
47.	AMERICAN CYANAMID	NEW ORLEANS,LA.	1965	30
48.	COASTAL CHEMICAL	PASCAGOULA,MI	1958	210
49.	COASTAL CHEMICAL	PASCAGOULA,MI	1972	495
50.	E.I.DUPONT DE NEM	BURNSIDE,LA.	1967	450
51.	FREEPORT MINERALS	UNCLE SAM,LA.	1968	1632
52.	RUBICON	GEISMAR,LA.	1968	78
53.	STAUFFER CHEMICAL CO	BATON ROUGE,LA.	1965	750
54.	AMERICAN CYANAMID	HAMILTON,OHIO	1948	63

APPENDIX H1 (Cont'd)

SULFURIC ACID PLANTS CONSIDERED IN MODEL

#	NAME	LOCATION	YEAR BUILT	ANNUAL CAPACITY
55.	INTERNATIONAL MINER.	CINCINNATI,OHIO	1946	30
56.	MOBIL OIL COMPANY	CINCINNATI,OHIO	1938	16
57.	AMER.ZINC,LEAD&SMELT	COLUMBUS,OHIO	1965	64
58.	AMERICAN ZINC OXIDE	COLUMBUS,OHIO	1949	53
59.	AMERICAN ZINC OF ILL	COLUMBUS,OHIO	1955	54
60.	BORDEN CHEMICAL IND.	COLUMBUS,OHIO	1937	18
61.	FARMERS FERTILIZER	COLUMBUS,OHIO	1937	24

APPENDIX H2


ILLINOIS
Lake Michigan
Chicago
Joliet
Calumet City
Chicago Heights
INDIANA
TEXAS
LOUISIANA
MISSISSIPPI
Houston
Beaumont
Baton Rouge
Geismar
Burnside
Convent
Taft
New Orleans
Tampa
Plant City
Lakeland
Mulberry
Nichols
Bartow
Fort Meade
FLORIDA

APPENDIX I

SULFURIC ACID PRODUCTION COSTS

#	LOCATION	SULFUR FACTOR	CONVERSION & TOTAL COSTS 1975	
1.	HELENA,ARK.	.3006	4.65	12.14
2.	N.LITTLE ROCK,AR	.3053	7.58	15.25
3.	HOUSTON,TEXAS	.3006	5.11	11.82
4.	TEXAS CITY,TEXAS	.3053	6.03	12.85
5.	HOUSTON,TEXAS	.3006	3.98	10.69
6.	LAPORTE,TEXAS	.3053	3.87	10.68
7.	BEAUMONT,TX	.3053	5.03	11.85
8.	PASADENA,TEXAS	.3006	4.06	10.77
9.	PASADENA,TEXAS	.3006	4.65	11.35
10.	PIERCE,FLORIDA	.3053	3.46	11.77
11.	PALMETTO,FLORIDA	.3006	3.20	11.61
12.	BONNIE,FLA.	.3053	2.88	11.42
13.	PLANT CITY,FLA.	.3053	4.01	12.08
14.	PLANT CITY,FLA.	.3053	3.54	11.60
15.	PIERCE,FLORIDA	.3053	3.99	12.30
16.	TAMPA,FLORIDA	.3053	3.02	10.40
17.	NICHOLS,FLORIDA	.3006	2.88	11.07
18.	PIERCE,FLORIDA	.3006	3.47	11.65
19.	GREENBAY,FLA.	.3006	2.79	11.19
20.	BARTOW,FLA.	.3006	3.58	11.99
21.	BARTOW,FLA.	.3053	3.19	11.73
22.	BARTOW,FLORIDA	.3006	2.65	11.06
23.	BONNIE,FLA.	.3006	3.14	11.55
24.	PIERCE,FLORIDA	.3006	3.77	11.96
25.	BARTOW,FLA.	.3053	5.02	13.56
26.	BARTOW,FLA.	.3053	3.79	12.33
27.	FORT MEADE,FLA.	.3006	3.38	11.89
28.	E.ST.LOUIS,ILL.	.3053	6.31	14.27
29.	MONSANTO,ILL	.3006	4.60	12.44
30.	E.ST.LOUIS,ILL.	.3053	4.82	12.78
31.	MARSEILLES,ILL.	.3006	4.37	12.51
32.	CALUMET CITY,ILL	.3053	6.07	14.43
33.	JOLIET,ILLINOIS	.3053	10.10	18.40
34.	FORT MADISON,IA.	.3006	3.08	11.14
35.	JOLIET,ILLINOIS	.3053	5.27	13.56
36.	STREATOR,ILL.	.3053	10.61	19.43
37.	E.CHICAGO,IND.	.3053	4.94	13.30
38.	LASALLE,ILLINOIS	.3053	11.32	19.57
39.	DEPUE,ILLINOIS	.3006	3.35	11.48
40.	JOLIET,ILLINOIS	.3053	5.10	13.40
41.	CALUMET CITY,ILL	.3053	11.88	20.24
42.	CHICAGO HTS,ILL	.3053	10.25	18.61
43.	DONALD'VLLE,LA.	.3006	2.27	9.31
44.	TAFT,LA	.3006	3.31	10.35
45.	GEISMAR,LA.	.3006	3.14	10.18
46.	BATON ROUGE,LA.	.3053	6.88	14.06
47.	NEW ORLEANS,LA.	.3006	9.57	16.58
48.	PASCAGOULA,MI	.3053	4.70	11.93
49.	PASCAGOULA,MI	.3006	2.76	9.88
50.	BURNSIDE,LA.	.3006	3.14	10.18
51.	UNCLE SAM,LA.	.3006	2.21	9.25
52.	GEISMAR,LA.	.3006	5.71	12.75
53.	BATON ROUGE,LA.	.3006	2.84	9.91
54.	HAMILTON,OHIO	.3053	8.42	17.28

APPENDIX I (Cont'd)

SULFURIC ACID PRODUCTION COSTS

#	LOCATION	SULFUR FACTOR	CONVERSION & 1975	TOTAL COSTS
55.	CINCINNATI,OHIO	.3053	11.97	20.26
56.	CINCINNATI,OHIO	.3053	17.01	25.31
57.	COLUMBUS,OHIO	.3006	6.55	16.52
58.	COLUMBUS,OHIO	.3053	8.97	19.09
59.	COLUMBUS,OHIO	.3053	8.26	18.38
60.	COLUMBUS,OHIO	.3053	15.92	26.04
61.	COLUMBUS,OHIO	.3053	13.64	23.76

APPENDIX J

STEAM PLANTS CONSIDERED

#	NAME	REPORT NAME	COST	CAPACITY 1975
1.	COLBERT	COLB	.20	121.9
2.	CUMBERLAND	CUMB	.20	578.7
3.	GALLATIN	GALL	.20	165.3
4.	PARADISE	PARA	.20	617.3
5.	SHAWNEE	SHAW	.20	270.0
6.	WIDOWS CREEK	WIDC	.20	92.6
7.	JOHNSONVILLE	JOHN	.20	135.9

APPENDIX K1

SULFURIC ACID TRANSPORTATION COSTS USED IN MODEL
100% BARGE

#	LOCATION	STEAM PLANTS COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
1.	HELENA,ARK.	285	245	285	285	195	345	245
2.	N.LITTLE ROCK,AR	370	315	370	370	275	400	315
3.	HOUSTON,TEXAS	590	530	590	590	490	655	530
4.	TEXAS CITY,TEXAS	590	530	590	590	490	655	530
5.	HOUSTON,TEXAS	590	530	590	590	490	655	530
6.	LAPORTE,TEXAS	590	530	590	590	490	655	530
7.	BEAUMONT,TX	550	490	550	550	450	615	490
8.	PASADENA,TEXAS	590	530	590	590	490	655	530
9.	PASADENA,TEXAS	590	530	590	590	490	655	530
10.	PIERCE,FLORIDA	1126	1210	1169	1210	1210	1106	1189
11.	PALMETTO,FLORIDA	1126	1210	1189	1231	1231	1106	1210
12.	BONNIE,FLA.	1126	1189	1169	1210	1210	1082	1189
13.	PLANT CITY,FLA.	1106	1189	1169	1189	1210	1082	1169
14.	PLANT CITY,FLA.	1106	1189	1169	1189	1210	1082	1169
15.	PIERCE,FLORIDA	1126	1210	1169	1210	1210	1106	1189
16.	TAMPA,FLORIDA	1000	940	1000	1000	890	1050	940
17.	NICHOLS,FLORIDA	1126	1189	1169	1210	1210	1082	1189
18.	PIERCE,FLORIDA	1126	1210	1169	1210	1210	1106	1189
19.	GREENBAY,FLA.	1126	1210	1169	1210	1210	1106	1189
20.	BARTOW,FLA.	1126	1189	1169	1210	1210	1082	1189
21.	BARTOW,FLA.	1126	1189	1169	1210	1210	1082	1189
22.	BARTOW,FLORIDA	1126	1189	1169	1210	1210	1082	1189
23.	BONNIE,FLA.	1126	1189	1169	1210	1210	1082	1189
24.	PIERCE,FLORIDA	1126	1210	1169	1210	1210	1106	1189
25.	BARTOW,FLA.	1126	1189	1169	1210	1210	1082	1189
26.	BARTOW,FLA.	1126	1189	1169	1210	1210	1082	1189
27.	FORT MEADE,FLA.	1126	1189	1169	1210	1210	1082	1189
28.	E.ST.LOUIS,ILL.	250	230	250	250	160	300	230
29.	MONSANTO,ILL	250	230	250	250	160	300	230
30.	E.ST.LOUIS,ILL.	250	250	250	250	160	300	230
31.	MARSEILLES,ILL.	350	290	350	350	250	400	290
32.	CALUMET CITY,ILL	370	320	370	370	285	445	320
33.	JOLIET,ILLINOIS	365	315	365	365	275	435	315
34.	FORT MADISON,IA.	320	260	320	320	220	390	260
35.	JOLIET,ILLINOIS	365	315	365	365	275	435	315
36.	STREATOR,ILL.	560	510	560	560	470	620	510
37.	E.CHICAGO,IND.	385	325	385	385	285	450	325
38.	LASALLE,ILLINOIS	335	285	335	335	245	395	285
39.	DEPUE,ILLINOIS	330	280	330	330	240	390	280
40.	JOLIET,ILLINOIS	365	315	365	365	275	435	315
41.	CALUMET CITY,ILL	370	320	370	370	285	445	320
42.	CHICAGO HTS,ILL	385	325	385	385	285	450	325
43.	DONALD'VLLE,LA.	465	405	465	465	355	515	405
44.	TAFT,LA	465	405	465	465	355	515	405
45.	GEISMAR,LA.	465	405	465	465	355	515	405
46.	BATON ROUGE,LA.	465	405	465	465	355	515	405
47.	NEW ORLEANS,LA.	465	405	465	465	355	515	405
48.	PASCAGOULA,MI	545	485	545	545	445	600	485
49.	PASCAGOULA,MI	545	485	545	545	445	600	485
50.	BURNSIDE,LA.	465	405	465	465	355	515	405
51.	UNCLE SAM,LA.	465	405	465	465	355	515	405
52.	GEISMAR,LA.	465	405	465	465	355	515	405
53.	BATON ROUGE,LA.	465	405	465	465	355	515	405
54.	HAMILTON,OHIO	536	486	531	426	451	596	486

APPENDIX K1

SULFURIC ACID TRANSPORTATION COSTS USED IN MODEL
100% BARGE

#	LOCATION	STEAM PLANTS COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
55.	CINCINNATI,OHIO	330	280	325	220	245	390	280
56.	CINCINNATI,OHIO	330	280	325	220	245	390	280
57.	COLUMBUS,OHIO	965	910	965	965	860	1030	910
58.	COLUMBUS,OHIO	965	910	965	965	860	1030	910
59.	COLUMBUS,OHIO	965	910	965	965	860	1030	910
60.	COLUMBUS,OHIO	965	910	965	965	860	1030	910
61.	COLUMBUS,OHIO	965	910	965	965	860	1030	910

APPENDIX K2

SULFURIC ACID TRANSPORTATION COSTS USED IN MODEL
80% BARGE

#	LOCATION	STEAM PLANTS						
		COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
1.	HELENA,ARK.	352	331	384	384	291	437	331
2.	N.LITTLE ROCK,AR	462	433	495	495	401	524	422
3.	HOUSTON,TEXAS	736	693	760	760	661	816	693
4.	TEXAS CITY,TEXAS	736	693	760	760	661	816	693
5.	HOUSTON,TEXAS	736	693	760	760	661	816	693
6.	LAPORTE,TEXAS	736	693	760	760	661	816	693
7.	BEAUMONT,TX	686	647	709	714	620	766	647
8.	PASADENA,TEXAS	736	693	760	760	661	816	693
9.	PASADENA,TEXAS	736	693	760	760	661	816	693
10.	PIERCE,FLORIDA	1126	1210	1169	1210	1210	1106	1189
11.	PALMETTO,FLORIDA	1126	1210	1189	1231	1231	1106	1210
12.	BONNIE,FLA.	1126	1189	1169	1210	1210	1082	1189
13.	PLANT CITY,FLA.	1106	1189	1169	1189	1210	1082	1169
14.	PLANT CITY,FLA.	1106	1189	1169	1189	1210	1082	1169
15.	PIERCE,FLORIDA	1126	1210	1169	1210	1210	1106	1189
16.	TAMPA,FLORIDA	1021	990	1034	1042	954	1056	988
17.	NICHOLS,FLORIDA	1126	1189	1169	1210	1210	1082	1189
18.	PIERCE,FLORIDA	1126	1210	1169	1210	1210	1106	1189
19.	GREENBAY,FLA.	1126	1210	1169	1210	1210	1106	1189
20.	BARTOW,FLA.	1126	1189	1169	1210	1210	1082	1189
21.	BARTOW,FLA.	1126	1189	1169	1210	1210	1082	1189
22.	BARTOW,FLORIDA	1126	1189	1169	1210	1210	1082	1189
23.	BONNIE,FLA.	1126	1189	1169	1210	1210	1082	1189
24.	PIERCE,FLORIDA	1126	1210	1169	1210	1210	1106	1189
25.	BARTOW,FLA.	1126	1189	1169	1210	1210	1082	1189
26.	BARTOW,FLA.	1126	1189	1169	1210	1210	1082	1189
27.	FORT MEADE,FLA.	1126	1189	1169	1210	1210	1082	1189
28.	E.ST.LOUIS,ILL.	361	328	356	335	271	418	328
29.	MONSANTO,ILL	361	328	356	335	271	418	328
30.	E.ST.LOUIS,ILL.	361	344	356	335	271	418	328
31.	MARSEILLES,ILL.	595	520	573	541	461	641	525
32.	CALUMET CITY,ILL	617	544	589	557	489	677	555
33.	JOLIET,ILLINOIS	613	540	585	553	481	669	551
34.	FORT MADISON,IA.	565	496	555	528	431	649	496
35.	JOLIET,ILLINOIS	613	540	585	553	481	669	551
36.	STREATOR,ILL.	752	690	736	703	623	811	696
37.	E.CHICAGO,IND.	629	548	601	569	489	681	559
38.	LASALLE,ILLINOIS	577	516	556	529	443	637	516
39.	DEPUE,ILLINOIS	573	512	552	525	439	633	512
40.	JOLIET,ILLINOIS	613	540	585	553	481	669	551
41.	CALUMET CITY,ILL	617	544	589	557	489	677	555
42.	CHICAGO HTS,ILL	629	548	601	569	489	681	559
43.	DONALD'VLLE,LA.	594	561	627	618	525	653	556
44.	TAFT,LA	581	551	613	623	516	639	551
45.	GEISMAR,LA.	554	523	584	588	483	624	519
46.	BATON ROUGE,LA.	554	523	584	588	483	624	519
47.	NEW ORLEANS,LA.	550	523	584	588	488	611	523
48.	PASCAGOULA,MI	610	583	635	648	555	667	583
49.	PASCAGOULA,MI	610	583	635	648	555	667	583
50.	BURNSIDE,LA.	559	532	584	593	492	616	528
51.	UNCLE SAM,LA.	559	532	584	593	492	616	528
52.	GEISMAR,LA.	554	523	584	588	483	624	519
53.	BATON ROUGE,LA.	554	523	584	588	483	624	519
54.	HAMILTON,OHIO	611	541	569	476	616	642	554

APPENDIX K2

SULFURIC ACID TRANSPORTATION COSTS USED IN MODEL
80% BARGE

#	LOCATION	STEAM PLANTS COLB	CUMB	GALL	PARA	SHAW	WIDC	JOHN
55.	CINCINNATI,OHIO	446	376	404	311	451	477	389
56.	CINCINNATI,OHIO	446	376	404	311	451	477	389
57.	COLUMBUS,OHIO	1093	1016	1044	1033	981	1128	1027
58.	COLUMBUS,OHIO	1093	1016	1044	1033	981	1128	1027
59.	COLUMBUS,OHIO	1093	1016	1044	1033	981	1128	1027
60.	COLUMBUS,OHIO	1091	1016	1044	1033	981	1128	1027
61.	COLUMBUS,OHIO	1093	1016	1044	1033	981	1128	1027

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA-650/2-73-051	2.	3. Recipient's Accession No.

4. Title and Subtitle
Marketing H2SO4 from SO2 Abatement Sources -- The TVA Hypothesis

5. Report Date December 1973

6.

7. Author(s)
D. Waitzman, J. Nevins, and G. Slappey

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Office of Agricultural and Chemical Development
Tennessee Valley Authority
Muscle Shoals, Alabama 35660

10. Project/Task/Work Unit No. ROAP 21ADE-24

11. Contract/Grant No. IAG0134D (Part B)

12. Sponsoring Organization Name and Address
EPA, Office of Research and Development
NERC-RTP, Control Systems Laboratory
Research Triangle Park, NC 27711

13. Type of Report & Period Covered Final

14.

15. Supplementary Notes

16. Abstracts The report gives results of a hypothetical study of marketing abatement H2SO4 from SO2 removal and acid production facilities assumed to be installed at selected TVA coal-burning steam plants. The net return to TVA is determined by assigning a zero dollar value for the acid at the steam plants, computing the transportation cost of shipping the acid to existing acid producers, and selling to the existing acid producers at their avoidable manufacturing cost. From an approximate 18,000-MW coal-burning power generation capacity in the TVA system, about 10,000 MW was considered for H2SO4 production and about 2 million tons of H2SO4 per year would be produced. Assuming that TVA would be the only utility producing abatement acid, a net sales revenue of about $5 to $9 per ton was indicated. The computer model developed for the study can be expanded to include other U.S. utilities. Such an expansion of the study is suggested.

17. Key Words and Document Analysis. 17a. Descriptors
Air Pollution
Flue Gases
Desulfurization
Marketing
Sulfuric Acid
Mathematical Models

17b. Identifiers/Open-Ended Terms
Air Pollution Control
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Acid Production
Tennessee Valley Authority

17c. COSATI Field/Group 12B, 13B, 14A

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